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Good practices for forest buffers to improve surface water quality in the Baltic Sea region

God praxis för kantzoner i syfte att förbättra ytvattenkvalitet i Östersjöregionen

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Sammanfattning

Här presenteras olika alternativ för hur man kan skapa kantzoner i syfte att skydda ytvattenkvaliteten samt en översikt av nuvarande skötselregimer för strandnära skog i Estland, Lettland, Litauen, Polen, Sverige och Finland, dvs inom Östersjöregionen. Skogar och vatten inom denna region uppvisar stor variation och rekommendationerna som presenteras här måste anpassas till lokala förhållanden d.v.s. områdets specifika egenskaper, nationell lagstiftning, andra bestämmelser och skogscertifieringsstandarder. "Kantzon" avser en zon med skog som lämnats som skydd utmed en ytvattenförekomst vid skogsbruk, främst avverkning. Kantzoner kan rymma värdefulla terrestra habitat och arter. I denna rapport ligger dock fokus på hur kantzoner och skötseln av dessa kan bidra till att skydda ytvattenkvaliteten, alltså inte i första hand på den terrestra biologiska mångfalden.

This is a revised version of the report, published on 5 April, 2022. On page 46, the citation of 6.1.4 from FSC-STD-POL-01-01-2013-Poland Natural and Plantations EN is corrected.

WAMBAF

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Preface

This report was produced as part of the WAMBAF-project (Water Management in Baltic Forests) (activity period 1 March, 2016 to 28 February, 2019), which was initiated to tackle problems associated with forestry activities in relation to water quality. The project is financed by the EU Interreg Baltic Sea Region programme. Special emphasis is placed on surface water quality, and the export of nutrients, suspended solids and mercury. WAMBAF focuses on three main topics: riparian forests, forest drainage and beaver population management.

The aim of this report is to present options for riparian forest management, including forest buffers, to serve as inspiration for developing on-site practices, national legislation and guidelines within the Baltic Sea region. Here, various approaches for riparian forest management are presented. However, before implementing any of the measures proposed, it is essential to make sure that the measure complies with national legislation, other regulations and forest certification standards. We would like to thank the stakeholders within the Baltic Sea countries who provided valuable comments on an earlier version of this report.

Guidelines on ditch-network maintenance prepared within the WAMBAF-project are available from:

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Contents

Summary

Here, options for forest buffer implementation to protect surface water quality are presented, and overviews of the current management regimes for riparian forests are described for Estonia, Latvia, Lithuania, Poland, Sweden and Finland, i.e. within the Baltic Sea region. Forests and water bodies within this region show great diversity and the recommendations presented here must be adapted to local conditions, taking account of the characteristics of individual sites, national legislation, other regulations, and forest certification standards. "Forest buffer" refers to a zone with forest left for protection along a surface water body when carrying out forestry operations, mainly harvesting. Forest buffers may be valuable terrestrial habitats supporting important biota. In this report, however, the main focus is on how forest buffers and their management can be used to protect surface water quality, hence, not primarily terrestrial biodiversity. In short, the recommendations are:

Planning forestry operations with respect to water

- Take both a short-term and long-term perspective to avoid short-term negative effects and secure long-term water protection.
- Protect all types of surface waters. Springs, small streams and rivers are more severely affected by forestry operations than large rivers and lakes.
- Determine if surface waters are present on or adjacent to the forest compartment.
- Plan the forestry operation well ahead of the on-site operation. Undertake a field inspection before starting the operation. Acknowledge that the extent of forest streams may vary with season and weather.
- Before the operation, explain the management of forest buffers to the machine operators, for example by providing them with written instructions and maps.
- Tell the machine operators how to act when the on-site conditions become unsuitable for carrying out or continuing the logging, for example if the soil bearing capacity is lowered by rainfall.

Fig. 1. All types of surface water need protection, as do small streams. Photo from Zalvīte, central Latvia by Zane Lībiete.

Delineation and management of forest buffers

- To mitigate elevated export of plant nutrients, suspended solids and mercury to surface water, establish forest buffers along springs, small streams, rivers and lakes.
- Adjust buffer width to local conditions such as soil type, topography, vegetation and discharge areas.
- Prevent soil disturbance adjacent to surface water, especially in discharge areas, to avoid increased erosion and export of suspended solids and mercury from the soil. Therefore, try to leave or create wind-resistant forest buffers, and, within the buffer, minimize off-road traffic and avoid site preparation, ditching, remedial drainage, and stump lifting.
- Logging residue can be used for soil protection when driving in the riparian zone cannot be avoided, but do not store logging residue within this zone.
- Do not apply or handle fertilizers, pesticides or other chemicals within the riparian zone.

Tree species composition and structure of forest buffers

- Try to leave or create a multi-layered and uneven-aged forest buffer, which is generally considered beneficial for functionality.
- Promote broadleaved trees near forest streams. Litter from broadleaved trees is an important nutrient source for aquatic life, especially in streams.
- Leave trees of all ages to secure the continuous supply of long-lived large woody debris to the streams. Both conifers and broadleaved trees can provide such long-lived woody debris.
- If necessary, adjust the tree-species composition and age structure in the forest buffer zone at pre-commercial thinning and thinning.

Terminology

The terminology used in this report is as follows:

Riparian zone is an area adjacent to a water body, including the bank of the water body, which has an impact on the ecology, hydrology and water quality of the water body. The width of the riparian zone varies along/around a water body as well as between water bodies.

Riparian forest is the forest that grows in the riparian zone.

A **forest buffer** is a zone of forest left for protection, adjacent to a water body.

A **discharge area** is where groundwater flows out from the ground via spring seepage or to a stream or lake.

A **catchment** represents the area from which water flows into a surface water body.

Forest certification – two forest certification systems dominate in the Baltic Sea region, namely the Forest Stewardship Council (**FSC**) and the Programme for the Endorsement of Forest Certification Schemes (**PEFC**).

Fig. 2. Forest buffers in a landscape in Finland. Photo by Erkki Oksanen.

Aims and scope

The aim of this report is to suggest measures for riparian forest management which counteract or reduce excess export of nitrogen (N), phosphorus (P), suspended solids and mercury (Hg) to surface water. Focus is placed on how forest buffers can be used to achieve this goal – their efficacy and implementation. Furthermore, forest buffers may provide essential functions for aquatic organisms and host valuable terrestrial habitats which must also be considered during practical forest management. Such aspects are, to some extent, also addressed.

The predicted changes in future climate may affect the forests and surface waters within the Baltic Sea region and, as a result, influence riparian forest management. The recommendations given within this report include mapping on-site conditions. Such mapping will include possible effects related to climate change. Furthermore, revision of recommendations and on-site operation procedures should be a continuous process within forestry.

The use of forests and the demand for forest products may increase in the future (FAO 1997, European Commission 2013). The use of forests needs to be sustainable not only economically but also ecologically, so impacts on water quality, biodiversity and climate should be considered. The recommendations given in this report attempt to acknowledge this complex setting.

Introduction

WATER CHEMISTRY IN THE FOREST LANDSCAPE

Forest land covers between 31 and 73% of the land area in the Baltic Sea countries (in total 67.5 Mha), and contains numerous lakes and watercourses (Piirainen *et al.* 2017). In large parts of the region, tree growth is limited by the low availability of N. In general, the leaching of N from forest land is low, especially in comparison to agricultural land. In agriculture, N and P fertilization is widely used, but much less in forestry. Nitrogen leaching from forest land is elevated after clear-cutting and N fertilization (Sponseller *et al.* 2016). In some regions, where the atmospheric N deposition is high, N leaching is elevated (Gundersen *et al.* 2006). Furthermore, forest dieback may affect N leaching (Gundersen *et al.* 2006). However, forest dieback has not been a large-scale problem in the Baltic Sea region, although at the local scale it will affect N cycling. Compared to N leaching, much less is known about P leaching from forest land. Some fertile organic forest soils on drained peatlands can be hot spots for N and P leaching (Nieminen *et al.* 2017a).

Industrial activities largely outside Fennoscandia have led to accumulation of Hg in the terrestrial and aquatic ecosystems of this region (Eklöf *et al.* 2016, cf. EMEP 2017). In Sweden, for instance, the Hg levels in fish from nearly 2900 waters (sampled during a 50 year-period) were above the EU Environmental Quality Standard (0.02 mg kg^{-1}) (Åkerblom *et al.* 2014). Moreover, the guideline set by FAO/WHO for Hg levels in fish used for human consumption (0.5-1.0 mg kg^{-1}) was exceeded in 52.5% of the waters sampled after the year 2000 (Åkerblom *et al.* 2014). In addition, in many places in Finland, Hg values in fish exceeding the EU quality standard have been reported (Mannio *et al.* 1986, Strandberg *et al.* 2016). There are limited data on Hg levels in waters and aquatic biota from the Baltic countries and Poland. However, elevated Hg concentrations in freshwater and seawater fish have been recorded in both Latvia and Estonia (Keskkonnaseire 2017, LEGMC 2017). New data obtained within the WAMBAF-project suggest that Hg concentrations in inland fish and some other aquatic biota exceed the EU Environmental Quality Standard not only in Sweden and Finland, but also in Latvia and Poland (unpublished data).

RIPARIAN FORESTS

Riparian ecosystems occupy the transitional zone between the aquatic and terrestrial ecosystems (Malanson 1993, USDA Natural Resources Conservation Service, Part 411). Riparian zones are markedly different from the surrounding land because of their unique soil and vegetation characteristics, which are strongly influenced by high water content in the soil (USDA Natural Resources Conservation Service, Part 411). The riparian forests supply food to aquatic organisms via falling leaves and insects, provide shade and large woody debris (deadwood) to surface water bodies, affect water flow rates in streams and stabilize streambanks (Broadmeadow & Nisbet 2004, Sweeney & Newbold 2014). Consequently, protecting riparian forests helps protect surface water ecosystems.

IMPACTS OF FORESTRY ON WATER QUALITY

Even-aged forestry is the dominant management strategy in the Baltic Sea Region, including clearcutting at the end of the forest rotation followed by site preparation for establishing the next tree generation. This creates a mosaic of stands of different ages across the forest landscape. Nitrogen leaching is low during the major part of the forest rotation and elevated leaching rates typically occur in conjunction with fertilization and clearcutting (Sponseller *et al.* 2016). The leaching of N declines as uptake by the re-establishing ground vegetation and tree seedlings increases (Hedwall *et al.* 2014, Palviainen *et al.* 2014).

In a review of the impacts of logging boreal forest, Kreutzweiser *et al.* (2008) state that the P cycling in forest soils is affected by many of the same site conditions as N cycling. These include, for example, changes in soil moisture and temperature, organic matter content, microbial activity, mineralization rates, and forest harvest and regeneration. Moreover, P export to water can also be facilitated by increased P weathering from exposed mineral soils caused by soil disturbance during logging, export of particulates to which dissolved P has been attached, and co-leaching with organic solutes such as dissolved organic carbon (DOC) (Kreutzweiser *et al.* 2008). Elevated leaching of N and P may increase eutrophication in downstream aquatic ecosystems since these systems are adapted to low N and P loads from surrounding terrestrial areas.

Ditch network maintenance and other forest drainage activities increase the export of suspended solids to surface water (Haahti *et al.* 2018, Nieminen *et al.* 2018). Moreover, site preparation exposes mineral and organic soil which can lead to increased erosion and export of suspended solids. Similar effects can occur if forestry machines are driven too close to surface waters. This can create wheel tracks which channelize water and deliver suspended solids directly to nearby streams and lakes (Fig. 3). Increased inputs of suspended solids and subsequent sedimentation may harm aquatic organisms such as filter-feeders (for example net-spinning caddisflies, *Hydropsyche* spp.) and organisms attached to the stream bed (e.g. mussels) and adversely affect or destroy habitats

(Österling *et al.* 2010). Moreover, increased export of suspended solids can increase the load of nutrients and hazardous trace metals bound to organic or mineral soil particles. Driving vehicles across groundwater discharge areas located adjacent to surface water may change the groundwater flow pathways and affect soil processes within the area (Kuglerová *et al.* 2014).

Fig. 3. Forestry machinery was driven across the stream without building a temporary bridge. The wheel tracks thus created increased the risk of erosion and export of suspended solids and mercury.
Photo by Eva Ring.

Logging, site preparation and in one case, driving forestry machinery, have been found to increase the loads of total Hg and methyl-Hg reaching surface waters by increasing the production of methyl-Hg and mobilizing Hg from the soil to surface waters (Porvari *et al.* 2003, Eklöf *et al.* 2016). However, Eklöf *et al.* (2016) report considerable variation in the effects on total Hg and methyl-Hg at different sites. The formation of bioavailable methyl-Hg may increase in harvested areas. Microorganisms capable of methylating Hg are favoured in waterlogged soils with low oxygen supply. By avoiding activities that can result in overland flow in the riparian zone, such as rutting and soil compaction, the input of methyl-Hg to surface water may be reduced (Fig. 3). Thus, avoiding driving near to surface water may prevent the methyl-Hg that is produced in waterlogged areas from being transported to adjacent surface waters via water-filled wheel tracks (Eklöf *et al.* 2018).

Forests have a great impact on the water cycle. After clearcutting, annual runoff often increases for some years due to decreased evapotranspiration (Rosén *et al.* 1996, Ide *et al.* 2013), and the effect may vary in the different seasons (Ide *et al.* 2013). Changes in hydrology may affect the export of N, P, suspended solids and Hg to surface water via a number of processes (Kreutzweiser *et al.* 2008).

RETENTION EFFICACY OF FOREST BUFFERS IN THE BALTIC SEA REGION

The efficacy of forest buffers to reduce inputs of nutrients, suspended solids and Hg in the Baltic Sea region was reviewed by Piirainen *et al.* (2017). The effectiveness of forest buffers for retaining N was estimated in three studies, and in two of them the impact of forest buffers on the levels of P and suspended solids that enter headwater streams after harvesting at mineral soil sites were assessed (Ahtiainen & Huttunen, 1999, Jacks & Norrström, 2004, Löfgren *et al.* 2009). The studied forest buffers were 5 to 30 meters wide, the soil type varied from mineral soil to peat, and the studies covered one to three years of measurement. The forest buffers retained 15 to 73% of the inflowing N, whereas P and suspended solids were not retained in one study and retained at a rate of 96% and 43%, respectively, in another. In boreal forests, the riparian zone may also act as a source of N entering surface water (Fölster 2000, Blackburn *et al.* 2017). The mechanisms affecting the role of the riparian zone for N export and retention are poorly known.

To our knowledge there are no studies that have evaluated the effect of riparian buffers on Hg. A study in Sweden (Sørensen *et al.* 2009) included one catchment with a forest buffer and one without. However, as this study included only two harvested catchments it is impossible to tell whether the lower impact on Hg in the catchment with a forest buffer compared to the one without was related to the forest buffer or some other site characteristics.

At present, the scientific evidence from the Baltic Sea region is too meagre to allow presentation of site-specific recommendations about the minimum size of forest buffers sufficient for reducing elevated export of N, P, suspended solids and Hg. When considering the impacts of forestry on surface water quality more generally, there is a significant amount of scientific knowledge from across the world that can be used to identify measures that may help to reduce negative impacts of forestry on water quality (for example Sabater *et al.* 2003, Kreutzweiser *et al.* 2008, Kreutzweiser *et al.* 2010, Richardson & Béraud 2014, Kuglerová *et al.* 2015, Laudon *et al.* 2016, Nieminen *et al.* 2017b).

Forest buffer implementation in practice

Before implementing any of the measures or approaches proposed in this report, make sure that they comply with national legislation, other regulations and forest certification standards.

MAP THE LOCATION OF SURFACE WATERS

To take adequate measures for water protection, it is vital to know the location of surface waters, but to be aware that this information may be incomplete (Małek *et al*. 2014, Ågren *et al*. 2015). In boreal forests, the extent of the stream network may vary considerably through the year (Ågren *et al*. 2015) (Fig. 4). During high-flow periods, the length and width of small streams may increase and connect new areas to the permanent stream network. Any soil disturbance within these temporarily connected areas could negatively affect the permanent streams and springs. A field inspection of the site to be managed or harvested provides valuable information and is strongly recommended.

Cartographic depth-to-water maps (DTW-maps) are a useful tool for locating wet areas and streams (Fig. 4). These maps are generated from digital elevation models based on high-resolution elevation scans using LiDAR technology, and they model the depth to a hypothetical groundwater surface (Murphy *et al*. 2008, Ågren *et al*. 2015). Thus, the closer the groundwater level is to the ground surface, the wetter the soil.

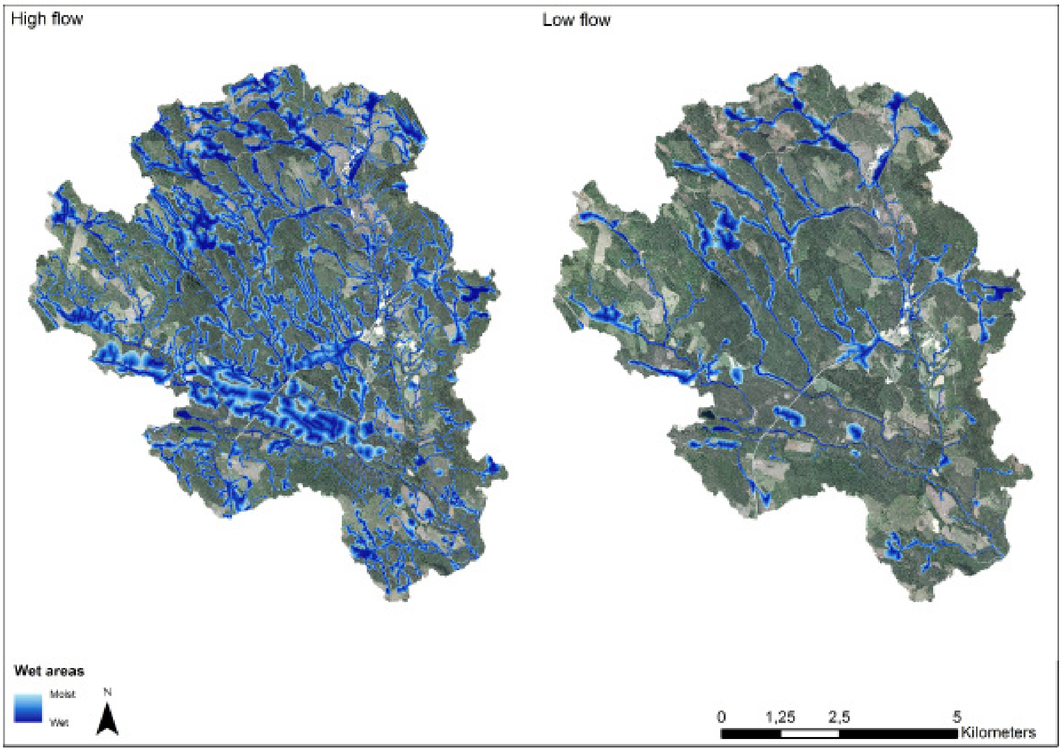

Fig. 4. Depth-to-water maps of the stream network in the Krycklan Catchment, northern Sweden, during high flow (left) and low flow (right). Modified from (Ågren *et al*. 2015). Illustration by William Lidberg.

IDENTIFY THE AIMS

Identification of clear and long-term aims for forest buffers and their functionality is likely to improve the benefits delivered by them. Such aims provide the basis for the management of forest buffers. One option for customizing the management of forest buffers is to manage them as a separate forest compartment.

REDUCE EXCESS EXPORT OF NUTRIENTS, SUSPENDED SOLIDS AND HG

Negative impacts of forestry on water quality can be prevented or mitigated using forest buffers with vegetation that takes up nutrients and facilitates sedimentation and infiltration of suspended solids (Table 1). To reduce export of suspended solids, forest buffers should be protected from soil disturbance caused by activities such as site preparation and stump lifting (Fig. 5). Moreover, driving forestry machinery should be avoided in forest buffers since soil compaction and rutting may facilitate channelized overland flow. The extension of stream length and width during high-flow periods must be taken into consideration to ensure forest buffer functionality during all hydrological conditions.

Fig. 5. The forest buffer forms a natural boundary during site preparation. Photo by Eva Ring.

Table 1. Proposed countermeasures which may reduce excess export of N, P, suspended solids and Hg caused by forestry operations. The forest buffers mentioned are assumed to include all discharge areas near surface water.

Element	**Forestry operations which may increase export rates**	**Possible mechanism for reducation**	**Proposed countermeasures**
N and P (dissolved)	Logging, site preparation[1] and fertilization	Nutrient uptake by vegetation, and volatilization (N only)	Promote and leave vigorously growing trees and ground vegetation in the forest buffer.
		No nutrient addition in sensitive areas	Any fertilizer used is applied outside the forest buffer as well as away from any other areas with high hydrological connectivity to surface water. Fertilizers are applied only during the growing season, avoiding periods with heavy rainfall. Logging residue is deposited outside the forest buffer unless it is used for ground protection.
Suspended solids[2]	Logging, driving forestry machinery, site preparation, stump lifting, ditching and ditch network maintenance	Sedimentation and infiltration within the forest buffer	Prevent export of suspended solids from adjacent clear-cuts and drained areas: Delineate an area for overland flow of sufficient size, where eroded soil particles can be deposited and infiltration can occur. Maintain the vegetation cover and prevent soil compaction and rutting within the overland flow area. Avoid sedimentation in discharge areas near surface water and areas which may become inundated at high streamflow.
		Elevated erosion prevented from the forest buffer itself	Prevent erosion and export of solids from the forest buffer itself. Avoid soil compaction and rutting within the buffer i.e. minimize driving in this area and use ground protection on soft ground. If a streamcrossing is necessary, build a bridge or install a portable bridge. No site preparation and stump lifting within the buffer. Leave wind-resistant forest buffers. Pay extra attention on highly erodible soils.
Hg	Logging, soil disturbance[3]	Formation of bioavailable methyl-Hg (Hg methylation) is not increased	Avoid damming. Therefore, do not drive across streams (without using a bridge) and do not leave logging residue in streams. Avoid disturbing the soil within the forest buffer, especially in areas with a peat layer. Thus, within the buffer, avoid (or minimize) driving, site preparation and stump lifting, and leave wind-resistant forest buffers.
		Mobilization of Hg from soil to surface waters is not increased	Avoid (or minimize) driving in the forest buffer: water channelized in wheel tracks may transport Hg released in more distant areas to surface water.

[1] Catchment studies separating the leaching caused by clearcutting and site preparation, respectively, are generally lacking. Results from two soil water studies indicate that N leaching from below the main part of the root zone may increase (Piirainen *et al*. 2007, Rappe George *et al*. 2017), while the effect on phosphate seemed insignificant (Piirainen *et al*. 2007).

[2] Suspended solids may include P and N.

[3] The connection to specific forestry operations appears more complex than for the export of N, P and suspended solids (Eklöf *et al*. 2016, 2018).

PROTECT AQUATIC LIFE

Apart from retaining nutrients and suspended solids, forest buffers can maintain other important functions especially along springs, small streams and rivers (Table 2). Forest buffers along larger rivers and lakes have similar functions as along smaller watercourses, but their impact is different. For example, forest buffers may control shading of small streams entirely while the shading provided along large rivers and lakes affects only the zone near the shore line. Moreover, a harvested area within a headwater catchment may affect the entire headwater stream, while a harvested area of the same size within a catchment of a large river would only affect a minor part of the entire river length.

Table 2. Functions provided by forest buffers along small and medium-sized streams and examples of how these functions can be promoted (Ring *et al*. 2008, Andersson *et al*. 2013). Consideration of scenic values is outside the scope of this report.

Function	Proposed management
Protect aquatic and terrestrial habitats	Delineate the forest buffer so that important habitats are included and protected. A multi-layered and uneven-aged forest buffer is often considered beneficial for its functionality. Avoid any soil disturbance within the forest buffer caused by driving forestry machinery, site preparation, ditching, remedial drainage, and stump lifting. Try to leave wind-resistant forest buffers.
Supply aquatic organisms with food (e.g. fallen leaves, insects)	Promote broadleaved trees near surface water in conifer stands.
Provide shading	Leave trees, shrubs and other vegetation that can provide shading over time. If necessary, the tree-age and canopy structure can be modified at thinning.
Supply large coarse woody debris (deadwood) to watercourses	Leave trees of all ages in the forest buffer to ensure the continuous supply of long-lived large woody debris to the streams (note: this does not include deposition of logging residues at harvesting). Both conifers and broadleaved trees can provide such long-lived woody debris. However, large amounts of deadwood causing damming should be avoided.
Protect the soil adjacent to surface waters	Try to create forest buffers resistant to wind felling and, within the buffer, avoid driving forestry machinery, site preparation, ditching, remedial drainage and stump lifting.
Stabilize streambanks	Try to create forest buffers resistant to wind felling.

DELINEATION

Fixed or variable buffer width

Forest buffers with a fixed width are common in many parts of the world (McDermott *et al*. 2009). Creating forest buffers with variable widths, including groundwater discharge areas, has been proposed by Kuglerová *et al*. (2014). This may be a way to concentrate the environmental considerations on areas where the greatest benefits are obtained. Fixed-width buffers are also efficient if they cover all essential areas such as permanent discharge areas and valuable habitats.

Fixed-width forest buffers are easier to implement than variable-width buffers, since the same width is defined along the entire water body. For variable-width buffers, the border must be uniquely identified along its entire length. This can be achieved in the field by interpreting the topography and factors reflecting the groundwater conditions such as the tree-species and field-layer composition or the cover of *Sphagnum* spp. (for example Kazoglou *et al*. 2011, Ring *et al*. 2018). Variable-width forest buffers can also be delineated using DTW-maps (Kuglerová *et al*. 2014) (Figs. 4 and 6). In mountain regions, the climatic-vegetation zone should be taken into consideration when leaving forest buffers (Małek *et al*. 2014).

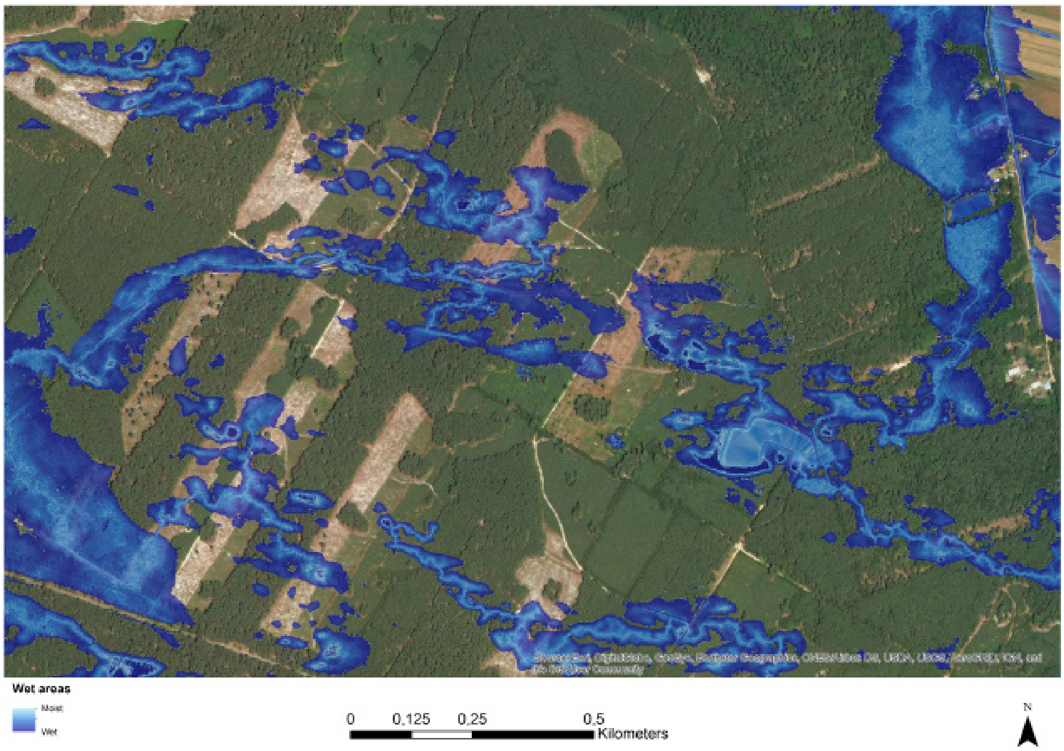

Fig. 6. A depth-to-water map of the WAMBAF demonstration area, Sokalak, in East-central Poland. Wet areas are shown in blue with increasing wetness indicated by darker shades. Illustration by William Lidberg.

Required minimum width

The gaps in knowledge about the forest buffer width required for retaining excess loads of nutrients, suspended solids and Hg in the Baltic Sea region prevent us from giving detailed recommendations about their width. The width required depends on the element in question, or function desired, and the characteristics of the site (for example Kazoglou *et al*. 2011). For retention of nutrients and suspended solids, forest buffers are more important along watercourses than around lakes and seas, to which the main terrestrial load is transported via rivers, and less from surrounding soils.

Forest buffers also serve other functions. They help maintain litter inputs to aquatic organisms, supply coarse woody debris and shade and stabilize the streambanks, which are all essential for aquatic life (Broadmeadow & Nisbet 2004, Sweeney & Newbold 2014). Broadmeadow and Nisbet (2004) concluded that buffer widths towards the lower end of the interval ranging between 10 and 30 m tend to protect the physical and chemical characteristics of a stream, while maintaining ecological integrity requires widths at the upper end. A buffer width of ≥30 m for small streams (corresponding to about ≤100 km² or a 5th order catchment) was reported to be necessary in a review by Sweeney and Newbold (2014).

TREE SPECIES COMPOSITION

For structure and species composition of the riparian buffer, Broadmeadow and Nisbet (2004) found that the benefits are greatest where the buffer replicates native riparian woodland with an open canopy of mixed species of varied age classes. Collen *et al*. (2004) concluded that coniferous needles generally provide a poorer food resource for leafprocessing stream biota than deciduous leaves. Thus, a higher proportion of broadleaved trees near watercourses may be warranted. In a survey study of riparian forests on productive forest land in Sweden, a higher proportion of *Alnus* spp. and *Betula* spp. trees were found in the 5 m zone bordering the watercourses compared to the adjacent 25 m upland (Ring *et al*. 2018). Preserving such features throughout the forest rotation is likely to improve the quality of the forest buffer to be left at final felling.

Compared to other common tree species within the Baltic Sea region, *Alnus* spp. increase the soil N store as a result of their symbiotic relationship with N-fixing bacteria. This may contribute to higher N leaching rates (Gundersen *et al*. 2006). In most cases, i.e. when alder makes up a smaller share of the riparian forest, the N-fixing capacity of *Alnus* spp. need not be taken into consideration during riparian forest management. *Alnus* spp. thrive in wet soils and are common near surface water (Fig. 7). To maintain a high N removal rate, forest buffers should maintain vigorously growing trees and ground vegetation and any harvesting should involve selective cutting.

Fig. 7. Alder forest along Narewka river in Hajnówka Forest District, Białowieża Primeval Forest complex, northeastern Poland. Photo by Wojciech Gil.

Since the riparian zone is characterized by high groundwater levels, the tolerance of different tree species to waterlogging must be acknowledged. *Salix* spp., *Alnus glutinosa*, *Betula pubescens*, *Quercus* spp., *Fraxinus excelsior*, and *Ulmus* spp. are more tolerant to water logging than Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst) (Dembek *et al*. 2002, Niinemets & Valladares 2006, Danielewicz 2008, Jasik *et al*. 2017). Furthermore, conifers with large crowns are more vulnerable to wind felling and to snow damage during winter. At exposed sites, a large proportion of conifers with large crowns in the forest buffer may lead to widespread wind felling. Although large woody debris in streams is valuable for aquatic life, extensive wind felling along watercourses may be harmful, leading to excessive sediment transport and damming (Fig. 8). However, small gaps in unmanaged buffers, which emulate natural disturbances and create variation in light and shade may benefit stream biodiversity (Kreutzweiser *et al*. 2012). In addition, small gaps provide space for tree seedlings, promoting the formation of multi-layered vegetation within buffers. If considered necessary, tree species composition and the age and structure of riparian forests can be modified at pre-commercial thinning and thinning.

Fig. 8. Widespread wind felling in the forest buffer may lead to harmful sediment transport and damming. Photo by Eva Ring.

PREDICT AND PREVENT IMPACT

Taking the environment into account during planning involves foreseeing possible negative impacts and putting in place adequate mitigation measures. However, forestry operations are carried out in a dynamic environment, where local conditions may change rapidly because of changing weather. Rainfall can rapidly reduce the soil bearing capacity and increase the area with soft soil. Moreover, seasonal variation must be kept in mind (Fig. 4). For instance, a wheel track created during low streamflow conditions may not affect sediment transport at the time, but during future rainfall events and snowmelt, erosion in the wheel track may increase sediment inputs to nearby surface waters. Thus, planning must include both short-term and long-term perspectives.

In highly sensitive sites, areas or water bodies, extra care should be taken during delineation to avoid unforeseen negative impacts of, for example, heavy rainfall or unexpectedly low soil bearing capacity. In these cases, we recommend that wider forest buffers are defined than normally required, to ensure that the desired functionality is obtained.

Finally, negative environmental impacts may be avoided by providing clear instructions to the machine operators about how to act when on-site conditions become unsuitable for carrying out or continuing the forestry operation. Having an overall policy for the entire forest company, regarding for example rutting, can support decision-making for production leaders when guiding on-site personnel in difficult situations.

PLANNING ROUTINE FOR AN INDIVIDUAL FOREST COMPARTMENT

Forestry operations are typically planned at the compartment level. To plan at larger spatial scales is challenging since this may involve several land owners and requires knowledge of how different forestry measures, such as forest buffers, should be applied at larger scales to achieve the desired function. Within the Baltic Sea region, there are examples of co-operation projects among several land owners within a larger region (for example **https://flisik.org/**). Planning at the larger spatial scale is easier in countries with a high proportion of state-owned forests, managed by one enterprise, as is the case in Poland and the Baltic countries. Given the limited scientific knowledge about forest buffers within the Baltic Sea region, the present report focuses on how to implement forest buffers at the compartment level.

To facilitate planning for individual forest compartments, it is useful to start at a company or state-forest level by

1) finding out the environmental protection requirements defined in legislation, forest certification standards (if applicable) and guidelines for forest buffers, and

2) identifying the short-term and long-term company aims for leaving forest buffers.

While acknowledging that many factors in addition to surface water quality must be considered when planning a logging operation, for example profitability, logistics, and protection of terrestrial biodiversity and cultural remains, we propose the following procedure for forest buffer planning:

1. Start planning in the office:
   a) Does the forest compartment contain surface water?
      - If so, what kind of protection does the surface water require?
      - How should the forest buffer be delineated to achieve this protection?
      - How should the logging be carried out to ensure protection?

   b) Map on-site characteristics using available maps, planning tools and other information concerning, for example, tree species composition, habitats, soil type, slope inclination.

2. Undertake a field inspection in snow-free conditions to check the tree species composition and age structure of the riparian forest as well as sensitive or problematic spots or areas. Make use of GPS/GIS when collecting field data. Mark out the border of the forest buffer in the field, for example using marking tape, and on maps.
3. Tell the machine operators and other persons carrying out the logging operation how the forest buffer should be created and managed.
4. Save details of the delineation of the forest buffer for future operations, for instance on digital maps, along with recommendations for management of the buffer.
5. Follow up and analyse the results and give feedback to personnel involved.

Planning tools

Planning is the key to successful forestry work, including management and implementation of forest buffers. Here, some tools are presented, which can be useful when planning forest buffers.

PLAN FOR WATER

A simple model for water planning, Plan for Water, was proposed by Ring et al. (2008) including the following five questions, which can also be useful when planning forest buffers:

1. **What special characteristics of the landscape and local environment need to be considered?**
   This includes factors such as topography, climate-vegetation zone in mountain areas (Małek et al. 2014), topographic gradient, soil types, erodibility, network of surface waters and their dynamics (e.g. flooding frequency), aquatic and terrestrial species composition, and characteristics of the riparian forest. Other factors that need to be considered are acidification, eutrophication, and trace metal loads and regulations related to protected areas for example Natura 2000.
2. **What type of water is it?**
   A temporary or permanent spring or stream, a rivulet, lake, pond or other.
3. **What are the goals?**
   For example, to reduce inputs of suspended solids and nutrients, maintain or improve the water quality status defined by the EU Water Framework Directive (2000/60/EC), maintain habitats, scenery and recreation values, preserve biodiversity.
4. **Which factor is the most critical for achieving the goals?**
   Soil type (erodibility), local topography, groundwater levels, soil disturbance, size of the managed forest area compared with the riparian zone, characteristics of the riparian forest for example tree species composition.
5. **How can the goals be reached?**
   At the local scale, long-term planning of forestry operations may be a successful strategy, whilst at broader spatial scales forestry must also be considered in the context of other types of land use.

DEPTH-TO-WATER MAPS

Knowing the location of surface water is essential for planning and carrying out water protection measures. Depth-to-water maps are useful tools for locating wet areas and streams (Figs. 4 and 6).

SYSTEMATIC DESIGN OF STRIP-ROAD NETWORKS

Methods for systematic design of strip-road networks have been developed in Sweden to prevent soil damage during off-road driving as part of logging operations (for example **https://storaensoskog.se/rattmetod/**). The basic idea is to start the logging operation by preparing the main extraction roads and place these in areas with the highest soil bearing capacity within the forest compartment. These roads are reinforced with logging residue to the extent needed and then used for transporting the largest volumes of wood to the landing.

TERRAIN CLASSIFICATION SYSTEMS

Terrain classification systems for forestry work (for example Berg 1992) can aid the planning of prevention of excess export of suspended solids due to off-road driving. Such classification can help to identify sensitive areas or forest compartments in need of ground protection, for example by using logging residue, corduroy bridges or portable logging mats.

BLUE TARGETING/NPK+

"Blue Targeting/NPK+" is a stream scale decision-support tool for assessing the biodiversity values of streams and their sensitivity to changes which can be useful when planning forest buffers (Henrikson 2018).

Managing riparian forests and forest buffers

Forest buffers can be narrower or wider than the riparian zone, depending on how they have been delineated. However, from a water protection perspective, forest buffers should preferably include the entire riparian zone, since this zone has an impact on the ecology, hydrology and water quality of the water body. The characteristics of riparian forests may vary considerably depending on vegetation zone, topography, and climate, but previous forest management may also have shaped the riparian forests of today, at least in some regions (Dahlström & Nilsson 2006, Ring *et al*. 2018). Riparian zones/forest buffers can be managed to promote features characteristic of unmanaged riparian forests and thereby improve their value for conservation. Moreover, to prevent or mitigate excess export of nutrients, suspended solids and Hg, it is important to protect the soil of the forest buffer against physical disturbance. Against this background, we present the following options for managing riparian forests and forest buffers:

1. Multi-layered and uneven-aged forest buffers are often considered beneficial for forest buffer functionality. Thus, if considered necessary, species composition and age and canopy structure can be modified at pre-commercial thinning and thinning to promote multi-layered and uneven-aged forest buffers.
2. A larger proportion of broadleaved trees is often warranted in riparian zones of conifer stands on productive forest land.
3. Trees are not planted in forest buffers for commercial purposes.
4. Where large woody debris in streams is sparse or lacking, single logs may be put into the streams to increase habitat diversity.
5. Any harvesting of the riparian forest should preferably be performed using selective harvesting methods to maintain a continuous tree cover alongside the surface water. Pay attention to the risk of wind felling.
6. Try to avoid excessive wind felling by preparing the trees in the buffer to withstand strong winds. More severe thinning in buffers than in adjacent stands can strengthen the tree root system and increase wind stability. At wind-exposed sites, a wider buffer can mitigate excessive tree fall close to the water. Another option could be to leave high stumps instead of some of the most wind-sensitive trees.
7. Minimize off-road forestry traffic near surface water. At logging, the harvester may use the full range of the boom to place the harvested timber away from the water. Intermittent patch or strip cutting may also be considered.
8. If forestry machinery must enter areas near surface water, take precautions to avoid rutting and soil compaction, for example by applying logging residue for ground protection and carry out the operation when the soil is dry or frozen. Furthermore, when extracting wood from sensitive areas near water, less impact may occur if the forwarder enters the sensitive area unladen, and subsequently start loading from the sensitive area towards the main extraction road or the landing.
9. If a stream crossing is necessary, identify a suitable location and build a permanent skid road and bridge across the stream if possible. Otherwise, build a temporary bridge or use a portable bridge (Fig. 9).

Fig. 9. An example of a temporary bridge. Photo by Eva Ring.

10. Do **not** fertilize the riparian forest.
11. Do **not** apply or handle pesticides or other chemicals within the riparian zone.
12. Do **not** carry out site preparation or stump lifting within the riparian zone.
13. Do **not** leave or store logging residue in the riparian zone, except when it has been used for ground protection associated with off-road transportation.

BEAVER ACTIVITY AND DITCH-NETWORK MAINTENANCE

Given the overall objectives of the WAMBAF-project, some considerations regarding the impact of beaver activity and ditch-network maintenance on forest buffers are presented.

Beaver activity has great impacts on the landscape, potentially where forest buffers have been left. Since beaver activity is a natural disturbance, no special consideration needs to be taken with respect to this when leaving forest buffers, except in cases where national "beaver management plans" or other related official documents state differently.

With respect to ditch-network maintenance, leaving an undrained forest buffer between surface waters and drained peatlands is essential to counteract increased export of nutrients and suspended solids. Any old ditches within the buffer should be blocked to avoid transporting water from the cleaned ditch network directly to adjacent surface water.

If the forest buffer is used as an overland flow area for drainage water, the area of the buffer should be ≥1% of the area of the upstream catchment (Joensuu *et al.* 2012). The overland flow area must be placed where sedimentation does not destroy valuable habitats. Furthermore, the overland flow area must be located away from areas affected by inundation, otherwise the deposited solids may be re-suspended and transported to the watercourse.

Riparian forest management within the Baltic Sea region

There is considerable geographical variation in terms of forests and waters within the Baltic Sea region (Appendix 1). To serve as inspiration, riparian forest management in the Baltic Sea countries is described here.

Estonia

Fig. 10. Left: Suitable forests for buffer zones on the banks of a remediated drainage system. Right: A natural peatland stream in the middle reach of the Mustjõgi Stream – classified as a water body with "dark water" (EU Water Framework Directive). Photos by Elve Lode.

The Estonian Nature Conservation Act prescribes *limited management zones* in protected areas on the shores and banks of surface water bodies with fixed widths (50, 100 and 200 m). Clearcutting is forbidden in the limited management zones, adjacent to the sea and large lakes, and restricted in the zones adjacent to the remaining terrestrial water bodies, with 2 ha as the maximum size of a logging area (Ring *et al*. 2017). The Water Act defines fixed-width *water protection zones* to avoid bank erosion and diffuse pollution to water bodies (*ibid*.). The width and management restrictions within water protection zones are stipulated by this Act i.e. 20 m on the shores of the sea and large lakes; 10 m for other inland lakes, reservoirs, rivers, brooks, springs, main ditches and canals, and artificial recipients of land improvement systems; and 1 m for artificial recipients of land improvement systems with a catchment area of less than 10 km^2 (for more details, see Ring *et al*. 2017). The Water Act prohibits felling of trees and shrubs in these zones unless permission has been obtained from the Environment Agency, for example in connection with drainage operations (*ibid*.).

Forest *buffer* is not used as a term in Estonia. Instead, *limited management zones of nature protection areas and water protection zones* are used. However, the meaning and purpose of these zones are comparable to "forest buffers" used in this document.

Latvia

Fig. 11. In Latvia, the width of forested riparian zones is determined by law. Left: Wide protection zone of the river Pērse. Right: Protection zone of minimal width along Zalvīte stream (10 m). Photos by Zane Lībiete.

The forested riparian zones along surface waters fall into the category of protection zones for environmental and natural resources (Protection Zone Law 1997). The width of the riparian buffer zone for streams and lakes in Latvia is prescribed by law and varies from 10 to 500 m depending on the size of the waterbody (length of the river or surface area of the lake).

The Protection Zone Law (1997) defines the following objectives of the buffer zones: to reduce pollution of the aquatic environment, to prevent and limit erosion, to suspend management activities in periodically flooded areas and to preserve the characteristic landscape of the region. It is forbidden to carry out clear-felling in a 50 m wide buffer zone (or in the whole width of the buffer zone if under 50 m) and to carry out final felling (including selective felling) in a 10 m wide buffer zone. The only exception is forest with grey alder as the dominant tree species. In grey alder stands, it is permissible to carry out clear-felling in the buffer zone if the size of the clear-cut area does not exceed 1 ha, all valuable hardwoods (for example oak, lime, elm and maple) are retained, the slope inclination does not exceed 30 degrees and the percentage of Norway spruce in the regeneration area does not exceed 80%.

These changes in legislation were introduced in 2015 after consultations with landowners, forest managers and experts, following ecological problems observed in areas with a high percentage of grey alder stands in riparian zones, mainly on former agricultural lands. The very dense canopy of grey alder stands with no or limited ground vegetation in combination with fine soil texture facilitates erosion and consequently the increased sediment input destroys spawning grounds and habitats for valuable aquatic species, e.g., freshwater pearl mussel. Due to their shallow root system, grey alder trees are often uprooted and block the waterways creating obstacles for fish migration and raising the groundwater level in the riparian zone, which can enhance the leaching of nutrients. Furthermore, the fast decomposition of grey alder deadwood depletes oxygen in the watercourse, thus decreasing the ecological quality of the aquatic habitat. Even though Latvian regulations concerning the riparian buffers are prescriptive, they do not consider the ecological functions of the riparian zones and provide no guidance on how to enhance these functions.

Hydrogeological conditions – in the Latvian case, confined aquifer discharge – have to be considered when planning forest management. Latvia, together with Lithuania, Estonia, parts of Poland, Russia and Belarus, as well as large area of the Baltic Sea, including island of Gotland, form part of the Baltic artesian basin, a multi-layered and complex hydrogeological system. Intense confined aquifer discharge is an important factor influencing nutrient cycling in Latvian forests (Dzilna, 1970, Virbulis *et al.* 2013). In Latvia, 86% of the forests on wet and drained peat soils and 60% of the forests on wet and drained mineral soils are located in confined aquifer discharge areas, this situation is fundamentally different from that in Fennoscandia (Indriksons & Zalitis 2000, Zālītis 2006, Indriksons 2009, Zālītis 2012). As the hydrographic network in Latvia is very dense, a considerable proportion of forests affected by confined aquifer discharge is located in close proximity to watercourses.

Lithuania

Fig. 12. Left: Woodland key habitat (pine and mixed pine forests) on a stream slope. Right: A buffer of Scots pine stands on a peatbog on the shore of a lake. Photos by Kastytis Šimkevičius.

Forest for protection of surface waters were first distinguished in Lithuania in 1938. However, these forests comprised only 0.3% of the total forest area (Kenstavičius & Brukas 2003). From 1945 to 1988, two forest classes were covered by legislation, (I) protective (including forests for the protection of surface water bodies) and (II) exploitable forests. In 1994, four forest groups with different forest management regimes were defined in the Forest Law of the Lithuanian Republic (1994, supplemented in 2015):

I. **Forest reserves** (1.2% of the total forest land) with a regime including no management.

II. **Special-purpose forests** (12.2%) with two subgroups: IIA – forests for protection of ecosystems including forests for the Baltic Sea and Curonian Lagoon protection (up to 1 km from the coastline); and IIB – recreational forests. In these forests, clear cutting is prohibited, and selective cuttings are permitted only in forest stands that have reached the age of natural maturity.

III. **Protective forests** (15.2%) including forests in protective zones for surface waters (the widths of these zones are indicated below) comprised 6.7% in 2016 (ME/SFS, 2016). The size of clear cuts should not exceed 5 ha, and the final stand age for clear-cutting is extended by 10-20 years compared with exploitable forests. The width of clear-cuts on slopes of 15-45^{o} should not exceed 75 m. Clear-cutting is prohibited if the slope inclination exceeds 45^{o}. Clear-cutting is also prohibited in national parks, with the exception of forest stands that are growing on wetlands, peatbogs or permanently wet mineral soils.

IV. **Exploitable forests** (71.4%) with two subgroups: IVA – forests of normal final stand age for cutting; IVB – short rotation forests.

Forest protection zones for surface waters (rivers, streams, lakes, ponds, ditches, quarries that have been converted to water bodies) and buffer belts of trees or shrubs are covered by the Law of Protected Areas (1993, supplemented in 2001) and Water Law of the Lithuanian Republic (1997, supplemented in 2001). There are five reasons for the creation of forest protection zones and buffer belts alongside surface water bodies:

1. Prevent / minimize transport of hazardous substances (for example fertilizers, pesticides and petroleum products) into the water bodies (mainly from agricultural land).

2. Protect the banks of the water bodies from erosion.
3. Maintain / ensure the stability of the water body shore ecosystems.
4. Preserve natural landscape of the water body shore and its aesthetic value.
5. Establish / provide favorable conditions for recreation.

Description of the Procedure for defining surface water protection zones and unmanaged buffer zones/belts, according Order No 540 of 7 November 2001 of the Minister of Environment.

Width of protection zones for surface water

1. 500 m from the shoreline of the longest Lithuanian rivers, Nemunas (catchment ~98 000 km²) and Neris (~25 000 km²) and from the shoreline of lakes and ponds with an area greater than 200 ha.
2. 200 m from rivers longer than 50 km and from the shoreline of lakes and ponds with an area 10-200 ha.
3. 100 m from rivers shorter than 50 km and from the shoreline of lakes and ponds with an area 0.5-10 ha.
4. Only buffer belts (see below) are delineated in forests for streams shorter than 10 km and at the shoreline of lakes and ponds with an area less than 50 ha.
5. The width of zones could be enlarged or narrowed by 25%.
6. Only buffer belts (see below) are delineated in streams shorter than 5 km.

Forests in water protection zones are considered to be Protective forests (group III above).

Width of buffer belts

1. From the shoreline of rivers longer than 10 km, from lakes and ponds with an area greater than 0.5 ha as well as from artificial ponds bigger than 2.0 ha: 5 m if the slope is up to 5°; 10 m – if 5-10°; and 25 m – if the slope is >10°. Buffer zones twice as wide should be delineated in state forest parks, preserves, and biosphere reserves.
2. Half width buffer belts are required along canals, rivers shorter than 10 km, and around lakes and ponds less than 0.5 ha, as well as manmade ponds with an area less than 2 ha.

Some riparian forests are protected under the Natura 2000 and Woodland Key Habitats (WKH) network. For example, 66% of WKH in Lithuanian forests are situated on slopes down to rivers, streams and lakes, and floodplains of rivers and the shores of lakes (ME/SFS 2016). All state forests (1.09 Mha) and only a few private forests are FSC certified (there are no PEFC certified forests in Lithuania) (Appendix 2).

Along the rivers with a catchment area greater than 1000 km², natural riparian forests are divided into three classes according to the topography (Karazija & Vaičiūnas 2000): (1) floodplain riparian forests; (2) riparian forests on slopes; and (3) riparian forests on terraces above floodplains (see Appendix 4 for detailed descriptions).

Riparian forest management in practice
In general, some restrictions on clearcutting are covered by the legislation pertaining to protective forests in water protection zones, while clearcutting and destruction of the forest floor are prohibited in water protection buffer belts. However, other fellings, such as selective cutting, and occasional cutting, pre-commercial and commercial thinning, sanitary cuttings and some special cuts (for example to form the landscape and maintain biodiversity) are allowed.

Such management of riparian forests in Lithuania is based on a complex “Forest Management Plan” that is prepared periodically (approximately every 10 years) for State Forest Enterprises or private holdings. The “Forest Management Plan” is created based on continuous Standwise Forest Inventory (SFI) and mapping (minimum area of mapped and inventoried individual forest stand – 0.1 ha; the background for the mapping is the digital Lithuanian georeference base (M 1:10 000) that includes, for example, streams, ditches and roads). SFI has been carried out every year for the past 95 years. It is based on GIS and covers all state and private forests, region by region. SFI covers all forest land in Lithuania within 10 years. Results are used for planning mandatory forestry activities (for example cutting, forest regeneration, fire prevention and forest drainage), forest mapping (maps of M1:10 000 are available via web-browsers and mobile phones), and for supplying data for the Lithuanian State Forest Cadastre.

Thinning in water protection forests and buffer belts
The Lithuanian recommendations state that the main function of water protection forests is to transfer surface runoff to the groundwater and to protect the soil from erosion and water bodies from pollution. For these purposes, the formation of mixed, uneven-aged and multi-layered stands, which are dominated by tree species with deep root systems (for example Scots pine, European larch, and pedunculate oak) is recommended. Norway spruce stands are undesirable/ineligible because of their surface root system and deeper soil freezing due to the thinner layer of snow cover, resulting in low infiltration of surface water at snow melt. Therefore, one main aim of thinning is to decrease the proportion of Norway spruce in forest stands. In addition, at thinning it is essential to preserve the undergrowth (except spruce) and underbrush.

In water protection forests, except spruce stands, the general principles of thinning for exploitable forest stands are used. When cuttings are undertaken in the Norway spruce stands (starting from the age of 25-30 years) and it is not possible to change the composition of the stand, it is advisable to leave about 10% fewer trees. By reducing the density of Norway spruce stands, their protective properties are increased and sometimes the conditions arise for natural regeneration of other tree species and underbrush. In water protection forests, it is recommended that commercial thinning is performed during the winter. It is recommended that the harvesters do not drive into the 25-30 m wide zone near surface water bodies.

Poland

Fig. 13. Left: Riparian mixed forests along a river in the Suwalki Forest District, northeastern Poland. Right: Mixed alder-willow forest and shrubs along the San – one of the biggest rivers in the Bieszczady Mountains, southeastern Poland. Photos by Wojciech Gil.

The river valleys and streams are associated with specific forest communities dominated by riparian forests. Such habitats may also occur near lakes, if the water level fluctuates over the year. Many authors (Macicka & Wilczyńska 1993, Tomiałojć 1993, Tomialojć & Dyrcz 1993) draw attention to the particular value of these forests, highlighting the high biodiversity, role of ecological corridors and water protection function. Due to human activities, riparian forests in many places have been transformed. Therefore, the most urgent task is to restore, protect and properly manage them. An additional element of these activities is the preservation of peatbogs associated with river valleys. These bogs play an important role in water retention and provide habitats for specific fauna and flora.

It should be noted that some habitats in riparian forests are protected under the Natura 2000 network. These include:

9170 — *Galio-Carpinetum* oak-hornbeam forests
91E0 — Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*
91F0 — Riparian mixed forests of *Quercus robur, Ulmus laevis, Ulmus minor* and *Fraxinus excelsior*.

Riparian forests currently occupy about 4% of the forest area in Poland (Dembek *et al.* 2002).

Legislation and regulations related to riparian forest management
Issues related to the management of riparian forests are mentioned relatively rarely in legal regulations and guidelines for forest management. The existing guidelines relate, in particular, to water protection forests as a category of protection forests located on the banks of water bodies, but they can be transposed into all types of riparian forests. It is worth noting that in Polish forestry there was no definition of the width of buffer zones around/along waters in relation to forests until the Ordinance of the Minister of the Environment of 18 December 2017, relating to the requirements for good practice in forest management. There is a statement that the 10m strip around the edges of water reservoirs and watercourses should be left undisturbed: fallen tree trunks, undergrowth and large stones should remain to facilitate access to the water by animals and the migration of animals.

The Forest Act of 1991 (Forest Act of 28 września 1991 r. o lasach. Dz.U. 1991 nr 101 poz. 444) mentions land situated on the shores of water bodies in Article 14, which states that the forest resources are to be increased:

Art. 14. 2. Agricultural land unsuitable for agricultural production, agricultural land not used for agriculture [...] may be used for afforestation, in particular: The land located at the riverside or streams, along the banks of rivers and around the lakes and water reservoirs.

Furthermore, the Forest Act defines water protection forests (Art. 15) as forests which protect the banks and the sources of rivers from erosion.

A similar definition exists in the Regulation of the Minister for the Protection of the Environment, Natural Resources and Forestry of 25 August 1992 on detailed rules and procedures for the consideration of forests as protected forest and detailed rules for the management of such forests.

Paragraph1.2. *"Forests protecting water resources (water protection forests) are considered as protection forests."*

Riparian forest management is addressed in the FSC National Standard of Forest Management in Poland (2013) and the PEFC standard "Sustainable Forest Management – Requirements" (PEFC PL 1003:2012v.2) (Appendix 2).

Riparian forests are also indirectly referred to in the State Forest Policy (1997) stating that "the size of the harvest of mature stands should take into account the constraints arising from the implementation of protective and social functions" (Chapter III, point 5.). Point 6 of this Policy postulates: "The development of the principles of sustainability and sustainable forest management requires a radical reduction of the use of semi-natural forests and forests on watercourses that are ecological corridors."

Principles of riparian forest management in practice

The aforementioned recommendations are quite general. So far, the most comprehensive practical guidelines for riparian forest management are found in the Forest Research Institute report (Kliczkowska *et al.* 2003). However, these are limited to the most valuable habitats. In other cases, e.g. Scots pine forests, silvicultural management is planned in line with the aims described in "Legislation and regulations /.../" and according to Silvicultural Principles of State Forest Holdings, in which species composition, thinnings, harvesting and regeneration depend first of all on habitat conditions.

Riparian forests are an important part of river valley ecosystems and host many species of fauna and flora. They are very fertile habitats, with a tall forest stand. The riparian habitats usually occupy small, elongated areas. Most often they should be treated as microhabitats because of their small surface area and clear boundaries. Their delineation should be determined during forest management planning.

In mountain areas, particular attention should be paid to the upper reaches of streams in the higher and middle mountain forest zones because of their periodic disappearance and changes of course. A survey of the watercourses should be carried out in the low-flow period. It will then be possible to identify areas vulnerable to fluctuations in soil wetness during the growing season (Małek *et al.* 2014).

Thinning and harvesting
Riparian forests may be protected by creating or preserving adequate water conditions and encouraging species composition and structure similar to those under undisturbed natural conditions. These stands should generally be excluded from harvesting and any possible regeneration cuttings in older age classes should have a small-scale character (selective, small group and individual selective cutting). Any thinnings should be characterized by negative selection, aimed at eliminating individuals with reduced health, thus promoting vitality. It is also acceptable to reduce the density of the undergrowth – to encourage tree regeneration.

Regeneration and site preparation
The preferred method of regeneration in riparian forests is natural regeneration, but in some cases (after severe wind-felling and at afforestation) planting after careful site preparation can be used. For planting, bare root seedlings are used. The seedlings should be planted in spring or, if water conditions in spring prevent planting, in the autumn. Autumn planting of deciduous species is possible, though with a slightly higher risk due to early frosts.

When planning afforestation of riparian areas, attention should also be paid to their vegetation zonation within the river valley. In the case of large rivers, riverbanks that are not occupied by forest communities but by willow scrub should be left.

In the mountains, especially in areas with spruce decline, within a radius of 10 m from the spring and along the initial flow of streams together with common birch and mountain ash, beech and fir as well as sycamore should be introduced by planting of containerized seedlings with mycorrhiza in small groups. In the lower mountain forest zone it is also possible to introduce mountain elm, bird cherry and gray alder, small-leaved linden and Norway maple (Małek *et al.* 2014).

Sweden

Fig. 14. Left: Forest around a small lake in northern Sweden. Right: A forest buffer adjacent to a clear-cut. Photos by Eva Ring.

The Swedish Forestry Act states that damage to soil and water caused by forest management must be prevented or limited (according to the regulations valid on 1 April, 2017). When managing forests, harmful nutrient leaching and transport of suspended solids to lakes and streams must be prevented, and the water quality preserved or improved (recommended in cases where environmental quality standards for water are established). Furthermore, a protection zone with trees and shrubs must be left to provide required protection with respect to species, water quality and other factors, when managing forests. The accompanying guidelines recommend that the protection zones are adapted to site-specific conditions, such as species sensitivity and soil and water conditions.

The Swedish Forestry Act sets a minimum level for environmental considerations, and it is largely left to the forest owners to decide how the goals for production and environment, equally emphasized in the Act, should be reached. To clarify this further, strategic objectives for good environmental consideration have been developed through a dialogue process (cf. Mårald *et al.* 2015) within Swedish forestry (Andersson *et al.* 2013, Andersson *et al.* 2016). The main features of the strategic objectives for forest buffer zones along lakes and watercourses are presented in Appendix 3. The overall aim of the strategic objectives is to create forest buffers that protect surface water from the negative impacts of forestry. When creating forest buffers, the aim is to achieve the following six functions:

1. Maintain important soil processes adjacent to surface waters, such as nutrient uptake and denitrification.
2. Prevent export of suspended solids and stabilize stream banks.
3. Supply aquatic organisms with food via falling leaves and insects.
4. Provide shade.
5. Supply deadwood to watercourses.
6. Maintain biological diversity.

Strategic objectives have been developed for buffer zones at regeneration felling, regeneration, pre-commercial thinning, and thinning, and they are mainly applicable adjacent to lakes and permanent streams. However, they may be applied to temporary streams as well.

Finland

Fig. 15. Left: A forest buffer along a small stream at the Vengasoja demonstration site in northern Finland. Right: A gap in a buffer provides space for tree seedlings. Photo by Sirpa Piirainen (left) and Erkki Oksanen (right).

Scots pine is the most abundant tree species in Finland and pine forests dominate the landscape (Appendix 1). The number of surface waters, streams, rivers, ponds and lakes is high (Ring *et al.* 2017). However, intensive peatland ditching during the 1950s-1970s (30% of the Finnish peatlands, Appendix 1) destroyed the natural network of streams and changed the characteristics of channels in many places. Thus, the number of natural small streams and rivulets is quite low in Finland and programmes have been developed to maintain and protect them (Hämäläinen 2015). A minimum width of forest buffers is determined for cuttings, both final harvest and thinning. The width varies from 5 to 20 m depending on the type of water, excluding artificially made channels, ponds or ditches and sea coastlines. These widths are required for the Finnish FSC and PEFC forest certification, but not legally specified. Since these standards are widely followed (87% of productive forest land was certified by PEFC and 7% also by FSC, in January 2018), this has been effective in ensuring that forest buffers are present along waters. In addition, forest buffers containing rare or key habitats or habitats important for maintaining biodiversity e.g. springs, rare mire types, seepage or flood-water influenced meadows, are protected by the Forest Act, and no forest operations are allowed in these areas.

In the Finnish FSC standard, the minimum width of a forest buffer for ponds and lakes is 10 m and 20 m for streams, rivers and seashore; these distances cover restrictions on cuttings, site preparation, stump harvesting and drainage. For fertilization, the minimum width is 50 m for ponds, lakes and seashore and 20 m for streams. In the Finnish PEFC standard, the minimum width is 5-10 m for all waters and forestry operations. The PEFC certification standard allows harvesting of single trees from a buffer, which enables, for instance, changes in tree species composition in the developing stand. However, the FSC standard is much stricter and no harvesting at all is allowed. The target in both standards is to create forest buffers with multi-layered vegetation, which also delivers other ecosystem services, like providing shelter for wild animals.

As the minimum width required between a clear-cut area and a stream is quite small, the narrow band of standing trees is vulnerable to wind damage and wind-felling. Such damage and wind-felling may reduce the efficacy of buffers in retaining elements and may also change the physical environment of buffers for instance by lifting stumps and decreasing shade and litterfall. Thus, when determining the width of forest buffers, the local weather conditions should also be taken into consideration.

In Finland, forest buffers can also be used as overland flow areas for capturing suspended solids and nutrients after ditch network maintenance. However, in those cases, the width of the buffer zone should be sufficient to markedly decrease the runoff velocity. The recommendation is that the size of the overland flow areas should be at least 1% of the whole catchment area.

Water protection is also steered by guidelines made by advisory, regulatory and research organizations or by forestry enterprises themselves. These guidelines are more specific and include details which should be considered when planning forestry operations in riparian forest. For example, Metsähallitus, which is a state-owned forest enterprise, has developed their planning and management of buffer zones for increasing forest buffer efficacy both in aquatic and riparian ecosystems (Fig. 16). At sensitive locations, the buffer zone can be more than 30 m wide in their planning. Metsähallitus also use GIS analyses for illustrating water discharge areas along streams (Fig. 17). GIS-analyses of catchments size, water flow areas and main water routes are available for the whole of Finland and these maps can be accessed via common web-browsers or mobile phones at no cost. Maps can be downloaded from the webpages of the Finnish Forest Centre: **https://www.metsakeskus.fi/vesiensuojelutyokalut** and **https://www.metsakeskus.fi/vesiensuojelukartat**. There are good and easy-to-use tools for every forest owner and planner to improve water protection in Finnish forests.

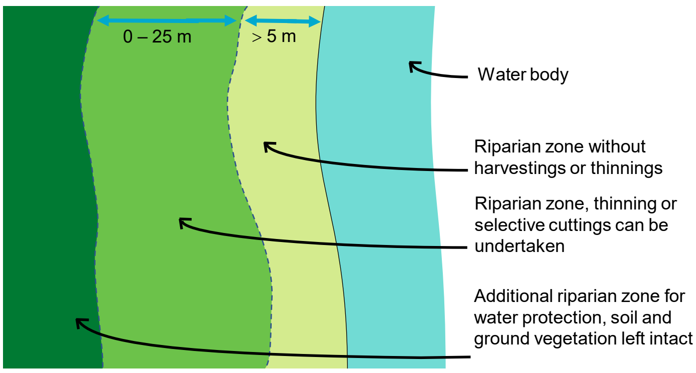

Fig. 16. Guidelines for the management of riparian forests by the state-owned forest enterprise Metsähallitus. Figure from Eeva-Liisa Jorri/Metsähallitus.

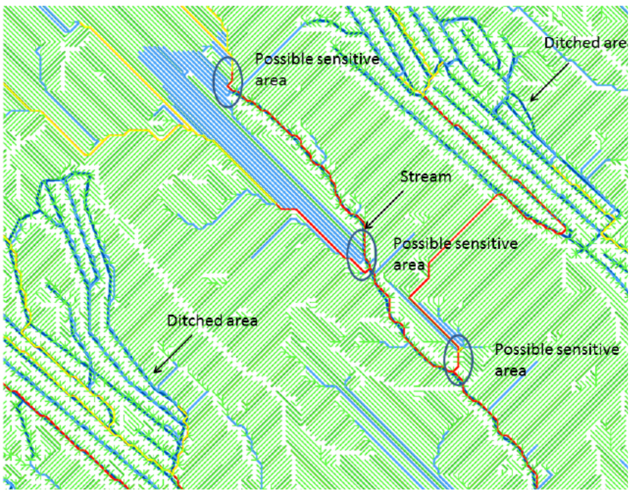

Fig. 17. Map of surface water flow. Green, blue and red lines indicate the flow direction of surface water. Streams and ditches are included on the flow map and are derived from topographical maps. Metsäkeskus, The Finnish Forest Centre.

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Appendix 1 – Forests and soils in the Baltic Sea countries

Country	Productive forest area[1] (% of total land area)	Forest types	% of productive forest area	Forest and soil types	%	Features of the forest landscape
Estonia	2.14 Mha stocked forest land (47.2%)[3]	<u>By dominant tree species[2]:</u> Pine Birch Spruce Aspen Grey alder Black alder Other	 29.5 30.1 19.3 6.2 7.5 3.6 1.2	<u>By forest site type[4] (% of forest land area):</u> a) Alvar forest — thin soils, dry during summer b) Heath forest — sandy dry areas, mainly on the coasts of the Sea c) Mesotrophic forest — dry boreal forest, depth of GWL7 below 2 m d) Mesoeutrophic forest — fresh boreal forest, moderately moist soils, GWL below 2 m e) Nemoral forest — fresh boreo-nemoral forest, fresh soils with good water conditions for tree growth f) Herb-rich forest on gley soil — flat sites with high GWL g) Forest on paludified soil with *Sphagnum* — low-productive forest growing on water-saturated soil above an impermeable soil layer h) Drained peatland forest — tree roots concentrated in the upper soil i) Swamp forest — minerotrophic swamp forest with permanently high GWL j) Forest on reclaimed pits — often quite rocky (limestone) and dry sites	 2.4 0.2 23.3 27.6 10.2 15.5 0.4 13.5 5.9 1.0	
Latvia	3.383 Mha (52%)	<u>By dominant tree species:</u> *Pinus sylvestris* forest *Betula* spp. forest *Picea abies* forest *Populus tremula* forest *Alnus incana* forest Other	 34 30 18 7 7 4	<u>% of total forest area (3.383 Million ha)</u> Forests on: dry mineral soils wet mineral soils (peat layer≤30 cm) wet peat soils (peat layer >30 cm) drained mineral soils (peat layer ≤20 cm) drained peat soils (peat layer >20 cm)	 49 10 8 19 14	Confined aquifer discharge in significant parts of wet and drained forest areas.
Lithuania	2.06 Mha (33%)[1]	*Pinus sylvestris* forest *Betula pendula* & *pubescens* *Picea abies* forest *Alnus glutinosa* *Alnus incana* Other softwood deciduous species (*Populus tremula* etc.) Hardwood deciduous (*Quercus robur*, *Fraxinus excelsior*)	35 22 21 7 6 6 3	The depth of soils varies from 40 cm to 2 m. <u>Prevailing soil parent material textural classes (% of total Lithuanian area, 6.53 Mha):</u> Glacial moraine soils - medium sandy loam or/and silt loam; Glaciolacustrine soils – fine silt loam or/and clay Glaciofluvial soils - coarse sand or/and gravel; Eolian soils – fine sand Organogenic soils – peat Other soils (marine/littoral, erosion, karst) <u>Major soil groups (WRB, 2014 2015) in Lithuanian forests (% of total forest land area, 2.19 Mha)[5]:</u> Arenosols Luvisols and Retisols Histosols Planosols, Gleysols and Podzols Cambisols and Fluvisols	 56 23 18 1 1 1 32 29 11 24 4	In the west is a narrow zone of coastal area of Baltic sea and Curonian Lagoon (Baltic Sea Coastal Area), including the delta of Nemunas river (with Arenosols and Fluvisols). Further east is the Žemaičiai Upland with a prevalence of Retisols and Luvisols (forest coverage 30-35%, mainly mixed Norway spruce stands). In the Middle Lithuanian Lowland there are Luvisols and Cambisols (forests coverage 20-30%, mainly mixed deciduous-spruce stands). East of this lowland is the land of the Baltic Upland with a prevalence of Retisols and Luvisols (forest coverage 35-40%, mainly mixed pine-spruce stands). East of the Baltic Upland is the North-Eastern Plain which is connected to the sandy South-Eastern Lithuanian Plain with Arenosols and

				Forest site types according to the hydromorphic properties of soil (% of total forest land area (2.19 Mha): Slopes (>15°) Normaly moistured (automorphic, always freely drained) Temporaly overmoistured (semi-hydromorphic, seasonally waterlogged) Overmoistured (hydromorphic, always waterlogged) Drained peatland Peatland	 2 41 38 6 6 7	Podzols (45-50%, mainly pure Scots pine stands). At the eastern border there are small areas of the highest Lithuanian uplands, Švenčionys upland and Medininkai upland with a prevalence of Retisols, Luvisols and Planosols.
Poland	9.42 Mha (30.8%)	By dominant tree species: Coniferous trees of which: Scots pine (*Pinus sylvestris*) Norway spruce (*Picea abies*) Fir (*Abies alba*) Other Broadleaved trees of which: Oak (*Quercus sp.*) Beech (*Fagus sylvatica*) Birch (*Betula sp.*) Alder (*Alnus sp.*) Other By site class: Coniferous forests (pure) Coniferous forests mixed Mixed forests Broadleaved forest	 68.7 58.1 6.3 3.1 1.2 31.3 7.7 5.9 7.3 5.5 4.9 21.2 29.5 26.3 23	Zonal soils (% of total land area): Podzolic, brown, brown podzolic and grey-brown podzolic soils Chernozems Alluvial soils, peat, half-bog and gley soils Azonal soils, e.g. regosol, lithosol, skeletal soils	 74 1 20 5	
Sweden	23.5 Mha (58%)	By forest type (2013-2017): *Pinus sylvestris* forest *Picea abies* forest Mixed conifer forest Conifer/broadleaved forest Other broadleaved forest	 38.9 27.3 13.5 7.4 6.2	Dominating soil parent material class (% of forest land area): Fine-grained till Medium-grained till Coarse-grained till Fine-grained sediment Medium-grained sediment Coarse-grained sediment Peat Bedrock outcrop	 12 49 9 9 6 1 8 6	
Finland	20.3 Mha (76%)	*Pinus sylvestris* forest[2] *Picea abies* forest[2] Mixed coniferous forest[2] Mixed forest Broadleaved forest[3]	58 20 10 5 6	Site fertility class (% of forest land area): Herb-rich and herb-rich heath forests on mineral soils Mesic forests on mineral soils Sub-xeric and xeric forests on mineral soils Barren forest, rocky and sandy soils and alluvial land Eutrophic and mesotrophic eutrophic peatlands Meso-oligotrophic eutrophic peatlands Oligotrophic eutrophic peatlands Oligo-ombrotrophic and ombrotrophic peatlands	 13 41 22 <1 3 7 9 4	Drained forest land[3]: drained mineral soils 1.3 Mha drained peatland forests 4.6 Mha

[1] Productive forest land is defined as land with a mean tree growth of ≥1 m³ yr⁻¹ (Sweden, Finland). For Lithuania, forest is defined as an area ≥0.1 ha with trees having a degree of tree volume stocking ≥0.3, and a height of ≥5 m at maturity in natural site conditions (Kuliešis et al. 2016).

[2] Without the Lake Peipsi area (Yearbook Forest 2016).
[3] Calculated from the managed forest area (Yearbook Forest 2016).
[4] There are no official soil type statistics available, therefore Forest site type (Yearbook Forest 2016) was used as an indirect indicator.
[5] The proportion of *P. sylvestris*, *P. abies* or broadleaved trees is ≥75%.
[6] The proportion of conifers is >50%.
[7] GWL – groundwater level
[8] Unpublished data of the Lithuanian forest soil survey at a grid of 9x9 km (2016).
[9] Total forest land area is 26.2 Mha.

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Appendix 2 – National forest certification standards: Riparian forest management and water protection

Here, requirements related to riparian forest management and water protection are listed, according to the national standards for forest certification. For a complete overview and full details, we refer to the national forest certification standards.

Estonia

PEFC National Forest Management Standard for Estonia, Version 10.08.15

The PEFC standard for Estonian forest management (i.e. National Forest Standard, 10.08.15) does not explicitly mention water protection zones, but forest management planning should include "nature conservation restrictions and other restrictions" (§1.2.3 in the PEFC Estonian National Forest Standard). Principle 10, relating to plantations of the FSC standard for Estonia (NEPCon Interim Standard for Assessing Forest Management in Estonia), stipulates that "water protection zones along watercourses and around water bodies shall be established according to the regional best management practices or local laws and regulations (Ring *et al*. 2017). Zones should be indicated on maps". For forest holdings less than 100 ha, "water protection zones and streamside management zones shall be protected" (*ibid*.). This means that in the preparatory stages of both planting and harvesting, existing national legislation, such as the Nature Conservation and Water Acts, should be considered (*ibid*.).

Latvia

PEFC Forest Management Standard for Latvia, 2015

(https://www.pefc.org/images/stories/documents/NGB_Documentation/Latvia/2.PEFC_FM_standard_2015.pdf) and National FSC Forest Stewardship Standard for the Republic of Latvia, 2013, FSC-STD-LVA V1-0 D2-5 EN (https://lv.fsc.org/download-box.10.htm)

The Latvian PEFC standard requires that forest areas adjacent to water bodies are protected and/or managed primarily to sustain water quality, but without specifying how this should be achieved. The standard also states that an assessment of potential environmental impact when planning forestry operations next to water bodies and implementation of mitigation measures should be carried out. In the Latvian FSC standard, forest adjacent to waterbodies (25 m-wide zones along salmonid waters and 10 m-wide zones along other waters) is one of the categories listed as being a valuable habitat for biodiversity. Identification and preservation of all types of such valuable habitats are required for 10% of the managed total forest area.

Lithuania

NEPCon Interim Standard for Assessing Forest Management in Lithuania (Version 19 December 2014)

In this standard, some requirements/indicators for forest management operations can be found for forest areas adjacent to water bodies; NEPCon evaluates these to make certification decisions according to the Forest Stewardship Council (FSC) certification system.

6.2.4. Operations in the conservation zones or nearby shall be conducted so that the conservation values are not harmed or endangered in any way.

6.5.4. No road fill or waste material (e.g. rocks, brush) from site preparation or other activities shall be placed in stream courses.

6.5.5. Buffer zones in clear cuts shall be left along water bodies and open landscape to ensure stability for forest ecosystems and microclimate.

10.2.2. Buffer zones along watercourses and around water bodies shall be established according to regional best management practices or local laws and regulations. Buffer zones should be indicated on maps.

10.6.3. Forest operations shall not degrade water quality or negatively impact local hydrology.

Poland

FSC National Standard of Forest Management in Poland, FSC-STD-POL-01-01-2013-Poland Natural and Plantations EN

The FSC standard for Poland, Principle 6 “Environmental impact” reads: “Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.” Under Criteria 6.1., 6.2. and 6.3. riparian forest is mentioned:

6.1.4. Wet soil types (their upland and mountain equivalents) shall be handled with particular precaution consisting in avoidance of soil damages and disturbances of water relations.

6.2. Safeguards shall exist which protect rare, threatened and endangered species and their habitats (e.g., nesting and feeding areas). Conservation zones and protection areas shall be established, appropriate to the scale and intensity of forest management and the uniqueness of the affected resources. Inappropriate hunting, fishing, trapping and collecting shall be controlled.

6.2.7. Surface springs as well as river and stream beds are protected during forest operations.

6.3.2. Wet, bog and riverine forest types (lowlands, highlands, mountainous) shall be treated according to existing regulations of felling systems intended to wet forest sites and tree species used for forest regeneration that results in age and structure differentiation.

6.3.3. Forest Manager shall refrain from exploitation of bog and fen forests whenever possible.

PEFC, Sustainable Forest Management – Requirements. PEFC PL 1003:2012v.2.

Similar indications can be found in the PEFC standard for Poland, criterion 5:

5.1. Forest management planning shall aim to maintain and enhance protective functions of forests for society, such as protection of infrastructure, protection from soil erosion, protection of water resources and from adverse impacts of water such as floods or avalanches.

5.2. Areas that fulfil specific and recognised protective functions for society shall be registered and mapped, and forest management plans or their equivalents shall take full account of these areas.

5.3. Special care shall be given to silvicultural operations on sensitive soils and erosion-prone areas as well as in areas where operations might lead to excessive erosion of soil into watercourses. Inappropriate techniques such as deep soil tillage and use of unsuitable machinery shall be avoided in such areas. Special measures shall be taken to minimise the pressure of animal populations.

5.4. Special care shall be given to forest management practices in forest areas with water protection functions to avoid adverse effects on the quality and quantity of water resources. Inappropriate use of chemicals or other harmful substances or inappropriate silvicultural practices influencing water quality in a harmful way shall be avoided.

5.5. Construction of roads, bridges and other infrastructure shall be carried out in a manner that minimises bare soil exposure, avoids the introduction of soil into water-courses and preserves the natural level and function of water courses and river beds. Proper road drainage facilities shall be installed and maintained.

Sweden

Swedish FSC Standard for Forest Certification including SLIMF indicators (FSC-STD-SWE-02-04-2010 Sweden Natural, Plantations and SLIMF EN)

"SLIMF" refers to "Small and Low Intensity Managed Forest". Indicators only applicable to SLIMF are not presented here.

Criterion 6.5

Written guidelines shall be prepared and implemented to: control erosion; minimize forest damage during harvesting, road construction, and all other mechanical disturb-ances; and protect water resources.

6.5.2S. Managers shall use intermittent site preparation methods on moist soils and on erosion-prone soils, and shall not carry out mechanical site preparation in edge zones along water and wetlands.

6.5.3. Managers shall implement procedures for avoiding damage caused by heavy machinery, including appropriate methodology and technology for transports across watercourses. (With footnote: Substantial ground damages refer to, for example, damages causing significant erosion and sediment transport to watercourses, wheel tracks changing the direction of water flows, damages in areas with specific biodiversity values, and wheel tracks in areas of particular importance to outdoor recreation, especially close to urban areas.)

6.5.4. Managers shall implement procedures to act on substantial soil damage caused by vehicles.

6.5.5. Managers shall implement procedures to ensure that construction of new roads does not change the running of, or cause damage to, natural watercourses.

6.5.6S. Managers shall remove obstacles to the migration of aquatic organisms when maintaining or reconstructing culverts.

6.5.7. Managers of major holdings shall develop action plans for removing obstacles caused by road culverts to the migration of aquatic organisms in watercourses with special biodiversity values,

6.5.8S. Managers shall not establish new ditches for soil drainage on land which has not previously been ditched. (With footnote: Exceptions shall be permitted in the case of flooding which threatens the stand vitality on condition that the required permissions have been obtained from the authorities concerned.)

6.5.9S. Managers shall apply protective ditching only where such measures are clearly necessary to comply with the regeneration requirements of the Forest Act.

6.5.10S. Managers shall ensure that ditches and road ditches do not discharge directly into watercourses, lakes or valuable wetlands. Exceptions may be applicable due to adverse topography or other special conditions.

6.5.11S. Managers shall not maintain previously established ditches on peat land with low forest production. (Authors´comment: With clarifications and exceptions, which are not presented here).

6.5.12. Managers shall be aware of existing local and downstream biodiversity values, and of options for restoration, prior to clearing of ditches. Protective measures shall be applied and consideration shall be documented.

6.5.13S. Managers that clear ditches, or apply protective temporary drainage, shall construct functional sedimentation ponds where necessary to minimise negative effects of sedimentation.

6.5.14. Managers shall implement procedures that promote continuously forested, if possible stratified, transition zones conditioned by topographical, hydrological and ecological features along watercourses and open water areas.

6.5.15S. Managers shall plan and manage their landholding so that stands, dominated by broadleaf trees and with high potential for biodiversity, are maintained and/or established:

a. on moist sedimentary soils adjacent to watercourses and open water bodies;
b. in sediment ravines;
c. on other moist/wet land that is naturally dominated by broadleaf trees.

6.5.16. Managers shall take account of aquatic habitats when forest land is set aside for nature conservation purposes.

6.5.17. Managers shall consider wetland and aquatic habitats in a watershed perspective beyond the context of the landholding and take specific consideration measures to such habitats with high biodiversity values.

6.5.18. Managers of major holdings shall use procedures to assess the need for, and practical/economic possibilities of, re-creating water environments in their ecological landscape planning.

PEFC Sweden Forest standard, PEFC SWE 002:4

5.6 Ditching

Consultation with the Forest Agency should be conducted before cleaning/ maintenance of ditches is made. Precautionary ditching may be applied when regeneration requirements of the forestry legislation cannot be met in any other way. In previously ditched areas where the frequency of ditches is too sparse or ditches are wrongly constructed, new ditches may be established provided that permission is obtained from the County Board.

5.6.1. Drainage must not be undertaken on forest land that has not been ditched before.

5.6.2. Ditches shall not be maintained on peat-land where the effect of ditching has not occurred, is very limited, or where high conservation values may be damaged, except where the ditch is draining another ditched area.

5.6.4. In connection to cleaning of ditches, ditches that fall directly into water courses and lakes shall be taken care of in order for sediment in the water to be given the possibility to settle before the water reaches the water course.

5.6.5. Exceptions from the rule of not establishing new ditches can be made in the event of floods threatening the vitality of the forest stand, and which are occurring beyond the land owner's own control. Excluded from this exception are forests with high conservation values that are naturally and recurrently flooded.

5.7 Methods for protection of soil and water

Forestry may affect soil and water in different ways. Extraction of timber and forest fuel decreases the amount of available nutrients, and soil damages may imply that nutrient turn-over in the soil is negatively affected, that the soil is compacted, as well as that ground- and surface water is affected through transport of sediment or soluble nutrients and heavy metals. Felling- and silvicultural work must be performed throughout the year, which places stringent demands on planning and implementation. The building of forest roads shall be coordinated across property borders where applicable and should not be built directly adjacent to lakes, wetlands, sensitive biotopes, cultural remains and frequently used tracks. Water catchment areas should be protected against present and future risks.

5.7.1. Measures shall be planned with respect to season and soil stability so that damages to soil and water are avoided.

5.7.2. Special consideration shall be shown to wetlands and other water environments when planning for forestry operations and road construction.

5.7.3. New roads shall be established in a way that preserves the running of natural watercourses and that minimises damages to watercourses and hinders for migration. New road ditches shall not fall directly into watercourses, lakes, or wetlands.

5.7.4. In connection to refurbishment of roads, road drains shall be fixed so that they do not constitute a hinder for migration.

5.7.5. Appropriate methodology and technology shall be used to minimise rutting in harvesting operations, especially where transports intersect watercourses.

5.7.6. Any rutting caused by harvesting equipment shall be taken care of in case damages are causing a direct flux of sediment and humus into a lake or watercourse, or if they constitute a hinder for accessibility to frequently used roads, tracks, trails, etc. In every other case, restoration risks doing more harm than good.

5.7.7. On land where there is risk of erosion, intermittent soil scarification methods shall be used.

5.8 Edge- and buffer zones

Edge zones and buffer zones are important to biological diversity on forest land as well as to adjacent land use classes. The prerequisites differ between areas and the buffer zones shall be adjusted to the current conditions.

5.8.1. In edge zones/forests edges and on the shores of lakes and watercourses, deciduous trees and bushes shall be favoured in order to create a layered and uneven-aged edge zone.

5.8.2. On sites where a buffer zone is needed but is lacking, measures shall be taken as soon as possible for the creation of a functional buffer zone, which breadth shall be adjusted to the object to be protected and conditions on the site.

5.8.3. Rutting at edge- and buffer zones shall be avoided.

Finland

FSC Standard for Finland (8.11.2010)

6.2.9 S. The forest owner shall leave buffer zones during ditching, site preparation and clear-felling, thereby ensuring not to degrade the water quality of small waters and rivers identified as valuable for fishing and nature conservation.

6.3.9 S. The forest owner shall minimise the impacts of fertilisation on water resources by leaving unfertilised buffer zones with the following minimum widths between the fertilised area and the water: a) water courses (sea, lake, river or pond): 50 m, b) brooks: 20 m, c) ditches: 5 m.

6.4.1.2.S. Rivers and brooks with natural or near-natural beds including their banks (wooded zone with a minimum width of 20 m to be preserved) as well as springs with a similar zone.

6.5. Written guidelines shall be prepared and implemented to: control erosion; minimize forest damage during harvesting, road construction, and all other mechanical disturbances; and protect water resources.

6.5.1 S. The forest owner shall leave a buffer zone determined by topography and soil type adjacent to water courses (including seashores) and small waters. The minimum width of the buffer zone shall be: a) 10 m on all ponds and lakes b) 15 m on brooks, rivers and seashores c) 30 m on flads and gloe lakes

6.5.1.1 S. Felling of forest, site preparation, ditching and stump harvesting are not permitted in the buffer zone. Forest machines shall not be operated in the buffer zone, with the exception of necessary crossings.

Note: Fellings done clearly for restoration or habitat management are possible in the buffer zone.

PEFC Finland Standard, Criteria for PEFC Forest Certification, PEFC FI 1002:2014

Criterion 17: All operations taking place close to watercourses and small water bodies shall safeguard water protection.

A buffer-zone that preserves layer composition of vegetation is left along watercourses and springs for capturing solid and nutrient run-off to. Leaving canopy biomass on the buffer zone should be avoided. On buffer zones there should be no – soil scarification – fertilization – stump removal – clearing of shrub layer vegetation – use of chemical pesticides or herbicides. Tree harvesting on buffer zones can focus on other trees than those that are retention and decaying trees mentioned in the Criterion 14, however so that a bush layer and small trees of the buffer zone are preserved.

Indicators: On the area of operations the buffer zone is considered to be preserved as required by the criterion when, based on monitoring, the soil is undisturbed on over 90 per cent of the length of the buffer-zone and the layer composition of vegetation has been preserved. The width of the buffer zone is at least 5-10 meters taking into account the vegetation of the shore area and shape of the landscape.

Definitions: Watercourses include seas, lakes, ponds, rivers and creeks. The shrub layer and small trees along water courses may be cleared for reasons related to landscape values and environmental management. Chemical pesticides and herbicides refer to the definitions of plant protection products defined in the Act on Plant Protection Products 1563/2011 and the Regulation of the European Parliament and Council (EC) N:o 1107/2009. Area of operations is an entity composed of one or several forest subcompartments or an area confined on a map where the same type of harvesting and other silvicultural measures is applied nearly on all of the territory.

Appendix 3 – Guidelines from Poland and Sweden

Poland – Guidelines for State Forest Holdings (Decree No. 11a (1999), ZG-7120-2/99)

"One of the key factors of forest sustainability is to reduce the degradation of water relations in forests. Thus it is necessary to develop and implement plans and programs for small water retention and recovery of water bodies and reservoirs in forests."

Furthermore, the Silviculture Principles of State Forest Holdings 2012 (DGLP, Warszawa) state:

Paragraph 67.5. The basic activities of silviculture should be directed towards the strengthening of the forest water protection function, with particular attention to the protection of drinking water resources in natural reservoirs, with the need to slow down the runoff of rainwater.

Par. 67.6. Increasing water retention and impact on water quality are possible through:

a) maintenance of sustainability of the forest;

b) maintenance of complex plant cover (in relation to species composition and structure);

c) adaptation of species composition of stands to habitat conditions;

d) conducting phytomeliorative treatments in monocultures of different species (by introducing of broadleaved trees in understorey);

e) increasing the forest cover, including river basin areas of river basins, river banks and surface water bodies, areas for supply of underground water bodies, areas threatened with water and wind erosion;

f) the introduction of forest stands at the upper limit of their occurrence, on degraded soils threatening to contaminate groundwater;

g) improvement of functionality, reconstruction or construction of new drainage facilities to maintain optimal water level or slow down its flow;

h) construction of so-called small retention facilities.

Some recommendations on this matter are also presented by Małek *et al.* (2014) and in the "Good-practice manual of sustainable maintenance of mountain streams and rivers" (Bojarski *et al.* 2005). The latter document states that riparian forest should be restored. No site preparation, fertilization or chemical treatments should be carried out in riparian forests and logging residue should be removed. Broadleaves should be favoured.

Sweden – Strategic objectives for forest buffers along lakes and watercourses

Strategic objectives for good environmental consideration have been developed through a dialogue process within Swedish forestry (Andersson *et al*. 2013, Andersson *et al*. 2016). Most of the strategic objectives for forest buffers along lakes and watercourses are presented below (Andersson *et al*. 2013):

The overall aim is to create forest buffers to protect surface water from the negative impacts of forestry. When creating forest buffers, the aim is to achieve the following six functions:

1. Maintain important soil processes adjacent to surface waters, such as nutrient uptake and denitrification.
2. Prevent export of suspended solids and stabilize stream banks.
3. Supply aquatic organisms with food via falling leaves and insects.
4. Provide shade.
5. Supply deadwood to watercourses.
6. Maintain biological diversity.

Strategic objectives were created for buffer zone during regeneration felling, regeneration, pre-commercial thinning, and thinning, and they are mainly applicable adjacent to lakes and permanent streams. However, they may be applied to temporary streams as well.

Strategic objectives for regeneration felling

- No felling in discharge areas located adjacent to surface water.
- Care-demanding biotopes bordering surface waters are left unmanaged, or management to promote biological values is carried out.
- All broadleaves within 10 meters of the surface water are left unharvested in stands dominated by conifers.
- Trees, shrubs and other vegetation which are expected to provide continuous shade over time, contribute food and deadwood to the water and act as a filter for suspended solids are left unharvested, depending on existing site conditions.
- The forest buffer zone is not cleaned prior to harvesting.
- No rutting in or close to watercourses and lakes. This means that forestry machinery is not driven within about 10 meters of surface waters.
- No soil disturbance that increases export of suspended solids to lakes and watercourses is caused by moving forestry machinery.
- No soil damage caused by forestry transportation in discharge areas.

To delineate a forest buffer at regeneration felling – examples of work routines

STEP 1
Delineate discharge areas and care-demanding riparian forests which are located directly adjacent to the watercourse or lake. Discharge areas are characterized by groundwater flowing on or close to the soil surface and the ground vegetation is often dominated by *Sphagnum* spp. and other hydrophilic vegetation. A care-demanding riparian forests is characterized by the presence of deadwood, old trees, elevated stem bases, boulders, pools of standing water, etc.

When large swamp forests which are not care-demanding biotopes are located adjacent to surface water, a special assessment can be undertaken to delineate an area of reasonable size. However, it is recommended that the width of the forest buffer is at least one tree length. Within the forest buffers delineated as described here, i.e. discharge areas and care-demanding riparian forests, usually no harvesting is carried out.

STEP 2
In cases where the delineation according to step 1 is insufficient for providing shading of the water, the forest buffer zone is expanded to achieve this function. A zone that provides sufficient shade should also supply sufficient amounts of food to the aquatic organisms. The required width of the zone depends on the degree of layering of the forest and the shade it provides. A zone without layering may need to be wider than a multi-layered zone. Preferably, wider zones should be delineated towards the south than the north. Additional areas may be needed to prevent erosion and export of suspended solids to the water. This delineation is based on the risk for erosion, i.e. the particle-size distribution of the soil and ground slope. Within forest buffer zones delineated as above, i.e. to provide shade, careful selective cuttings can be carried out provided that the shading of the forest buffer is maintained. Trees of high nature conservation value and some of the large-diameter trees should be left unharvested to serve as a possible source of deadwood to the watercourse in the future. Deadwood can be actively created by felling trees into the watercourse.

Proposed management when the risk of wind felling is high
There are cases when the planned forest buffer is considered highly susceptible to wind felling. By taking appropriate measures during thinning in uniform spruce stands, wind felling can probably often be prevented (see strategic objectives for and proposed management at thinning).

A risk assessment for wind felling must be undertaken prior to every logging operation. If the risk of wind felling and subsequent insect infestations is perceived to be great, felling can be carried out all the way to the water line along limited stretches of the watercourse. Preferably, only the forest on one side of the watercourse is harvested, and the other side is harvested when a new forest buffer has been established (see strategic objectives for regeneration). In order to supply deadwood to the watercourse and the riparian forest, some trees are always left unharvested, thus allowing wind felling of these trees, or deadwood is actively created by felling trees into the watercourse. The forest buffer zone is not harvested if it has high ecological values, even if the risk of wind felling is high.

Another way to deal with high risks of wind felling is to leave a wider forest buffer zone in which some trees are harvested. Keep in mind that the tallest trees are usually the most stable, as they have been more exposed to wind. Therefore, harvesting co-dominant trees might be preferred. Also note that trees in forest buffer zones along lakes and larger streams are more exposed to weather than trees along small streams in closed forest. Thus, trees in forest buffers along lakes and large watercourses are less likely to be wind felled compared with trees in forest buffers of small streams.

Strategic objectives for regeneration

- Where a functional forest buffer is present, the buffer forms the border for site preparation.
- Along stretches lacking a buffer, or with a narrow buffer, site preparation by continuous methods (disc trenching) is not carried out within approximately 10 m of lakes and watercourses.
- Patch scarification, mounding and sowing/planting is not performed closer than 5 m from lakes and watercourses.
- Site preparation does not cause export of suspended solids to lakes, watercourses or ditches connected to lakes and watercourses.
- To prevent damage caused by off-road traffic, the strategic objectives for regeneration felling apply.

If the forest buffer zone left at regeneration felling is narrow or lacking, a new forest buffer may be established by allowing the vegetation to develop naturally in this zone, or by planting broadleaves in the zone closest to water. In moist areas, broadleaves typically regenerate without site preparation and planting. If site preparation is found to be necessary for establishing a new forest buffer, patch scarification or intermittent methods should be used with caution. In the case of sowing/planting adjacent to older stands, such as forest buffers, the competition for water and nutrients is great. Therefore, sowing/planting within 5-10 meters of the forest buffer is not appropriate, which also means that this area can be left without site preparation.

Pre-commercial thinning and thinning

Functional buffer zones can be created in the forest landscape both by enhancing the value of the forest buffer zone and values for the aquatic environment and taking measures that result in forest buffers that are resistant to wind felling during future regeneration felling. Hence, some measures are proposed mainly related to pre-commercial thinning and thinning.

Strategic objective for pre-commercial thinning

- A forest buffer considered to be functional is not pre-commercially thinned. The zone thereby constitutes a self-defined boundary for future operations.

Examples of measures to increase forest buffer functionality at precommercial thinning

If the entire site was harvested during the previous logging and the current stand is now of the same age throughout, for example conifers planted all the way to the water line, there are several possible alternatives. Local site conditions and experience should guide action. It is important to deliver the functionalities that are possible at each site.

- The zone adjacent to water is not pre-commercially thinned and is left to develop freely. One way to delineate this zone is to follow the natural variation in ground conditions, using discharge areas and nearby zones rich in broadleaves as the edge. Over time, self-thinning will create gaps and contribute deadwood and new seedlings can regenerate in the gaps. The forest within this zone will become multi-layered and have an uneven age structure, and it will develop characteristics that are positive for the aquatic environment.
- In riparian zones with both conifers and broadleaves, one option is to remove a large proportion of the conifers and let the young broadleaved trees develop. This will create a forest buffer dominated by broadleaves but also including some conifers.
- Another option for riparian zones with both conifers and broadleaves is to thoroughly pre-commercially thin selected areas within the zone all the way to the shoreline. The development of single trees will then be promoted, possibly increasing diameter growth significantly. These trees will provide variation in tree size and provide important deadwood in the longer term.
- Within riparian zones completely dominated by conifers, gaps can be created and areas around single trees cleared of vegetation to achieve variation in age, tree dimensions and crown layering with time.

Strategic objectives for thinning

- A forest buffer perceived to be functional is not thinned.
- No thinning in discharge areas bordering surface water.
- Care-demanding biotopes bordering surface waters are left unmanaged, or management to promote biological values is carried out.
- The forest buffer is not cleaned.
- No rutting in or close to watercourses and lakes.
- This means that forestry machinery is not driven within about 10 meters of surface waters.
- No soil disturbance that increases export of suspended solids to lakes and watercourses is caused by moving forestry machinery.
- No soil damage caused by forestry transportation in discharge areas.

If the forest buffer is single-layered and uniform and broadleaves have been removed repeatedly, measures can be taken during thinning to create a more diverse and functional buffer for aquatic life. For instance, gaps can be created along limited stretches of the watercourse or the forest adjacent to water can be intensively thinned. This measure may also increase the future stability of the zone and increase the possibility of leaving a forest buffer more resistant to wind felling after regeneration felling. Always try to prevent soil damage! Local experience for example regarding the possibilities for increasing broadleaves must be considered at planning.

Examples of measures to increase forest buffer functionality at thinning

- When the forest buffer zone consists of single-layered, uniform Norway spruce forest down to the water line:

  Intensive thinning is carried out in the zone adjacent to water. The aim is to create a multilayered and more diverse forest buffer, which will be resistant to wind felling after regeneration felling.
- Where more broadleaved trees are desirable:
  First, determine the possibilities for increasing the proportion of broadleaved trees. Are broadleaved trees already present? Is the soil-moisture class moist or mesic? However, experience indicates that the conditions are usually better for wet / moist soil than on mesic soil, i.e. without site preparation (but there has been no general study of this). For example, if the conditions are good, gaps can be created at thinning (group selection cutting) or most of the conifers can be harvested while all broadleaves within about 10-15 m of the surface water are left unharvested, creating a corridor with broadleaved trees along the water.
- In single-layered stands lacking older trees, the supply of deadwood to water can be accelerated by actively felling trees into the water at thinning

Strategic objective for temporary streams

- The strategic objectives for permanent watercourses regarding regeneration felling, regeneration, pre-commercial thinning and thinning can also be applied to temporary streams.

Many small streams only transport water during snow melt and early summer, and during periods with high rainfall. During the remaining part of the year, the stream channel may be dry except in groundwater discharge areas and areas with small pools of water. The aquatic life in these streams is not the same as in permanent watercourses, but species in this system can survive drier periods by moving to groundwater discharge areas and deeper pools of water. Ensuring that there is shade around this type of area is particularly important.

Appendix 4 – Species description for riparian forests in Lithuania and Poland

Lithuania

Based on the topography along the rivers with a catchment area greater than 1000 km², natural riparian forests are divided into three classes (Karazija & Vaičiūnas, 2000): (1) floodplain riparian forests; (2) riparian forests on slopes; and (3) riparian forests on terraces above floodplains.

1) Floodplain riparian forests

On floodplains, shrublands (forest type – *Fluviale-urtico-salicetum*) of various *Salix species* (*S. viminalis, S. amygdalina, S. purpurea, S. pentadra, S. caprea, S. cinerea, S. aurita*) grow immediately beside the watercourse (permanently flooded in spring). The lowest areas of the floodplain host productive stands of *Alnus glutinosa (Fluviale-urticosa)* mixed with *Alnus incana*, *Salix alba* and *S. fragilis* (to a lesser extent with *Tilia cordata, Acer platanoides* and *Picea abies*). At the periphery of the floodplains, which are seldom paludified, productive mixed broadleaved stands (*Fliuviale-aegopodiosa*) of *Quercus robur, Ulmaceae* and *A. incana* mixed with *A. platanoides, Populus tremula, T. cordata, S. fragilis* and *A. glutinosa* can be found.

2) Riparian forests on slopes

On slopes adjacent to rivers, productive very mixed broadleaved forest stands occur (*Hepatico-oxalidosa-collina*) mainly of *Q. robur, P. abies, Carpinus betulus* and *P. tremula*, stands of *A. incana* or *Q. robur* (*Aegopodiosa collina*) mixed with *A. platanoides, Ulmaceae, T. cordata, P. tremula, P. abies, Betula pendula, C. betulus* and non-dense Scots pine stands (*Oxalidosa collina*) mixed with *P. abies, Q. robur, B. pendula* etc.

3) Riparian forests on terraces above floodplains

Quite productive complex/composite forest stands (*Fliuviale-oxalidosa*) of Scots pine-Norway spruce mixed with *Q. robur* and *B. pendula* and, to a lesser extent, even-aged *Pinus sylvestris* (mixed with *P. abies*) and *Q. robur* stands grow on the terraces above the floodplains.

Poland

Typical plant communities associated with riparian forests can be divided into two groups: alder, ash and elm forests and willow and poplar forests. In the alder swamp forests, the dominant species are black alder and ash, and these are mixed with (depending on the region) birches (*Betula pubescens* and *B. pendula*), spruce and elms (*Ulmus glabra* and *U. laevis*). In the riparian forests (floodplain forests), the main species are ash, common oak (*Q. robur*) and black alder, and these are mixed with elms, maple, lime and hornbeam. In the areas bordering watercourses, poplars and willows form an admixture.

On gley soils with ongoing paludification, ash and hornbeam should be introduced in smaller quantities and only in higher positions. Along small streams, the dominant species are ash, black alder, common oak and elms. The proportion of alder and common oak depends on the soil wetness. The proportion of ash depends on the health of the local population due to ash dieback.

The mountain areas represent special conditions in Poland. Here, the areas along water-courses (at a distance of 5 to 20 m from their stream banks) are particularly valuable due to higher soil wetness and they are suitable for spruce, beech and sycamore near springs and stream valleys in the upper forest zone. In the lower zones species variety is greater (mountain ash, common birch, mountain elm, bird cherry and gray alder, small-leaved linden and Norway maple) (Małek *et al.* 2014).