WAMBAF

Management of riparian forests for good water quality in the Baltic Sea Region countries – current knowledge, methods and areas for development

1. Introduction

This document was prepared by members of the project and some invited external experts. The project is running between 1.3.2016 - 28.2.2019 and is financed by the EU Baltic Sea Region Interreg program. It was initiated to find solutions for the detrimental effects of forestry activities on water quality.

This project places special emphasis on freshwater quality with respect to export of nutrient, suspended solids and mercury. WAMBAF focuses on three main factors that significantly impact water quality:

- riparian forests
- forest drainage
- beaver activity.

Here we summarize the findings of a review conducted in 2016 to evaluate

- the existing knowledge of how forest harvesting and riparian zone management affect the nutrient, suspended solids and mercury export
- the efficiency of forest buffer in maintaining runoff water quality
- the current tools and methods that are used to plan riparian zones
- the current legislation, certification standards and guidelines in various Baltic Sea Region (BSR) countries regarding riparian zones.

The research materials consists of literature surveys and information that was received from experts in Estonia, Finland, Latvia, Lithuania, Poland and Sweden.

In this document, the term *water body* refers to the following pools of water

- lakes, ponds and watercourses
- rivers
- streams
- brooks.

2. Definition of key terms

Riparian zone is defined as an area adjacent to a water body, including the bank of the water body, which has an impact on the ecology, hydrology or chemistry of the water body. The size of the riparian zone varies along a water body as well as between water bodies.

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

A forest buffer is a strip of forest left for protection adjacent to a water body (Fig. 1).

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

The term forest harvesting includes final cutting, clear cutting and seed tree cutting procedures. Forest thinning means a reduction in stem density.

Soil preparation refers to the mechanical preparation of soil after forest harvesting through mounding, harrowing or other methods.

3. Riparian forests in the Baltic Sea Region countries

Sweden and Finland have the largest forest and harvesting areas, as well as the longest length of rivers, streams and lake shorelines among the BSR countries.

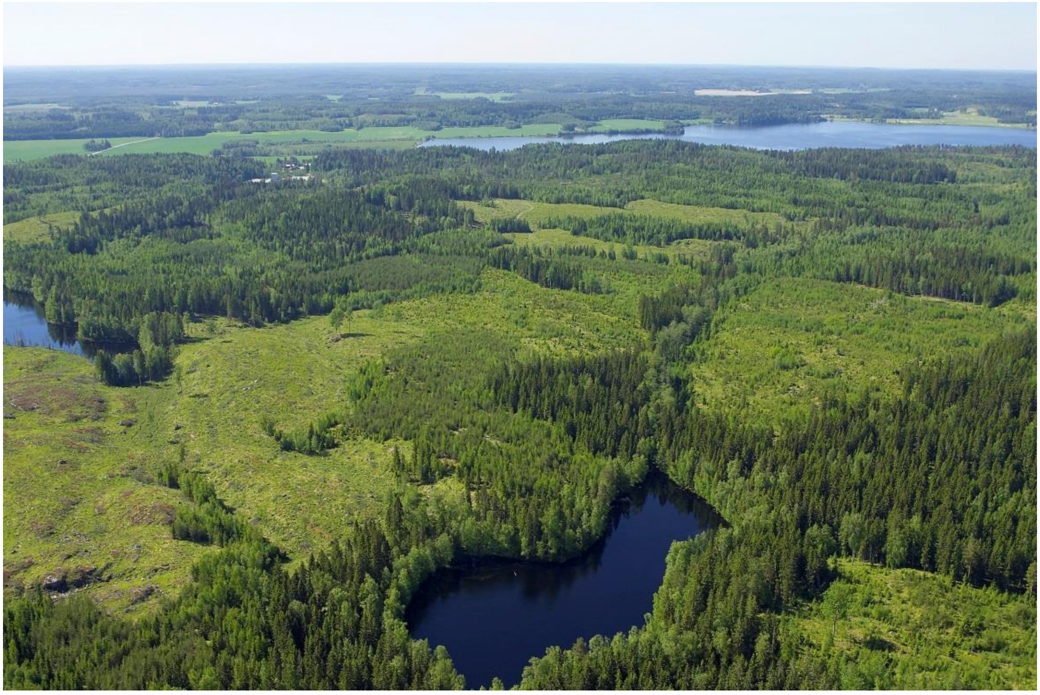

Figure 1. Riparian forests and forest buffers in a Finnish landscape. Photo: Luke/Erkki Oksanen

Table 1. The total area of forest land, annual harvesting (reforestation) area, number of lakes >1 ha, total river and stream length, and mean stream length per hectare of forest land in the Baltic Sea countries.

Country	Forest area, Mha[a] (% of land area)	Harvesting area in 2010, ha[a]	No. of lakes > 1 ha	Total river and stream length on forest land, km	Mean stream length per ha of forest land, m ha^{-1}
Estonia	2.23 (53)	23 800	2 804[b]	8 489[c]	3.8
Finland	22.2 (73)	140 000	56 000[b]	53 510[d]	2.4
Latvia	3.36 (54)	35 500	2 256[b]	16 875[e]	5.0
Lithuania	2.18 (35)	15 800	2 377[f]	12 678[g]	5.8
Poland	9.44 (31)	48 400	7 081[h]	n.a.	n.a.
Sweden	28.1 (68)	172 400	95 700[b]	313 453[d]	11
In total	67.51	435 900	166 218	>405 005	

[a] the FAO´s Global Forest Resource Assessment 2015; http://www.fao.org/forest-resources-assessment/current-assessment/en/.
[b] Ring et al. 2016 (submitted manuscript)
[c] Source: Estonian Environmental Agency (KAUR), answer to a special enquiry on 16 Oct., 2014
[d] Gundersen et al. 2010
[e] Estimation from topographical maps
[f] Jablonskis and Jurgelenaite 2007
[g] Taminskas et al. 2011
[h] Choiński 2006
n.a.=not available

There are 68 Mha of forest areas in the BSR countries, of which 0.65 percent is harvested annually (Table 1).

It has been estimated that a 10 meter wide forest buffer along all shores would cover 2.5 percent and 1.1 percent of the forest land area in these two countries, respectively (Gundersen *et al.* 2010). Riparian forests influence the ecology of water bodies by providing litter and coarse woody debris to the aquatic ecosystem, regulating insolation and affecting the physical environment through, for example, bank stability and water flow (Fig. 2). Riparian zones, partly as a result of special microclimates and hydrochemistry, may include key habitats for various species.

Forest buffers adjacent to harvested areas are able to reduce the influx of suspended solids and dissolved nutrients into water bodies, and help to maintain biodiversity and scenery after forestry operations (Fig. 3).

In many BSR countries, forest buffers are also used to reduce the nutrient and sediment loads from agricultural fields and areas subject to forest drainage. As riparian forests cover quite a large area in BSR countries, knowledge about their management is important to ensuring a certain level of water quality.

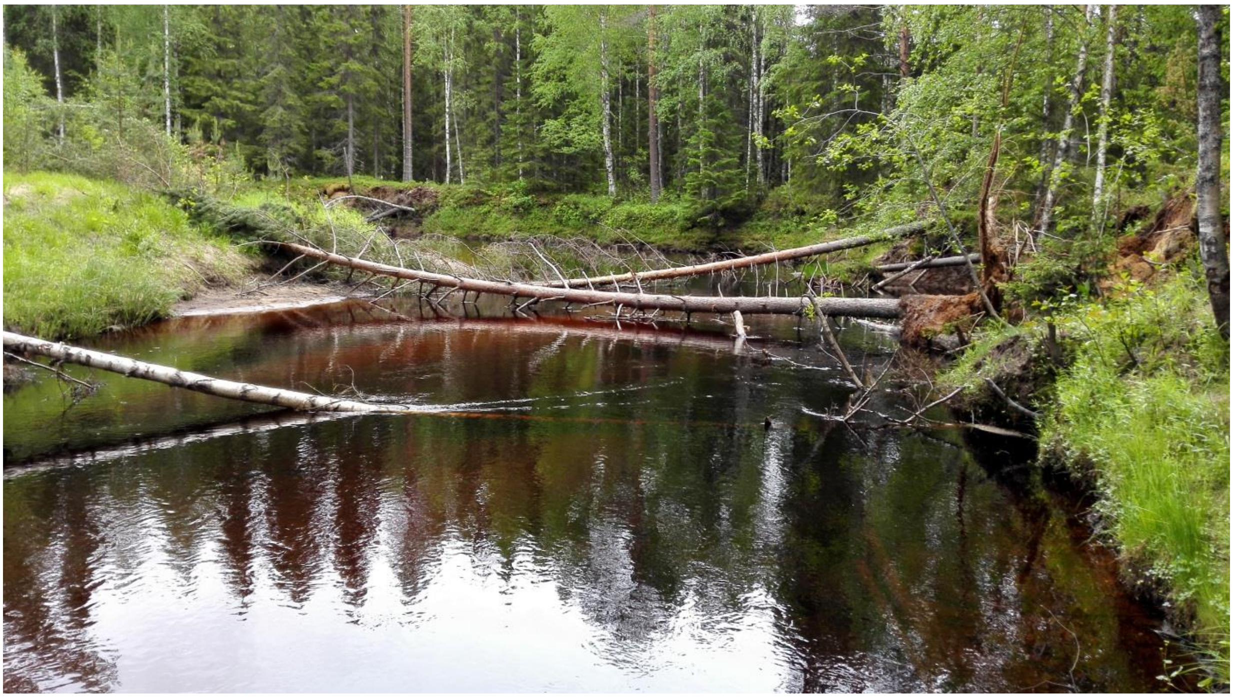

Figure 2. Coarse woody debris in a Finnish stream. Photo by Sirpa Piirainen

4. Management of riparian forests for good water quality following harvesting operations

Forest harvesting can increase the export of nutrients, suspended solids and metals such as mercury, which may end up in water bodies. Nitrogen and phosphorus leaching increases the eutrophication in water bodies, while the transport of suspended solids changes water colour and how far solar radiation can penetrate. The sedimentation of solids negatively impacts aquatic habitats and organisms. An increase in mercury levels can lead to bioaccumulation in food webs, which may then cause neurotoxic effects in wild animals and humans.

Since 1983, a total of 23 studies have been carried out in the BSR countries to study how riparian forest management affects the element loads in water bodies that result from different forestry

operations such as harvesting, soil preparation and thinning. An additional two studies focused on the capacity of forest buffers to retain added nitrogen and phosphorus.
Of these 25 studies, eight were performed in Finland, eight in Sweden and one in Poland. All 17 of these studies were published in English. Another eight studies (three from Finland, one from Latvia, two from Lithuania and two from Poland) were available in national languages.

The studies included a total of 39 catchments and 29 study plots. The impact of a forest buffer on the amounts of nutrients, suspended solids and mercury entering water bodies after forest harvesting was assessed in 15 studies, and eight of these also included the forestry operation of soil preparation. However, only three studies compared the effects of forest harvesting with and without a forest buffer to element loads. In addition, one study used two streams to investigate whether thinning operations and different tree species in forest buffers impact water quality. In Poland the studies investigated the effects of reforestation after forest dieback.

The sites were monitored before treatment in 17 of the studies, and in 13 of these studies the pre-treatment monitoring period continued for more than one year. In 16 studies, the post-treatment monitoring continued for more than three years.

The most frequently monitored parameters were nitrate (17 studies), ammonium (16 studies), phosphate (13 studies), total nitrogen (12 studies), total phosphorus (11 studies), potassium (8 studies), magnesium and total organic carbon (both in 7 studies). Suspended solids were monitored in 7 studies. Methyl mercury was only studied in two studies, and both of these were performed at one site in Sweden (Sørensen *et al.* 2009, Eklöf *et al*. 2014).

Table 2. Estimates of background nitrogen, phosphorus and suspended solid loads from forest areas and the excess loads from forest harvesting based on data from Finland and Sweden. Loads are presented in kg ha^{-1} over a 10-year period. The impacts from harvesting usually last approximately 10 years (Finér *et al*. 2010, Launiainen *et al*. 2014).

	Total nitrogen	**Total phosphorus**	**Suspended solids**
Harvesting, peatland	26[a]	0.64[a]	n.m.
Harvesting, mineral soil sites	3.4[b]	0.32[b]	16[c]
Background load	13[d]	0.5[d]	51[d]

[a]number of catchments=13 (Lundin 1999, Nieminen 2004), no buffers left
[b]number of catchments=8 (Haapanen *et al*. 2006, Löfgren *et al*. 2009, Mattsson *et al*. 2006a, Mattsson *et al*. 2006b, Palviainen *et al*. 2014), forest buffers left
[c]number of catchments= 7 (Ahtiainen and Huttunen 1999, Löfgren *et al.* 2009, Palviainen *et al*. 2014), forest buffers left
[d]number of catchments=42 (Kortelainen *et al*. 2006, Mattsson *et al*. 2003)
n.m. =not measured

According to studies in Finland and Sweden, harvesting increases the loads of nitrogen, phosphorus and suspended solids that enter water bodies (Table 2). The loads from peatland-dominated catchments are higher than those from catchments dominated by mineral soils. This load increase is highest during the first years and usually decreases to levels that are close to the initial conditions approximately 10 years after harvesting.

Three of the studies, estimated the efficiency of forest buffers to retain nitrogen inflows, and two studies assessed how forest buffers impact the levels of phosphorus and suspended solids that enter water bodies after harvesting at mineral soil sites (Ahtiainen and Huttunen 1999, Jacks and Norrström 2004, Löfgren *et al*. 2009). The width of the studied buffers varied from five to 30 meters, the soil type varied from mineral soil sites to peatlands, and the study durations ranged from two to three years. The efficiency of forest buffers to retain nitrogen varied from 15 to 73 percent of the inflow, whereas forest buffers retained phosphorus and suspended solids at a rate of 0 percent in one study and 96 percent and 43 percent, respectively, in another.

The efficiency depended on the amount of water discharge and water pathways (surface and preferential flow) in the buffer. One other study estimated that nitrate can be leached in to deep groundwater already in the cut area and therefore cannot be retained by microbial and vegetation ecosystem in the buffer zone (Kokkonen *et al.* 2006). There is also evidence that the formation of preferential flow paths over a buffer area decreases the retention of elements (Väänänen 2008).

In another study, the elevated groundwater level and increase in anoxia in a peatland-dominated buffer area increased the leaching of phosphorus (Sallantaus *et al*. 1998).

Furthermore, according to research by Högbom *et al.* (2002) at two streams, thinning and the tree species composition of the forest buffer had no clear effects on water quality during the first year after thinning. Moreover, measurements from a site in Sweden showed that the studied forest buffer had no impact on the leaching of mercury (Sørensen *et al.* 2009).

Needs for further research and development

There is a limited amount of scientific knowledge regarding the efficiency at which riparian zones and forest buffers retain element loads among the BSR countries, and part of this knowledge is only available in national languages. The publications that are written in English are mainly from Finland and Sweden and may thus not be fully applicable to the other countries due to the differences in, for example, climate, tree species and soil types.

The experiments were carried out only on mineral soil sites and there is a need for studies that focus on the riparian zones and forest buffers next to peatland harvesting areas. Furthermore, the published research includes short study durations. There is often no calibration period, and the post-treatment period covers between 3-5 years, which is too short to accurately estimate the duration of the excess leaching of elements associated with forestry activities.

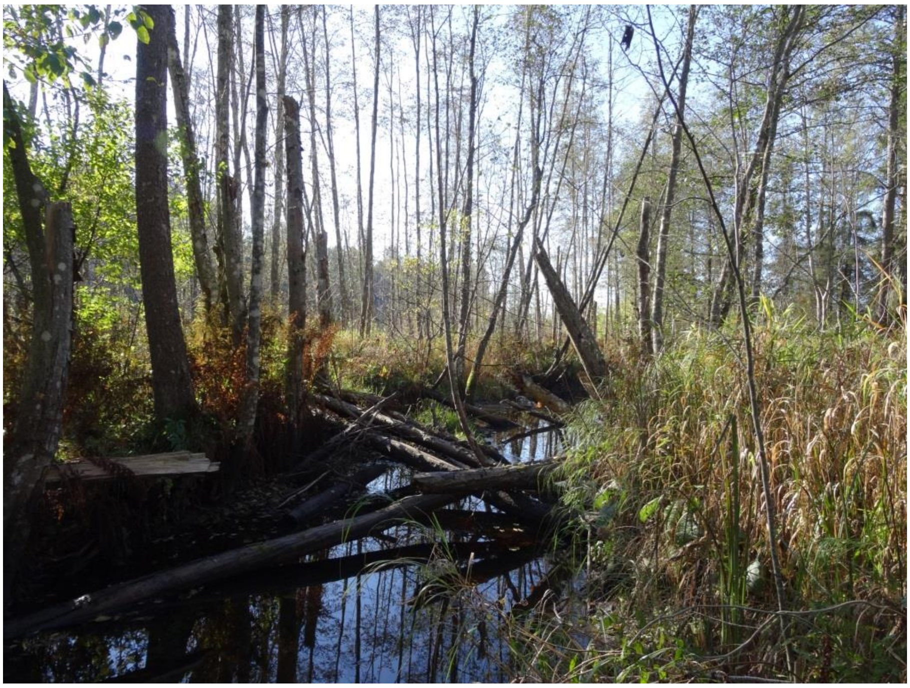

Figure 3. An unmanaged, 10 m wide forest buffer in Latvia. Photo by Zane Libiete.

Most research has investigated nitrogen and phosphorus levels, but more studies that assess the leaching and retention of suspended solids, carbon, cations, heavy metals including mercury following forestry activities are needed. The connection between forestry activities and the levels of toxic substances in biota should also be further researched.

Furthermore, there is relatively little knowledge about the effects of forest buffer soil type and tree species composition on hydrology and water chemistry. Such knowledge could improve the management of riparian forests, and thereby, the ecological status of water bodies. Another area that requires further investigation is whether the management regime of forest buffer (i.e. thinning or selective cutting) influences the retention capacity of it, or its impact on the aquatic ecosystem.

In addition, there is not enough knowledge about how the flooding of riparian zones, e.g. by beaver dams, influences the retention or leaching of elements. In comparison to the harvested area, it has been shown that a riparian forest or buffer zone will be able to retain more nitrogen, phosphorus and suspended solids (Palviainen *et al.* 2014).

However, maximizing water protection by increasing the width of forested buffers will substantially decrease the area that can be used for forest production in countries that are characterized by long shore lengths. Thus, finding a balance between water protection and forestry is one of the key issues that should be solved. Future research should also explore how other ecosystem services can be integrated into riparian zone management (Fig. 4).

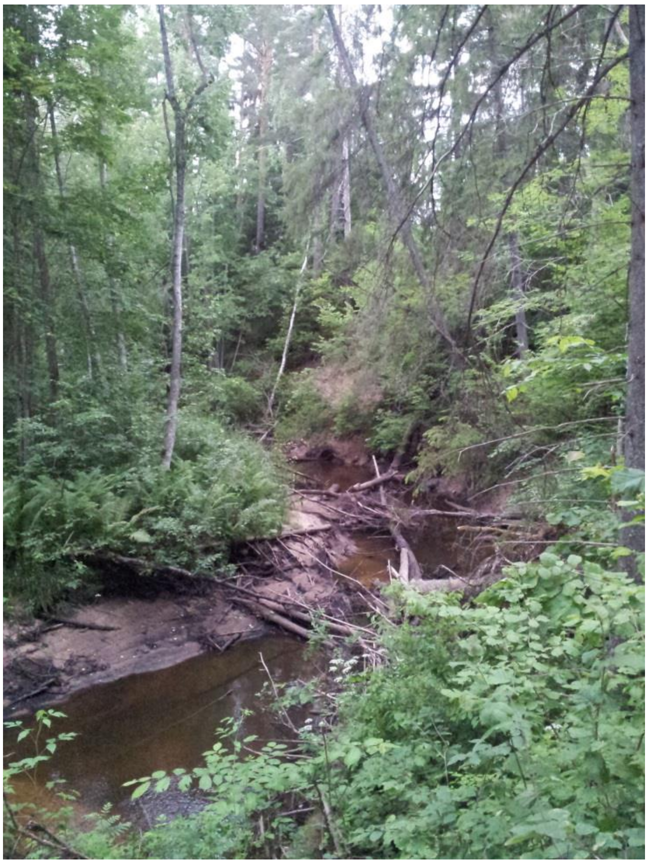

Figure 4. A riparian forest in Latvia. Photo by Juris Zarins.

5. Planning and demonstration of riparian forest management for good water quality

In Finland, five riparian zone planning tools, including maps, are available. Four tools, including maps, were identified in Sweden and two riparian zone planning tools are available in Latvia. Airborne laser scanned data and high-resolution digital terrain models have been used to create surface water pathway maps for the whole of Finland (http://www.metsakeskus.fi/vesiensuojelukartat) and soil wetness maps for the whole of Sweden (http://www.skogsstyrelsen.se/Aga-och- bruka/Skogsbruk/Karttjanster/ Laserskanning/). These maps are currently being further developed to enhance the planning tools even more. The maps are freely available in both countries in national languages, but in Finland their use requires GIS software and they are commonly used as planning tools by companies and forest owners with large holdings. In Finland, the maps were produced by the RLGis hydrological software tool. The software has been published in English and it is commercially available and can also be used to create maps for other countries (www.eia.fi).

The FEMMA model, which was developed for scientific purposes in Finland, can be used to simulate how efficiently forest buffers with varying sizes and/or management approaches reduce nutrient leaching to water bodies (Laurén *et al*. 2007).

The freely available KUHA-tool (http://www.ymparisto.fi/fi-FI/TASOhanke/Julkaisut) is used in Finland to calculate the annual excess loads caused by different forestry operations, and its results are used in planning forest buffers. The excess load values included in the KUHA-tool are only applicable in Finland.

In Sweden, a stream scale decision-support tool Blue Targeting/NPK+ has been developed (http://www.wwf.se/vart-arbete/vatmarkersotvatten/ 1129173-levande-skogsvatten). It is used to assess the biodiversity values of streams and their sensitivity to changes. In the future, it will be developed for other types of water bodies that have different characteristics than the Swedish ones. The Swedish forestry planning tool, Heureka Forestry Decision Support System, covers the entire decision support process, from data inventory to tools that use multi-criteria decision making techniques to select the optimal plan alternative (http://heurekaslu.org/wiki/Heureka_Wiki).

In Latvia, the Gauja/Koiva river basin (of which 9 percent is situated in Estonia) management planning tool is used to evaluate the loading effects of forest harvesting on water bodies.

Demonstrations, whether they are in a field or virtual environment, are an effective way to learn about forest management planning and understand how forest management affects water quality. Permanent demonstration areas have been established only in Sweden and Latvia. The sites in Sweden and the site in Latvia demonstrate how forest buffers affect water quality following final cutting at an adjacent regeneration area. In addition, the Swedish sites demonstrate different management options for riparian forests. Only temporary demonstration areas are used in the other BSR countries.

Needs for development of tools and establishment of demonstration sites

The availability of laser scanned data and digital terrain models are essential for the improvement of digital maps and planning tools and for their implementation in all BSR countries. Laser scanned data for all BSR countries are currently unavailable. Besides maps explanatory manuals are also needed. The available maps and tools have been mainly developed for national purposes in national languages. Therefore, translations are necessary if they are to be utilized in other BSR countries.

Figure 5. A riparian forest in Poland. Photo by Wojciech Gil.

The tools also include country-specific features, for instance, excess load values, and these should be updated with relevant data from each country so that the tools have better applicability. The implementation of the best available planning tools such as maps, Blue Targeting/NPK+ is vital for the development of water protection plans among the BSR countries. Lestander et al. (2015) have shown that these planning tools underlie progress in water protection. It is also important that tools serving different purposes are available, for example, modelling tools for research and simpler tools, maps and calculators for practice.

As yet, the sensitivity of a water body to forestry operation impacts can only be assessed in one planning tool, the Blue Targeting/NKP+ for riparian forest management. On the other hand, the calculation of loads is included only in the FEMMA and KUHA tools. It is also important to note that none of the planning tools include the loads that arise from other land uses. The apportionment of catchment scale and element load source could improve the planning of water protection measures.

In Finland, only large forest owners use catchment scale planning tools, and these tools need further development to be readily available to other users. In addition, planning is limited by restricted knowledge of how efficient different types of riparian zones are at retaining elements. Other functions of riparian zones, such as the protection of terrestrial species and habitats as well as from a landscape perspective, should be integrated into existing planning tools, which should also consider the cost efficiency perspective.

Forest and environment managers need to be trained in how to use the best available management practices and planning tools. Furthermore, the BSR countries should consider establishing new demonstration areas that will concretely present various riparian forest management approaches and can be used to monitor how efficiently riparian zones retain elements and maintain aquatic habitats.

6. Riparian forest management in legislation and certification systems

Legislation

Most of the BSR countries are members of the European Union and have implemented the *EU Water Framework Directive* (WFD, 2000/60/EC) and its daughter directives in their national legislation. The main objectives of the WFD are that all waters within the EU will reach a good ecological status and that quality standards will be set for hazardous substances in water. The management of riparian zones is not specified in the WFD.

The purpose of the national Acts is to protect water quality as well as aquatic and riparian zone habitats. Many of the BSR countries restrict, or even forbid, forestry activities in riparian zones. The regulated widths demands differ between countries.

In the national legislation of Estonia, the widths of riparian zones are fixed and the restricted operations are listed in the Nature Conservation (1.7.2015) and Water Acts (18.1.2016). The regulations depend on catchment area and the type of water body affected. In Finland, riparian zones are not specified in national Acts and only the riparian zones that include terrestrial key habitats are protected by the Forest Act (1093/1996).

In Latvia, protection zones are specified in the Protection Zone Act (Aizsargjoslu likums 5.2.1997), while in Lithuania, protection zones are specified in the Act of Protected area (No. I-301, 1993), the Order of Ministry of Environment (No. 540, 2001) and the Resolutions of Government (No. 343, 1992 and No. 1171, 2001). In both countries, the required width depends on the length of the stream or river.

In Poland, riparian forests are included in the Act of Forests (28.9.1991), which specifies the protective functions of forests, but no exact widths are defined (Fig. 5). In Sweden, protection zones are included in the Forestry Act (1979/429) and the Environmental Code (Miljöbalken 1998/808). Fixed widths are recommended for some operations (nitrogen fertilization and wood ash application), but in principle, the forest owners can decide on the width for most operations as long as the required protection is achieved.

Forest certification

Both the PEFC (Programme for the Endorsement of Forest Certification) and FSC (The Forest Stewardship Council) forest certification systems are used in the BSR countries (Table 3). Both systems are implemented according to the national standards developed by each country. Therefore, the contents of standards vary among countries.

Both certification systems require adherence to the applicable national laws. In general, when the regulations are included in the legal Acts they are not further elaborated upon in the certification standards and *vice versa.* Certain regulations or details can be included in the certification standards when they are not specified by a national Act.

In some countries, detailed regulations are included in the certification standards. Examples include the recommended number of trees that should be left uncut (PEFC in Finland), the width of the buffers for different operations or water body types (FSC in Finland), and operations prohibited in the riparian and buffer zone (both PEFC and FSC in Finland and Sweden). In Finland, the PEFC and FSC standards differ significantly, for example, they have different requirements for the width of forest buffers. Thus, in Finland, the minimum level of water protection depends on the forest owner's choice of certification system.

Table 3. The total area, as well as the proportion in relation to forest land, of FSC- and PEFC-certified forest areas in the different BSR countries. Forests can be certified by both systems.

Country	FSC certified forest area Mha (% of forest land)[1]	PEFC certified forest area Mha (% of forest land)[2]
Estonia	1.26 (57%)	1.13 (51%)
Finland	1.31 (6%)	16.5 (74%)
Latvia	1.30 (39%)	1.68 (50%)
Lithuania	1.09 (50%)	0 (0%)
Poland	6.94 (74%)	7.28 (77%)
Sweden	12.3 (44%)	11.5 (41%)

[1] https://ic.fsc.org, data: November 2016
[2] http://www.pefc.org, data: September 2016

Guidelines

There are also voluntary guidelines for riparian forest management in Latvia, Finland and Sweden. In Finland, these guidelines include the same type of details as the PEFC and FSC standards but are less demanding than the FSC standards.

In Latvia and Sweden, the guidelines include instructions for how to manage riparian zones to increase their function in water protection and nature conservation. There is an obvious need for guidelines that will cover the management of riparian zones in terms of different water body and forest types. However, the development of such guidelines will require research that can fill the aforementioned gaps in knowledge.

7. More information

Web pages of the WAMBAF -project:
http://www.skogsstyrelsen.se/en/AUTHORITY/International-activities/WAMBAF/

https://www.interreg-baltic.eu/fileadmin/user_upload/about_programme/Cooperation_priorities/P2_Natural_resources/R011_Water_management_in_Baltic_forests.pdf

References

Ahtiainen M, Huttunen P (1999) Long-term effects of forestry managements on water quality and loading in brooks. Boreal Environmental Research 4:101-114

Choiński A. Katalog jezior polski. Wyd. Nauk. UAM (Wydawnictwo Naukowe Uniwersytetu im. Adama Mickiewicza) w Poznaniu – Adam Mickiewicz University Press; 2006:600

Eklöf K, Schelker J, Sorensen R, Meili M, Laudon H, von Brömssen C, Bishop K. (2014) Impact of forestry on total and methyl-mercury in surface waters: Distinguishing effects of logging and site preparation. Environmental Science and Technology 48(9):4690-4698.

Finér L, Mattsson T, Joensuu S, Koivusalo H, Laurén A, Makkonen T, Nieminen M, Tattari S, Ahti E, Kortelainen P, Koskiaho J, Leinonen A, Nevalainen R, Piirainen S, Saarelainen J, Sarkkola S, Vuollekoski M (2010) Metsäisten valuma-alueiden vesistökuormituksen laskenta. Suomen ympäristö 10:33

Gundersen P, Lauren A, Finer L, Ring E, Koivusalo H, Satersdal M, Weslien J, Sigurdsson BD, Högbom L, Laine J, Hansen K (2010) Environmental Services Provided from Riparian Forests in the Nordic Countries. Ambio 39:555-566

Haapanen M, Kenttämies K, Porvari P, Sallantaus T (2006) Kivennäismaan uudistushakkuun vaikutus kasvinravinteiden ja orgaanisen aineen huuhtoutumiseen; raportti Kurunssa ja Janakkalassa sijaitsevien tutkimusalueiden tuloksista. In: Kenttämies K, Mattsson T (eds) Metsätalouden vesistökuormitus. MESUVE-projektin loppuraportti., pp 43-62

Högbom L, Nordlund S, Lingdell P, Nohrsted H (2002) Effects of tree species in the riparian zone on brook-water quality. In: Björk L (ed) Sustainable forestry in temperate regions. Proceedings of the SUFOR international workshop April 7-9, 2002 in Lund, Sweden, Lund, KFS AB., pp 107-113

Jablonskis J, Jurgelenaite A (2007) Lietuvos ežerų statistika. Geografija 43:16-26

Jacks G, Norrström A (2004) Hydrochemistry and hydrology of forest riparian wetlands. Forest Ecology and Management 196:187-197

Kokkonen T, Koivusalo H, Laurén A, Penttinen S, Piirainen S, Starr M, Finér L (2006) Implications of processing spatial data from a forested catchment for a hillslope hydrological model. Ecological Modeling 199:393-408

Kortelainen P, Mattsson T, Finér L, Ahtiainen M, Saukkonen S, Sallantaus T (2006) Controls on the export of C, N, P and Fe from undisturbed boreal catchments, Finland. Aquatic Sciences 68:453-468

Launiainen S, sarkkola S, Laurén A, Puustinen M, Tattari S, Mattsson T, Piirainen S, Heinonen J, Alakukku L, Finér L (2014) KUSTAA -työkalu valuma-alueen vesistökuormituksen laskentaan. Suomen Ympäristökeskuksen raportteja 33:55

Laurén A, Koivusalo H, Ahtikoski A, Kokkonen T, Finér L (2007) Water protection and buffer zones: How much does it cost to reduce nitrogen load in a forest cutting? Scandinavian Journal of Forest Research 22:537-544

Löfgren S, Ring E, Claudia von Brömssen, Sørensen R, Högbom L (2009) Short-Term Effects of Clear-Cutting on the Water Chemistry of Two Boreal Streams in Northern Sweden: A Paired Catchment Study. Ambio 38:347-356

Lundin L (1999) Effects on hydrology and surface water chemistry of regeneration cuttings in peatland forests. International Peat Journal 9:118-126

Mattsson T, Ahtiainen M, Kenttämies K, Haapanen M (2006a) Avohakkuun ja ojituksen pitkäaikaisvaikutukset valuma-alueen ravinne- ja kiintoainehuuhtoumiin. In: Kenttämies K, Mattsson T (eds) Metsätalouden vesistökuormitus, MESUVE-projektin loppuraportti, pp 73-81

Mattsson T, Finér L, Kortelainen P, Sallantaus T (2003) Brook water quality and background leaching from unmanaged forested catchments in Finland. Water, Air and Soil Pollution 147:275-297

Mattsson T, Finér L, Kenttämies K, Ahtiainen M, Haapanen M, Lepistö A (2006b) Avohakkuun vaikutus fosforin, typen ja kiintoaineen huuhtoutumiin; raportti VALU-tutkimushankkeen ja Siuntion Rudbäckin alueiden tutkimuksista. Suomen ympäristö 816:63-70

Nieminen M (2004) Exports of dissolved organic carbon, nitrogen and phosphorus following clear-cutting of three Norway spruce forests growing on drained peatlands in southern Finland. Silva Fennica 38:123-132

Palviainen M, Finér L, Laurén A, Launiainen S, Piirainen S, Mattsson T, Starr M (2014) Nitrogen, phosphorus, carbon, and suspended Solids loads from forest clear-cutting and site preparation: Long-term paired catchment studies from Eastern Finland. Ambio 43:218-233

Sallantaus T, Vasander H, Laine J (1998) Prevention of detrimental impacts of forestry operations on water bodies using buffer zones created from drained peatlands. Suo 49:125-133

Sørensen R, Meili M, Lambertsson L, von Brömssen C, Bishop K (2009) The effects of forest harvest operations on mercury and methylmercury in two boreal streams: relatively small changes in the first two years prior to site preparation. Ambio 38:364-372

Taminskas J, Pileckas M, Simanauskiene R, Linkevičienė R (2011) Lithuanian wetlands: classification and distribution. Baltica 24:151-162

Väänänen, R. (2008) Phosphorus retention in forest soils and the functioning of buffer zones used in forestry. Dissertationes Forestales 60, Helsinki, 42 p.

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Piirainen, S.[1], Finér, L.[1], Andersson, E.[2], Belova, O.[3], Čiuldiené, D.[3], Futter, M.[4], Gil, W.[5], Glazko, Z.[6], Hiltunen, T.[7], Högbom, L.[8], Janek, M.[5], Joensuu, S.[9], Jägrud, L.[10], Libiete, Z.[11], Lode, E.[12], Löfgren, S.[4], Pierzgalski, E.[5], Ring, E.[8], Zarins, J.[11] and Thorell, D.[13]

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