REPORT

Mapping policies for surface water protection zones on forest land in the Nordic–Baltic region: Large differences in prescriptiveness and zone width

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Abstract The forest landscape across the Nordic and Baltic regions hosts numerous lakes and watercourses, which must be included in forest management. In this study, national policy designs regarding protection zones for surface waters on forest land were reviewed and compared for the Nordic countries, Estonia and Latvia. The focus was how each country regulates protection zones, whether they are voluntary or mandatory, and the rationale behind adopting a low or high degree of prescriptiveness. Iceland and Denmark had a low degree of policy prescriptiveness, whereas Norway, Estonia and Latvia had a high degree of prescriptiveness. Sweden and Finland relied to a large extent on voluntary commitments. The prescribed zone widths within the region ranged from 1 m to 5 km. The results indicated that land-use distribution, forest ownership structure and historical and political legacies have influenced the varying degrees of prescriptiveness in the region.

Keywords Buffer · Certification · Forestry · Guidelines · Legislation · Riparian

INTRODUCTION

The forest landscape in the Nordic and Baltic countries hosts numerous lakes, rivers, streams and reservoirs, hereafter referred to as surface waters. The riparian forests along these water bodies play an important role for the aquatic ecosystems, for instance, by regulating water temperature, quality and flow rate, providing litter, coarse woody debris and shade, reducing sediment inputs and stabilising the streambanks (Kuglerová et al. 2014). To ensure adequate water protection, forestry operations near surface waters need to be conducted with extra care. In

order to maintain the ecological functions of the riparian forest after harvesting, it is common forestry practice to leave strips of forest along surface waters at harvesting (inter alia Richardson et al. 2012). Furthermore, surface waters need to be protected from excessive inputs of nutrients, pollutants and sediments caused by forest management (Kreutzweiser et al. 2008; Eklöf et al. 2016). Site preparation, drainage, stump harvesting and off-road transportation may increase erosion and sediments inputs to surface waters, while harvest, drainage and fertilisation generally elevate the nutrient leaching rates (inter alia Ahtiainen and Huttunen 1999; Kreutzweiser et al. 2009; Nieminen et al. 2010; Lundin and Nilsson 2014). However, these environmental impacts may vary depending on, for example, site characteristics, such as soil type and topography, and on-site performance. By restricting or prohibiting forestry operations near surface waters, negative impacts can be avoided or limited. In the remainder of this paper, any areas, zones or strips near surface waters subjected to any kind of management limitations are referred to as protection zones (PZs).

To establish effective PZs on forest land requires knowledge on how to design these zones to achieve desired goals. Site characteristics such as topography, forest and surface water characteristics, soil type and groundwater pathways must be considered (Hoover et al. 2011; Kuglerová et al. 2014). The width of PZs is important to their ability to provide various functions (inter alia Mayer et al. 2007; Sweeney and Newbold 2014; Bilby and Heffner 2016). From a governance perspective, there are several ways to achieve implementation, from voluntary commitments such as forest certification schemes to mandatory law enforcement. Since the 1990s, private, market-based regulatory initiatives, for instance forest certification, have emerged as a response to the loss or degradation of various

global resources (McDermott et al. 2009; Johansson 2013). Such voluntary regulations aim to set higher international bars for environmental consideration measures than traditional governmental or international policies. Yet, the overall pattern of the adoption of such complementary and voluntary instruments varies considerably among countries and sectors (Jordan et al. 2005). Hereafter, the entire range of voluntary or mandatory systems which in some way regulate forestry operations near surface waters within a country is referred to as the national policy design.

The aim of this study was to compare how the Nordic countries, Estonia and Latvia have designed PZs for surface waters on forest land, and how forestry is regulated within these zones. We analysed the national policy designs, whether voluntary or mandatory, if they had a high or low level of prescriptiveness, and discuss the influence of some factors (e.g. forest area and forest ownership structure) on the discovered differences in policy design (McDermott et al. 2009). Sweden, Finland and Latvia were included in the study of riparian buffer zone regulation by McDermott et al. (2009) but at a lower level of detail than presented here. Our study focused on the on-the-ground policy requirements and how these were specified in legal acts, ordinances and other regulatory texts, but also in guidelines and forest certification standards. Our analysis was based on the policy classification framework by Cashore (1997) and later adapted by McDermott et al. (2009) with the aim to ‘set the bar’ for on-the-ground environmental performance by comparing specific forestry practice requirements.

MATERIALS AND METHODS

The requirements for PZs for surface waters were reviewed for Norway, Sweden, Finland, Denmark, Iceland, Estonia and Latvia, including rules for zone width, forest management (including off-road transportation, ditching, fertilisation, selective felling, clearcutting and soil scarification) and economic compensation to forest owners for income lost due to such restrictions. The requirements for PZs related to the use of pesticides were not reviewed. Each topic was reviewed in national legislation, national forest certification standards issued by the Forest Stewardship Council (FSC), the national schemes endorsed by the Programme for the Endorsement of Forest Certification Schemes (PEFC) and selected published guidelines (Table 1). Both the FSC and PEFC certification standards stipulate that forest management must comply with applicable national legislation (PEFC 2010; FSC 2015). Although the countries selected represent a relatively narrow geographical region, they cover a wide range of forest areas, forest ownership structures, and socio-economic and

historic backgrounds (Table 2). The study was facilitated by the CAR-ES network of Nordic–Baltic scientists (<http://www.nordicforestresearch.org/sns-research/car/>), funded by the Nordic Forest Research Co-operation Committee under the auspices of the Nordic Council of Ministers (NCM). NCM aims at strengthening the Nordic and regional interests and values in a global world (NCM 2017), and comparative analysis of national policies may contribute to identifying such common interests and values. Scientists from this network provided the detailed knowledge on national conditions and the diverse language skills required for the study.

The information presented here is based on the policy designs that were valid on 1 April 2016. When citing text from the reviewed sources, the translations used were mainly unofficial versions by the authors, since official translations were rare. All of the countries included in this study, except Norway and Iceland, are members of the European Union (EU), and therefore EU legislation applies in large parts of the region. For this study, the EU Water Framework Directive (2000/60/EC) was of special interest. The EU member states incorporate the objectives of an EU directive into domestic legal systems (Borchardt 2010), which therefore will mirror EU legislation to some extent. However, each member state individually decides how to achieve the objectives.

Our analysis is based on the policy classification framework developed and applied to riparian zone management by McDermott et al. (2009) (Fig. 1). They created the framework to overcome major methodological difficulties of comparing complex forestry rules for on-the-ground management within a given jurisdiction to other cases worldwide. The national legislations in the Nordic and Baltic countries were classified with respect to their degree of ‘prescriptiveness’ defined as “the degree to which they prescribe the precise nature and extent of acceptable harvesting practices” (McDermott et al. 2009). However, forestry operations other than harvesting were also included in our study. The degree of prescriptiveness was assessed based on whether a policy was (1) voluntary or mandatory and (2) emphasised procedures or performance (referred to as “procedural” and “substantive”, respectively) (McDermott et al. 2009). Mandatory policies are often considered more prescriptive than voluntary ones. A procedural policy is a regulation, voluntary or mandatory, that does not specify the on-the-ground management in detail, but requires, for instance, that surface water protection must be addressed in forest management plans. Thus, a procedural policy leaves room for individual interpretation and variation in management. On the other hand, a performance-based policy prescribes the precise on-the-ground management such as the width of PZs. As in the study by McDermott et al. (2009), a “mixed” policy

Table 1 Reviewed acts, forest certification standards and guidelines for the Nordic countries, Estonia and Latvia, valid on 1 April 2016

Country	Act, certification standard and guidelines	Date of legal force or approval of standard by the FSC Director General or PEFC Councils
Norway	Forest Act	27 May 2005
	Norsk PEFC Skogstandard, PEFC N 02	14 January 2016
Sweden	Forestry Act (according to the handbook “Skogsvårdslagstiftningen, Gällande regler 1 januari 2016” by the Swedish Forest Agency, compiling skogsvårdslagen 1979:429, skogsvårdsförordningen 1993:1096 and ordinances and guidelines by the Swedish Forest Agency (SKSFS 2011:7))	Regulations valid on 1 January 2016. Skogsvårdslagen is updated including SFS 2014:890, skogsvårdsförordningen including SFS 2014:1027 and ordinances and guidelines including SKSFS 2015:3.
	Swedish FSC Standard for Forest Certification (Svensk skogsbruksstandard enligt FSC med SLIMF-indikatorer, FSC-STD-SWE-02-02-2010 SW)	24 February and 5 May 2010
	Swedish PEFC Forest Standard (Svensk PEFC Skogsstandard, PEFC SWE 002:3)	2 November 2011
Finland	Forest Act (Metsälaki) 1093/1996, amendments up to 567/2014	1 January 2015
	Nature Conservation Act (Luonnonsuojelulaki) 1096/1996, amendments up to 1710/2015/2014	1 January 2015
	FSC Standard for Finland, FSC-STD-FIN-(Ver1-1)-2011	21 January 2011
	PEFC standards PEFC FI 1002:2014	27 October 2014
	Guidelines for the state-owned forests related to biodiversity and water (Metsähallituksen metsätalouden ympäristöopas)	16 August 2011 (Päivinen et al. 2011)
	Guidelines for sustainable forest management-Water protection and water (Hyvän metsänhoidon suositukset-Vesiensuojelu)	2012 (Joensuu et al. 2012)
Denmark	Watercourse Act, LBK no 1579	8 December 2015 ^{1,2}
	Environmental Goals Act, LBK no 1531	8 December 2015 ^{1,2}
	Nature Conservation Act, LBK no 1578	8 December 2015 ^{1,2}
	The Forest Act, LBK no 1577	8 December 2015 ²
	Standards for FSC Certification in Denmark (15th draft)	November 2004
	PEFC Denmark's Forest Management Standard, PEFC DK 001-3	Revised standard March 2012, with amendments October 2012 and November 2013
	Guidelines for zoning around water courses and lakes	Vejledning om bræmmer langs vandløb og søer, 2002. http://www.sns.dk/udgivelser/2002/87-7279-424-0/Braemmevejledninghel.pdf
	Nature management strategy. Strategy for management of the Nature Agency's protected nature areas (included in General guidelines for management of state forests)	Naturplejestrategi, 1999. Strategi for plejen af Skov- og Naturstyrelsens arealer med beskyttet natur. http://www.sns.dk/netpub/naturstr/indhold.htm
	Natural Forest Strategy (included in General guidelines for management of state forests)	Strategi for de danske naturskove og andre bevaringsværdige skovtyper. 1992 http://naturstyrelsen.dk/publikationer/2012/okt/naturskogsstrategien/
	General guidelines for management of state forests	Generelle retningslinier for drift af statsskovene, 2008 http://www2.skovognatur.dk/skov/netpub/strategioversigt/indhold.htm http://www.sns.dk/netpub/naturstr/indhold.htm
Iceland	The Water Act (Vatnalög) 15/1923	16 March 2012
	Lög um stjórn vatnamála 36/2011	15 April 2011
	Forest Act 3/1955	30 September 2011
	Guide to good afforestation practice (published by the Icelandic Forestry Association) (guidelines)	2009

Table 1 continued

Country	Act, certification standard and guidelines	Date of legal force or approval of standard by the FSC Director General or PEFC Councils
Estonia	Nature Conservation Act	1 July 2015
	Water Act (Veeseadus)	18 January 2016
	Forest Act	1 July 2015
	PEFC National Forest Management Standard for Estonia, Version 10.08.15	3 December 2015
	NEPCon Interim Standard for Assessing Forest Management in Estonia, FSC TM /ASI	19 December 2014
	NEPCon Interim Standard for Assessing Forest Management in Estonia (Below 100 ha). Applicable only for forest holdings less than 100 ha	19 December 2014
Latvia	Protection Zone Law	11 March 1997, latest relevant amendments 22 Dec. 2015
	Forest Act	17 March 2000
	Nature Protection Regulations in Forest Management	1 January 2013
	Regulations of Tree Felling in the Forest	1 January 2013
	NEPCon Interim Standard for Assessing Forest Management in Latvia	19 December 2014
	PEFC Forest Management Certification Standard for Latvia	28 April 2010

¹ The Act was revised in September 2016

² The Act was revised in January 2017

approach refers to policies that require a PZ but do not specify its size, for instance, if site preparation is prohibited adjacent to surface water but the width of the PZ is not specified. Since a large proportion of the forest area is certified in accordance with the FSC and PEFC schemes in the studied region, a classification of the national FSC and PEFC standards was made as well. This classification only included the procedural, substantive or mixed approaches, since it is voluntary to adopt a forest certification scheme. Finally, limits for width and management within PZs are presented for the countries studied. McDermott et al. (2009) also developed the following inductive hypotheses to explore the extent to which environmental science and socio-economic factors influence the degree of prescriptiveness: (1) “The greater the scientific consensus about the existence of an ecological problem, the more likely it is

that prescriptive/high threshold policies will be adopted”, (2) “The higher a country’s level of economic development, the higher the likelihood that prescriptive/high threshold policies will be developed”, (3) “Policies governing public lands are more likely to be prescriptive than those governing private land” and (4) “The higher the expectation that policies will be consistently enforced, the greater the pressure to limit environmental performance thresholds”. The socio-economic factors above appeared to strongly influence the policy variation observed in a comparison of forest practice requirements across 47 jurisdictions worldwide, whereas environmental science alone tended not to explain this variation (McDermott et al. 2009). Thus, factors such as economic development and land ownership need to be assessed. Although the present study did not set out to assess the influence of socio-economic factors per se, such factors were considered when discussing our findings.

Fig. 1 Direction of increasing policy prescriptiveness for five policy approaches as described by McDermott et al. (2009) Adapted from Cashore (1997) and McDermott et al. (2009)

RESULTS

The proportion of total land area that was forest varied considerably between the studied countries, from 0.5 to 73% (Table 2), giving an indication of the importance of forestry in each country. The proportion of publicly owned forest land ranged from 14 to 50% of the total forest area.

Table 2 Forest and water statistics for the Nordic countries, Estonia and Latvia, including the forest area certified in accordance with FSC or PEFC schemes, respectively. Note that one forest owner can be certified by both systems. The total stream lengths presented are not fully comparable between countries since “stream” was defined in different ways. The mean stream and ditch lengths per hectare forest land were calculated from the data in the table. nd = no data

	Norway	Sweden	Finland	Denmark	Iceland	Estonia	Latvia
Land area (Mha) ¹	30.4	41.0	30.4	4.24	10.0	4.24	6.22
Forest land area (Mha) ¹	12.1	28.1	22.2	0.612	0.049	2.23	3.36
Proportion of forest land of total land area (%) ¹	39.8	68.4	73.1	14.4	0.5	52.7	54.0
Public forest land (%) ²	14	27	30	25	18	47	50
Total no of lakes >1ha in the whole country	100 136	95 700	56 000	3280	8841	2804	2256
Total stream length on forest land (km)	nd	280 000	53 000	2600	1190	8489	16 875
Total ditch length on forest land (km)	8850 ⁶	610 000	1 300 000	nd ⁷	1039	97 169	43 000 ⁸
Mean stream length per ha forest land (m ha ⁻¹)	nd	10	2.4	4.2	24	3.8	5
Mean ditch length per ha forest land (m ha ⁻¹)	1 ⁶	22	59	nd ⁷	21	44	13
FSC-certified forest area (Mha) ³	0.42	12.2	1.23	0.21	0	1.26	1.70
Proportion of forest land area (%)	3	43	6	35	0	57	51
PEFC-certified forest area (Mha) ⁴	9.1	11.4	17.6	0.26	0	1.03	1.68
Proportion of forest land area (%)	75	40	79	42	0	46	50
Gross national income per capita 2015, according to the Atlas method (US dollars) ⁵	93 740	57 920	46 550	58 550	50 140	18 360	14 980
Data on surface waters obtained from	Inquiry to Norwegian Institute of Bioeconomy June 2016	Swedish Hydrological and Meteorological Institute, (http://www.smhi.se/), Statistics Sweden (http://www.scb.se/), and Esseen et al. (2004), assuming the stream and ditch lengths on forest land proportional to the proportion of forest land	Raatikainen and Kuusisto (1990), Gundersen et al. (2010)	Friberg (1998), Forest and Nature Agency (2010)	Alþingi (http://www.althingi.is/)	Tamre (2006), Inquiry to Estonian Environmental Agency (KAUR), 16 Oct 2014	Topographic data base for lakes and rivers (http://map.lgia.gov.lv/)

¹ FAO (2015)

² Proportion of forest land area that is public forest land (Swedish Forest Agency 2014)

³ Forest Stewardship Council (2016)

⁴ Programme for the Endorsement of Forest Certification Schemes (2015)

⁵ World Bank (2017)

⁶ Refers to ditches created in the period 1994–2014 (Answer by Norwegian Agricultural Agency to specific inquiry on 6 July 2015)

⁷ Nearly all Danish groundwater-influenced forests were ditched during the 1800s and 1900s, especially state forest and larger private estates (Friis-Møller et al. 2010). It has been estimated that 50–70% of the old forest regions on the eastern islands of Denmark are influenced by artificial drainage, locally up to 100%. However, the management paradigm is changing to re-establish natural water-level conditions, especially for state forests

⁸ Refers to public forest land only

A large variation in the number of lakes and the total lengths of streams and ditches between countries was indicated (Table 2). The topography ranged from steep mountains in Norway and Iceland to flat lowlands in Denmark, Estonia and Latvia. Over 40% of the forest land was certified in accordance with FSC or PEFC standards in all countries except Iceland. Legislation regarding PZs for surface waters existed in all countries (Tables 3, 4), although their focus on forest land or the potential impacts of forestry tended to vary.

Purposes for protection

Five distinct purposes for creating PZs for water on forest land could be discerned in the reviewed policy designs: (1) to sustain functions important for aquatic and terrestrial habitats after forest harvesting; (2) to avoid inputs of chemicals used by the forestry; (3) to avoid increased sediment inputs due to soil erosion caused by forestry operations; (4) to protect water quality in drinking water supply areas and (5) to protect coastal areas sensitive to erosion. Other purposes, related to non-forestry activities, were found as well, for instance construction activities near shores and banks. Although such activities may occur on forest land, they were not included in this study. Here, we focused on PZs aimed at achieving purposes 1–3. These PZs are hereafter referred to as PZ forest, PZ chemicals and PZ soil. PZ forest included zones where trees and/or shrubs are left unharvested in conjunction with harvesting operations. PZ chemicals included zones where addition of chemicals such as fertilisers and petrochemicals must be avoided, and PZ soil refers to zones where rutting, site preparation, stump harvesting and other activities, causing physical soil disturbance, are not allowed.

Permanent and temporary protection zones

In the reviewed policy designs, PZs on forest land were either regarded as permanent or temporary, i.e. established in conjunction with certain forestry operations such as fertilisation and clearcutting, to mark off areas where the operation is not to be carried out. For permanent PZs, as found in the Finnish, Danish, Estonian and Latvian legislation, the border of the zone is permanent and the management within the zone is regulated. For temporary PZs, the prescribed width is related to the forestry operation being carried out (Tables 3, 4).

Policy prescriptiveness

PZ forest, PZ chemicals and PZ soil were mandatory in all countries except Denmark (with “no policy” for PZ forest and PZ chemicals) and Iceland with “no policy” relating to

forest land (Table 3). The Finnish legislation did not specify PZs, but the protection of key habitats in riparian zones was mandatory. In Sweden and Finland, widths were, in most cases, not specified. Therefore, these policies were classified as mixed, as in the study by McDermott et al. (2009). The Norwegian Forest Act states that environmental considerations are to be made in accordance with the requirements described by the Norwegian PEFC standard. Therefore, the classification of the Norwegian policy approach was made based on the requirements in the Norwegian PEFC standard.

When comparing the degree of policy prescriptiveness among the countries, based on legislation alone (“Law” in Table 3), three groups could be distinguished (Table 5). Iceland and Denmark had the lowest degree of prescriptiveness, and Norway, Estonia and Latvia the highest (mandatory–substantive). Sweden and Finland, with a mandatory-mixed approach, fell in between these two groups.

Limits for width and management

The prescribed widths for PZs varied between 1 m and 5 km (Tables 3, 4). In the Latvian and Estonian legislations, the stipulated width increased with increasing size of water body or catchment area (Table 4). The Swedish Forestry Act defines a PZ as an area needed for preventing or limiting harmful impact on adjacent environments when managing forests, but explicit widths are not given (except in non-binding guidelines for nitrogen fertilisation and nutrient compensation). According to the Swedish Forestry Act, site preparation and stump harvesting must not be carried out in PZs for lakes and streams. Thus, the limit for carrying out these operations is clearly stated, but the Act leaves room for interpretation of the PZ width.

In the studied region, forestry operations which may increase the export of chemicals and sediments were generally restricted or prohibited within the PZs on forest land (Table 3). Leaving PZs as part of the environmental considerations of day-to-day forestry operations did not entitle forest owners to economic compensation in any of the studied countries.

Strategies for addressing spatial scale and geographic variation

Operational forestry typically works at the stand scale, but legislation, government guidelines and certification standards need to address the entire range of spatial scales and geographical variation present within a country. Both scale and geographical variation were addressed in the reviewed policy designs; the PZ width was related to the size of a water body in the Estonian and Latvian legislations and the

Table 3 Policy approach and width of protection zones (PZ) on forest land according to legislation and ordinances (Law), FSC and PEFC certification standards and non-government or government guidelines for the studied countries. The policy approach shows if the policy with respect to PZs is mandatory (M), voluntary (V) or does not exist (no policy), and if the policy is substantive (performance-based), procedural (systems-based) or mixed (PZ required but width not specified) (McDermott et al. 2009). For PZ forest, trees or shrubs must be left in the PZ in conjunction with harvesting. For PZ chemicals, addition of chemicals, i.e. fertilisers or pettochemicals, is forbidden in the PZ (note: requirements for the use of pesticides are not reviewed here), and for PZ soil, forestry operations causing soil disturbance are not allowed in the PZ. – = not applicable, ns = not specified

	PZ	Norway	Sweden	Finland	Denmark	Iceland	Estonia	Latvia
Policy approach	Forest	M—substantive ¹	M—mixed	M ² —mixed	No policy	No policy ⁴	M—substantive	M—substantive
	Chemicals	M—substantive ¹	M—mixed	M ² —mixed	No policy	No policy ⁴	M—substantive	M—substantive
	Soil	M—substantive ¹	M—mixed	M ² —mixed	M—substantive	No policy ⁴	M—substantive	M—substantive
	Forest	Mixed	Mixed	Substantive	Substantive	–	Substantive	Substantive
	Chemicals	ns	Substantive	Substantive	Substantive	–	Substantive	–
	Soil	ns	Mixed	Substantive	Mixed	–	Substantive	Substantive
	Forest	Substantive	Mixed	Substantive	No policy	–	Substantive	Mixed
	Chemicals	Substantive	Mixed	Substantive	Substantive	–	Substantive	–
	Soil	Substantive	Mixed	Substantive	Mixed	–	Substantive	Mixed
	Forest	ns	ns	ns	ns	ns	1–200 m	10 m–5 km (Baltic Sea and Gulf of Riga)
Width (min–max)	Chemicals	–	25 m (guidelines)	ns	ns	ns	1–200 m	10–500 m (surface water bodies)
	Soil	–	ns	ns	2 m + specified adjacent areas	ns	1–200 m	10 m (surface water bodies)
	Forest	5–30 m	ns	10–30 m	ns	–	1–200 m	At least 300 m, in settlements at least 150 m (Baltic Sea and Gulf of Riga)
	Chemicals	–	25 m (fertilisation)	5–50 m	ns (generally to be avoided)	–	1–200 m	10 m (surface water bodies)
	Soil	–	ns	10–30 m	2 m + specified adjacent areas (generally to be minimised)	–	1–200 m	ns
	Forest	5–30 m	ns	5–10 m	ns	–	1–200 m	ns
	Chemicals	25 m	ns	5–10 m	10 m for intensively cultivated areas ³ (generally to be phased out)	–	1–200 m	–
	Soil	5 m	ns	5–10 m	2 m + specified adjacent areas and 10 m for intensively cultivated areas ³ (generally to be minimised)	–	1–200 m	ns
	Guidelines	–	25 m (nutrient addition)	≥1–50 m	State forests: 5 m (fertilisation), 50 m for protected lakes >1 ha. PZ required for protected watercourses, with width to be decided when planning ordinary forest management	≥5 m	–	ns
	Forest, chemicals, soil	–	–	–	–	–	–	–

¹ The Norwegian Forest Act states that environmental values should be protected in conjunction with forestry operations in accordance with the requirements in the Norwegian PEFC standard, which were classified as “substantive”

² PZs are not mentioned, but some habitats are protected

³ The 10-m zone prevents establishment and re-establishment of specifically assigned intensively managed areas near watercourses, typically Christmas trees or coniferous greenery stands. Products from these areas do not classify as PEFC certified, except for wood, which is typically produced when stands are no longer suitable for Christmas tree or greenery production

⁴ National legislation for forestry and water does not exist in Iceland but municipalities can include decisions on forestry (afforestation) in their regional planning

Table 4 Required width and forest management regulations for protection zones (PZ) in the Nordic countries, Estonia and Latvia as defined by national legislation, ordinances and guidelines (Table 1). For PZ forest, trees or shrubs must be left in the PZ in conjunction with harvesting. For PZ chemicals, application of chemicals is forbidden in the PZ, and for PZ soil, physical soil disturbance must not occur in the PZ. ns = not stated

Country	Source	PZ	PZ width	Forest management regulations within PZ
Norway	Forest Act	ns	According to the PEFC standard	<p>The Norwegian PEFC standard requires:</p> <p>PZ forest: 5–30 m, adjust to site-specific conditions starting from a width of 10–15 m. Multi-layered vegetation zones along lakes and watercourses wider than 2 m are desirable. For streams narrower than 2 m, PZs must be covered with shrubs and small trees</p> <p>PZ chemicals: No fertilisation within 25 m from lakes, rivers and perennial watercourses</p> <p>PZ soil: Soil damages due to off-road forestry transportation must not cause sediment export to water. Site preparation is not carried out within 5 m of perennial watercourses or within PZ forest.</p>
Sweden	Forestry Act with ordinances and government guidelines	Forest	ns	PZ with trees and shrubs must be left to the extent needed with respect to species, water quality, etc., when managing forests
	Forestry Act with ordinances and government guidelines	Chemicals	25 m for lakes and perennial watercourses according to guidelines for nitrogen fertilisation and nutrient compensation after forest biofuel harvesting	<p>When managing forests, harmful nutrient leaching and sediment transport to lakes and streams must be prevented and water quality preserved or improved. When using pesticides, fuel or oils, this must be done so that damage to the environment is prevented</p> <p>When forest fertilisation is carried out, damages must be prevented or limited</p>
	Forestry Act with ordinances and government guidelines	Soil	ns	Severe damages due to off-road forestry transportation must be prevented, and site preparation and stump harvesting are prohibited in PZ
Finland	Forest Act	Forest, chemicals, soil	ns (the entire habitat is protected)	No management or off-road forestry transportation are allowed that change the key features of the protected habitat
Denmark	Watercourse Act LBK no 1579 + Guidelines of zoning around water courses and lakes	Forest, soil	2 m	§69. Cultivation, soil tillage, planting, cf. however §34, changes of the terrain, fencing, cf. however §29, and establishment of buildings in rural zones are not allowed in a buffer strip of 2 m along open, natural streams and lakes. The same is valid for artificial streams and lakes, which in the water plan, according to the Environmental Goals Act, must fulfil the goal of ‘good ecological potential’ or ‘maximum ecological potential’. The requirements do not include isolated lakes of less than 100 m ²
	Nature Conservation Act, LBK no 1578	Forest, chemicals, soil	<p>Lakes >100 m² and certain types of adjacent nature areas, if their areas altogether are more than 2500 m²</p> <p>Lakes or watercourses protected by §1.2 and adjacent bogs and similar areas, even if the area is less than 2500 m²</p>	<p>§3.1. No changes must be made to the conditions of natural lakes with an area of more than 100 m², or streams, or parts of streams that have been appointed as protected by the Environment and Food Minister, after recommendations from the Municipal Boards. However, the prohibition is not valid for ordinary maintenance work on watercourses</p> <p>§3.2. No changes must be made to the condition of (1) heathland, (2) bogs and similar areas, (3) salt marshes, (4) meadows and pastures, when such areas, alone, together, or when adjacent to the lakes mentioned in §3.1., are larger than 2500 m² in total</p> <p>§3.3. Additionally, no changes must be made to the condition of bogs and similar areas, with an area of less than 2500 m², when they are adjacent to a lake or a watercourse, that is protected according to §1.2</p>

Table 4 continued

Country	Source	PZ	PZ width	Forest management regulations within PZ
	The Forest Act, LBK no 1577 with ordinances and government guidelines	Forest, chemicals, soil	All lakes or watercourses in forest reserve land, i.e. forests with a legal clause that it is forest and must remain forest ('fredskov', nearly all forest in Denmark) and their adjacent bogs, heathland, meadows and pastures, regardless if these are protected by §1.2 of the Nature Conservation Act	<p>§28.1 Lakes, bogs, heathland, salt marshes, meadows and pastures that belongs to forest reserve land (in Danish 'fredskov', i.e. forest with a legal clause that it is forest land and must remain forest land; the vast majority of forests in Denmark have this status), and which are not protected under §1.2 and §3 of the Nature Conservation Act, because they are smaller than the size thresholds in this Act, must not be cultivated, drained, be subjected to planting or be changed in any other manner</p> <p>§28.2. The prohibition in §28.1 is also valid for watercourses that are not under §3 of the Nature Conservation Act, because they have not been protected by the Environment and Food Minister according to recommendations from the Municipality Boards. However, the prohibition is not valid for ordinary maintenance work on watercourses</p> <p>Guidance to the Act: Ordinary maintenance work is understood as cleaning every 7–8 years. If time intervals are longer or if a deepening of the watercourse takes place, it is a change in the condition, which requires a waiver from the law</p> <p>Guidelines for nature conservation, watercourses and lakes in state forests: Detailed recommendations are included regarding forest waters. Among other, it is stated that:</p> <p>The main aim of management of the protected watercourses is to ensure and improve the condition for the benefit of wild flora and fauna. If maintenance is needed, it should only be carried out manually. Buffer zones with permanent forest cover must be established along the shores of forest watercourses and lakes >1 ha and coniferous forest in the PZ must be converted to broadleaf or mixed forest. The appointment of the watercourses to be protected, the PZ width and the more precise prescriptions for the PZ management must be decided in the first-coming revision of the forest management plans. For the lakes >1 ha, the required PZ width is 50 m.</p> <p>Guidelines for ecological management in state forests: recommendations state among other that larger clearcuts and fertilisation near clean and nutrient-poor lakes must be avoided. Natural watercourses are kept shadowed and damming is omitted. In coniferous forest: surface waters are kept open through maintenance work, as needed, and they are kept free from pollution. The management should aim at surrounding all lakes and water courses with broad bands of broadleaved trees</p> <p>Guidelines for fertilisation in state forests: Fertilisation must not take place within a distance of 5 m from lakes, water courses and larger ditches</p>
Iceland	Water Act	ns	ns	All human-induced changes in protected freshwater supply zones are prohibited. Protected drinking water supply areas must not be cultivated

Table 4 continued

Country	Source	PZ	PZ width	Forest management regulations within PZ
Estonia	Water Act	Forest, chemicals, soil	Water PZs (also referred to as belts): Baltic Sea shore and two large lakes (Lake Peipsi and Võrtsjärv): 20 m Remaining lakes and streams: 10 m Recipient water bodies with a catchment area <10 km ² : 1 m	Felling of trees and shrubs is forbidden without the consent of the Environment Agency, except when maintaining ditch networks. Use of fertilisers, pesticides, sewage sludge is forbidden. Pesticides may be used in exceptional cases after permission by the Environment Agency
	Nature Conservation Act	Forest, chemicals, soil	Baltic Sea and two large lakes (Lake Peipsi and Võrtsjärv with water body areas >200 km ²): 200 m Lakes and reservoirs with an area >10 ha and rivers with a catchment area >25 km ² : 100 m Springs, lakes and reservoirs with an area <10 ha and streams with a catchment area <25 km ² : 50 m	Baltic Sea and two big lakes: clearcutting is prohibited Lakes, reservoirs and springs: the clearcut area must not exceed 2 ha, except when maintaining ditch networks. Driving an all-terrain vehicle is permitted for work related to the management of a protected natural object, and for permitted forestry work
	Forest Act		The act refers to the Water Act and the Nature Conservation Act	
Latvia	Protection Zone Law	Forest, chemicals, soil	Restricted economic activity zone for the Baltic Sea and Gulf of Riga: 5 km PZ for coastal dunes: at least 300 m (at least 150 m in settlements)	Restricted economic activity zone for the Baltic Sea and Gulf of Riga: no final felling, i.e. selective felling or clearfelling, from 1 April to 30 September, no clearfelling in Scots pine stands (where Scots pine accounts for 80% or more of the basal area) on dry mineral soils PZ for coastal dunes: no final felling (except in emergencies), no off-road driving, no damage to vegetation, no excavation of sand and gravel
	Protection Zone Law	Forest, chemicals, soil	All watercourses and water bodies in rural areas, except drainage ditches, minimum widths along each shore: (1) The four longest rivers (Daugava, Gauja, Lielupe, Venta): 300–500 m (2) Other rivers with a length >100 km: 300 m (3) Streams and rivers with a length of 25–100 km: 100 m (4) Streams and rivers with a length of 10–25 km: 50 m (5) Streams and rivers with a length <10 km: 10 m (6) Water bodies with an area >1000 ha: 500 m (7) Water bodies with an area 100–1000 ha: 300 m (8) Water bodies with an area 25–100 ha: 100 m (9) Water bodies with an area 10–25 ha: 50 m (10) Water bodies with an area <10 ha: 10 m (11) Watercourse or water body with floodplain—at least the width of the floodplain independent of the length or area of the floodplain	No ditching without approval within 10 m, no clearfelling within 50 m (except for grey alder stands, restoration of floodplain meadows and after emergent events such as windthrows, windbreaks and snowbreaks), no fertilisation within 10 m, no excavation of sand and gravel within 10 m, no final felling within 10 m (except emergencies, windthrows, windbreaks, snowbreaks, grey alder stands). The latest amendments of the Latvian Protection Zone Law (enforced on 22.12.2015) allow final felling and clearfelling in the surface water PZ if the dominant species is grey alder (<i>Alnus incana</i> (L.) Moench), provided that the size of the clearcut area does not exceed 1 ha and the slope steepness is less than 30 degrees. It is mandatory to preserve all oaks, limes, elms, maples, pines, black alders, willows and crab-apple trees within the PZ, and at subsequent regeneration the share of spruce trees must be at most 80% of total number of trees

Table 5 Classification of the legislation in the studied countries according to the scheme developed by McDermott et al. (2009)

No policy	Voluntary		Mandatory		
	Procedural	Substantive	Procedural	Mixed	Substantive
Iceland				Sweden	Norway
Denmark ¹				Finland	Estonia
					Latvia

¹ In Denmark, there was a policy for PZ soil but not for PZ forest and PZ chemicals

Norwegian PEFC standard (for PZ forest), and the Swedish Forestry Act stipulated that PZ forest must be left at forest management to “the extent needed” in order to achieve protection (Table 4). Furthermore, recommendations to consider site-specific conditions when delineating PZ forest were sometimes given.

National policy designs

General descriptions of the national policy designs regarding PZs are summarised here, while detailed information on limits for width and management are shown in Table 4.

Norway

In Norway, PZ forests are not explicitly mentioned in the Forest Act, but the Act states that the ecological functions of the riparian zone should be preserved and that environmental values must be protected in conjunction with forestry operations in accordance with the requirements of the Norwegian PEFC standard. The Norwegian PEFC standard requires PZ forest along perennial waters (lakes and ponds), rivers and streams, PZ chemicals (for fertilisation) and PZ soil (for off-road forestry transportation and site preparation). For PZ forest, adaptation to site-specific conditions is emphasised and the width of an individual zone may vary.

Sweden

The Swedish Forestry Act stipulates that damage to soil and water caused by forest management must be prevented or limited. When managing forests, harmful nutrient leaching and sediment transport 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). A PZ with trees and shrubs must be left to provide protection to the extent needed with respect to species, water quality, etc., when managing forests. The accompanying guidelines for PZ forest recommend that the PZs are adapted to site-specific

conditions, such as species sensitivity and soil and water conditions. The requirements related to water protection in the Swedish FSC and PEFC standards are similar to those found in the Forestry Act.

Finland

The Finnish legislation does not explicitly prescribe PZs, but some key habitats located in the riparian zones are protected from forestry operations, or their key features are protected from damage by management operations. These habitats include the immediate surroundings of springs, brooks, rivulets with a permanent water-flow channel, and small ponds in a pristine or pristine-like state. The Finnish forest certification standards prescribe PZs at harvesting, fertilisation and stump harvesting. The PEFC standard, which dominates the certification of land in Finland (Table 2), requires that PZ forests are left along surface waters and springs. Site preparation, fertilisation, stump harvesting and herbicide treatments must not be carried out in these zones.

Denmark

In Denmark, lakes and watercourses and their adjacent areas are regulated by several laws (Table 4). The purpose of the Watercourse Act is to ensure that natural and artificial watercourses can be used as recipients for waste water, drainage water and surface runoff, while also considering environmental requirements included in other legislation. The Act applies to almost all streams and lakes in Denmark, also on forest land. In order to prevent erosion and sedimentation, the Act requires a 2-m-wide PZ around natural watercourses and lakes, and artificial watercourses that are classified as having ‘good ecological potential’ or ‘maximum ecological potential’ based on the Environmental Goals Act (Table 1). In the 2-m-wide PZ, soil preparation, planting and change to the terrain are prohibited along with some other activities, except that authorities may require planting to provide shade to limit excessive growth of water weeds.

The Nature Conservation Act (§1 and 3) stipulates that no changes are to be made to the condition of larger natural lakes ($>100\text{ m}^2$) or streams that have been appointed by the Environment and Food Minister in agreement with recommendations from the Municipal Boards, except as a result of ordinary maintenance work. There are no general requirements for PZs, but no alterations can occur in certain specified nature areas ($>2500\text{ m}^2$) that are adjacent to natural lakes ($>100\text{ m}^2$) (§1).

The Nature Conservation Act also applies to forests, and the Danish Forest Act expands the requirements on designated forest reserve land, i.e. forests with a legal clause that they will always remain forest land (“fredskov”) comprising the vast majority of forests in Denmark. In these forests, the area around smaller natural lakes and streams that have not been appointed for protection in accordance with §3 of the Nature Conservation Act must not be cultivated, drained, planted or changed in any other manner, except as a result of ordinary maintenance work. Guidelines specify that the management aim for protected watercourses in state forests is to ensure and improve the conditions for flora and fauna. The guidelines also provide detailed management instructions for protection of surface waters on forest land, for instance establishment of permanent forest of broadleaved indigenous trees on shores to provide shade (Table 4). For non-protected ditches, maintenance should aim to ensure the health and stability of the surrounding forest.

The Danish FSC certification standard requires streams and lakes to be maintained in, or restored to, their natural condition, and PZs must be established along their shores. When plantations are designed and laid out, zones with vegetation of indigenous species must be established and/or protected around watercourses. However, an exact zone width is not specified. The Danish PEFC standard requires PZs to be created only in intensively cultivated areas, but otherwise relies on legislation. Regeneration of existing, and establishment of new, intensively cultivated areas, typically for Christmas tree production, must never occur closer than 10 m from watercourses protected in accordance with the Nature Conservation Act §3. Both the FSC and PEFC standards generally assume that fertiliser and other chemicals are not used, and that soil scarification is limited except in intensively cultivated areas (PEFC).

Iceland

In Iceland, there is no legislation that regulates the interaction between forestry and surface waters. Protections zones are not mentioned in the Forest Act. The Water Act prohibits all human-induced activities in protected drinking water supply areas that reduce surface water or groundwater quality. These areas are mostly outside forests given

the small proportion of forest land. Areas protected for drinking water supply must not be altered by cultivation (including afforestation), since this involves measures that could cause a deterioration in water quality. However, in the regional planning undertaken by municipalities, local authorities can make decisions about afforestation and water. Such decisions vary between municipalities. For instance, in one municipality, a special licence is required for establishing a forest closer than 50 m to streams or lakes. In 2009, the Icelandic Forestry Association set up guidelines for good afforestation practices for stakeholders and the forest sector (Table 1). The only reference to water in these guidelines regards protections zones for drinking water supply sites.

Estonia

The Estonian Nature Conservation Act prescribes PZs (referred to as buffer strips or belts) with fixed widths where management is restricted. Clearcutting is forbidden in the 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. The Water Act defines fixed-width PZs to avoid bank erosion and diffuse pollution to water bodies. The Water Act also prohibits felling of trees and shrubs in these zones unless permission has been obtained from the Environment Agency, for instance, in connection with drainage operations.

The Estonian PEFC standard does not explicitly mention PZs for water, but forest management planning shall “enhance the quality of the economic, ecological, cultural and soil values of forest resources, including soil and water”. Principle 10 regarding plantations of the FSC standard for Estonia (NEPCon Interim Standard for Assessing Forest Management in Estonia, Table 1), stipulates that “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”. For forest holdings less than 100 ha, “riparian buffer 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 (Table 4), should be taken into account.

Latvia

The Protection Zone Law of Latvia defines five types of PZs. The PZs for the Baltic Sea, Gulf of Riga and surface waters fall into the category of PZs for environmental and natural resources. The coastal PZs for the Baltic Sea and Gulf of Riga have been established in order “to decrease

the effects of pollution in the Baltic Sea, to preserve the protective functions of the forest, to eliminate the development of erosion processes, to protect the coastal landscapes, to ensure preservation and protection of coastal natural resources, including resources necessary for leisure and tourism and other territories important for society, and the balanced and the continuous utilisation thereof". This zone is divided into two parts: one with restricted economic activity and one for protecting coastal dunes. Land-use change and building in the 5-km-wide restricted economic activity zone is generally regulated by the territorial planning documents of the respective municipalities; limitations and additional architectural requirements may be enforced to preserve the characteristic cultural landscape of the coastal region. Protection zones for surface water bodies have been defined for reservoirs (lakes, ponds and storage ponds), watercourses and artificial water bodies in order "to decrease the negative effects of pollution to water ecosystems, to eliminate the development of erosion processes, and to restrict economic activity in the flood zones, as well as to preserve the characteristic landscape of the area". The law prescribes PZs with fixed widths and forestry is restricted within these zones.

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 mitigating 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 is required for 10% of the managed total forest area.

DISCUSSION

The degree of policy prescriptiveness varied considerably among the studied countries. There may be many reasons for this, including socio-economic, historical and political reasons, often neglected within this field of research, as well as forest ownership structure (McDermott et al. 2009). Further studies are needed to fully explain the extent to which level of economic development, land ownership structure and enforcement capacity contribute to the variation in policy prescriptiveness in the Nordic–Baltic region. Here, however, the level of economic development does not seem to be the most important factor. The Nordic countries have a high economic development (Table 2) but showed different degrees of policy prescriptiveness, while

Estonia and Latvia with a lower level of economic development showed the highest degree of prescriptiveness. The proportion of the country that is forest land and land ownership structure might be more important. In five of the reviewed countries, the proportion of forest land was 40% or more, while in Denmark and Iceland other types of land use dominated. In Denmark, over 60% of the land area is arable land (World Bank 2016), and its legislation was generally focused on the function of watercourses as recipients of waste water, drainage water and surface runoff, as well as the maintenance of a good ecological condition, with the greatest consequences for agriculture. In Iceland, 77% of the land area is defined as semi-natural (EEA 2016), such as bare rock and sparsely vegetated areas, and only 0.5% of the land area is covered by forest. The low prescriptiveness for PZs on forest land in these two countries suggests that national policy designs are less focused on forestry when the proportion of forest land is small.

Sweden and Finland, with the highest proportions of forest land, had a lower degree of prescriptiveness than Estonia, Latvia and Norway. Differences in land ownership structure may explain some of this variation. In Sweden and Finland, the timber supply relies on a large number of private owners. Regulating such a diverse owner structure may be more difficult than in countries with a higher proportion of state-owned land as in Latvia and Estonia (cf. McDermott et al. 2009). However, Norway had the lowest proportion of public forest land but still a high level of prescriptiveness. In Norway, many private forest owners do not manage their forests, because these grow on inaccessible, steep hillsides. Forestry is concentrated mainly to the south-eastern part of Norway. Thus, the conditions in Norway are different from those in Sweden and Finland, but we are unable to determine if, or how, this may help explain the difference in policy prescriptiveness.

The mixed policy approach used by Sweden and Finland (although PZs were not explicitly mentioned in the Finnish legislation) meant that PZs were mandatory but without specifying any widths. In Sweden, a dialogue process (cf. Mårald et al. 2015) was initiated in 2011 within the forest sector, with the aim clarifying areas such as environmental concerns and legal requirements (Andersson et al. 2013). A target goal for PZ forest was defined in this process and this was more detailed than those found in the Swedish Forestry Act and the national FSC and PEFC standards. This suggests that in countries with less prescriptive policy designs, voluntary commitments such as dialogue processes and forest certification may be more important for on-the-ground implementation than legislation. In Sweden, forest policy was de-regulated in the early 1990s as a result of the development of the Forestry Act framework (Johansson 2013), putting equal emphasis on biodiversity

conservation and timber production. Although the Act sets a minimum level, it is largely left to the forest owners to decide how these two goals should be reached.

The required PZ width spanned a wide range between the studied countries. The greatest widths were found in the Estonian and Latvian legislations. The Estonian legislation is strongly influenced by the environmental protection policy, i.e. the Nature Conservation Act and the Water Act, as a result of intensive exploitation pressure on natural resources. The Latvian legislation includes remnants from the time when Latvia was part of the Soviet Union and the main purpose of PZs was, and still is, to protect the water quality in water bodies. The widest PZs of 1 km were applied along rivers containing the spawning areas of salmonid fish species. Also, drainage networks were subject to PZs. As a consequence, nearly all forest land was within PZs in some areas. With the adoption of the Protection Zone Law (Table 1), the protection was narrowed to ecosystems along the banks of watercourses and water bodies, thus excluding drainage networks. This more resembled the situation before the Soviet occupation when the main goal of PZs in forests was to protect the banks of rivers, lakes, canals, etc., from soil erosion (cf. Danish legislation). Another goal before Soviet occupation was to prevent the movement of shifting dunes, but this is no longer an issue (Latvian Ministry of Agriculture 1923, 1937). Moreover, the wide PZs prescribed in Estonia and Latvia may be warranted by the topography in these countries, where the lowlands are sometimes exposed to large-scale inundation. Although extensive research on riparian forests has been carried out (inter alia Broadmeadow and Nisbet 2004; Gundersen et al. 2010; Kuglerová et al. 2014; Richardson and Béraud 2014), many questions regarding the optimal width and management of PZs for different environmental goals remain unanswered for the Nordic–Baltic region. One important reason for this is the large diversity in forests and surface waters, calling for studies in a wide range of conditions.

CONCLUSIONS

Our analysis showed how the Nordic and Baltic countries currently (1 April 2016) interpret the need for protection zones around surface waters on forest land, and the level of protection and regulation required. It revealed great variations in the national policy designs and prescribed widths for PZs for surface waters on forest land in these countries. Furthermore, it suggests that land-use distribution, forest ownership structure and historic and political legacies are important factors in explaining this variation. Yet, to what extent mandatory or voluntary regulations are the most effective in providing a high level of on-the-ground

implementation and achievement of protection goals remains unanswered. Future studies seeking explanations to different levels of protection should consider the socio-economic context in which policy is being developed as well as ecological conditions. Finally, more knowledge on how to adapt the design of protection zones to local conditions and different management goals could help improve protection zone functionality.

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REFERENCES

- Ahtiainen, M., and P. Huttunen. 1999. Long-term effects of forestry managements on water quality and loading in brooks. *Boreal Environment Research* 4: 101–114.
- Andersson, E., M. Andersson, Y. Birkne, S. Claesson, O. Forsberg, and G. Lundh. 2013. Target goals for good environmental consideration. A part delivery from Dialog om miljöhänsyn. Swedish Forest Agency, Report 5, Jönköping, Sweden (in Swedish).
- Bilby, R.E., and J.T. Heffner. 2016. Factors influencing litter delivery to streams. *Forest Ecology and Management* 369: 29–37. doi:10.1016/j.foreco.2016.03.031.
- Borchardt, K.D. 2010. *The ABC of European Union law*. Luxembourg: Publications Office of the European Union. doi:10.2830/13717.
- Broadmeadow, S., and T. Nisbet. 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. *Hydrology and Earth System Sciences Discussions* 8: 286–305. doi:10.5194/hess-8-286-2004.
- Cashore, B. 1997. Governing forestry: environmental group influence in British Columbia and the US Pacific Northwest. Ph.D. Thesis. Canada: University of Toronto.
- Eklöf, K., R. Lidskog, and K. Bishop. 2016. Managing Swedish forestry's impact on mercury in fish: defining the impact and mitigation measures. *Ambio* 45: 163–174. doi:10.1007/s13280-015-0752-7.
- Esseen, P.-A., A. Glimskär, and G. Ståhl. 2004. Linear landscape elements in Sweden: estimates from the NILS-data of year 2003. Swedish University of Agricultural Sciences, Department of Forest Resource Management and Geomatics, Arbetsrapport 127 (in Swedish).
- EEA. 2016. European Environment Agency. <http://www.eea.europa.eu/soer/countries/is/land-use-state-and-impacts-iceland>. Accessed 8 Apr 2016.

- FAO. 2015. FAO's Global Forest Resource Assessment 2015. Rome: Food and Agriculture Organization of the United Nations. <http://www.fao.org/forest-resources-assessment/current-assessment/en/>.
- Forest and Nature Agency. 2010. Forest and nature in numbers 2010. Ministry of Environment, Forest and Nature Agency. <http://naturstyrelsen.dk/media/nst/Attachments/SkovognaturiTal2010.pdf> (in Danish).
- FSC. 2015. FSC® International Standard, FSC principles and criteria for forest stewardship, FSC-STD-01-001 V5-2 EN. Forest Stewardship Council.
- FSC. 2016. FSC Facts & Figures March 1, 2016. Forest Stewardship Council. <https://ic.fsc.org/>.
- Friberg, N. 1998. Forest and forest streams. Danmarks Miljøundersøgelser (now Danish Centre for Environment and Energy), Temarapport from DMU 21/1998 (in Danish).
- Friis-Møller, P., J. Bigler, B.O. Nielsen, I.M. Thomsen, R.M. Buttenschøn, and J. Heilmann-Clausen. 2010. Dynamics and disturbances in the forest. In *Naturen i Danmark. Skovene*, ed. P. Friis-Møller, 271–303. Copenhagen: Gyldendalske Boghandel og Nordisk Forlag A/S. (in Danish).
- Gundersen, P., A. Laurén, L. Finér, E. Ring, H. Koivusalo, M. Sætersdal, J.-O. Weslien, B.D. Sigurdsson, et al. 2010. Environmental services provided from riparian forests in the Nordic countries. *Ambio* 39: 555–566. doi:10.1007/s13280-010-0073-9.
- Hoover, T.M., X. Pinto, and J.S. Richardson. 2011. Riparian canopy type, management history, and successional stage control fluxes of plant litter to streams. *Canadian Journal of Forest Research* 41: 1394–1404. doi:10.1139/x11-067.
- Johansson, J. 2013. Constructing and contesting the legitimacy of private forest governance: the case of forest certification in Sweden. Ph.D. Thesis. Sweden: Umeå University.
- Joensuu, S., M. Kauppila, M. Lindén, and T. Tenhola. 2012. *Guidelines for good forestry practices—water protection*. Helsinki: Publications of Tapio. (in Finnish).
- Jordan, A., R.K.W. Wurzel, and A. Zito. 2005. The rise of 'new' policy Instruments in comparative perspective: has governance eclipsed government? *Political Studies* 53: 477–496. doi:10.1111/j.1467-9248.2005.00540.x.
- Kreutzweiser, D., S. Capell, K. Good, and S. Holmes. 2009. Sediment deposition in streams adjacent to upland clearcuts and partially harvested riparian buffers in boreal forest catchments. *Forest Ecology and Management* 258: 1578–1585. doi:10.1016/j.foreco.2009.07.005.
- Kreutzweiser, D.P., P.W. Hazlett, and J.M. Gunn. 2008. Logging impacts on the biogeochemistry of boreal forest soils and nutrient export to aquatic systems: a review. *Environmental Reviews* 16: 157–179. doi:10.1139/a08-006.
- Kuglerová, L., A. Ågren, R. Jansson, and H. Laudon. 2014. Towards optimizing riparian buffer zones: ecological and biogeochemical implications for forest management. *Forest Ecology and Management* 334: 74–84. doi:10.1016/j.foreco.2014.08.033.
- Latvian Ministry of Agriculture. 1923. *Instruction for forest inventory*. Riga: Latvian Ministry of Agriculture. (in Latvian).
- Latvian Ministry of Agriculture. 1937. *Instruction for forest protection*. *Valdības Vestnesis* 260: 1–4. (in Latvian).
- Lundin, L., and T. Nilsson. 2014. Initial effects of forest N, Ca, Mg and B large-scale fertilization on surface water chemistry and leaching from a catchment in central Sweden. *Forest Ecology and Management* 331: 218–226. doi:10.1016/j.foreco.2014.08.017.
- Mayer, P.M., S.K. Jr, M.D. McCutchen Reynolds, and T.J. Canfield. 2007. Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality* 36: 1172–1180. doi:10.2134/jeq2006.0462.
- McDermott, C.L., B. Cashore, and P. Kanowski. 2009. Setting the bar: An international comparison of public and private forest policy specifications and implications for explaining policy trends. *Journal of Integrative Environmental Sciences* 6: 217–237. doi:10.1080/19438150903090533.
- Mårald, E., C. Sandström, L. Rist, O. Rosvall, L. Samuelsson, and A. Idenfors. 2015. Exploring the use of a dialogue process to tackle a complex and controversial issue in forest management. *Scandinavian Journal of Forest Research* 30: 749–756. doi:10.1080/02827581.2015.1065343.
- NCM. 2017. Nordic Council of Ministers. <http://www.norden.org/en/om-samarbejdet-1/formal-nordic-co-operation>. Accessed 22 Mar 2017.
- Nieminen, M., E. Ahti, H. Koivusalo, T. Mattsson, S. Sarkkola, and A. Laurén. 2010. Export of suspended solids and dissolved elements from peatland areas after ditch network maintenance in South-Central Finland. *Silva Fennica* 44: 39–49. doi:10.14214/sf.161.
- Päivinen, J., N. Björkqvist, L. Karvonen, M. Kaukonen, K.-M. Korhonen, P. Kuokkanen, H. Lehtonen, and A. Tolonen. 2011. *Forestry and environmental management*. Vantaa: Metsähallitus Publications of Forestry 67. (in Finnish).
- PEFC. 2010. Sustainable forest management—requirements. PEFC ST 1003:2010. Programme for the Endorsement of Forest Certification Schemes.
- PEFC. 2015. PEFC Global Statistics: SFM & CoC Certification, Data: December 2015. Programme for the Endorsement of Forest Certification Schemes. <http://www.pefc.org/>.
- Raatikainen, M., and E. Kuusisto. 1990. The number and surface area of the lakes in Finland. *Terra* 102: 97–110. (in Finnish).
- Richardson, J.S., and S. Béraud. 2014. Effects of riparian forest harvest on streams: a meta-analysis. *Journal of Applied Ecology* 51: 1712–1721. doi:10.1111/1365-2664.12332.
- Richardson, J.S., R.J. Naiman, and P.A. Bisson. 2012. How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices? *Freshwater Science* 31: 232–238. doi:10.1899/11-031.1.
- Swedish Forest Agency. 2014. *Swedish statistical yearbook of forestry 2014*. Jönköping: Swedish Forest Agency.
- Sweeney, B.W., and J.D. Newbold. 2014. Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review. *Journal of the American Water Resources Association* 50: 560–584. doi:10.1111/jawr.12203.
- Tamre, R. 2006. List of lakes in Estonia. Natural and artificial lakes. Ministry of the Environment Information Centre. http://www.keskkonnainfo.ee/publications/113_PDF.pdf (in Estonian).
- The World Bank. 2016. <http://data.worldbank.org/indicator/AG.LND.AGRI.ZS>. Accessed 8 Apr 2016.
- The World Bank. 2017. <http://databank.worldbank.org/data/download/GNIPC.pdf>. Accessed 13 Mar 2017.

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