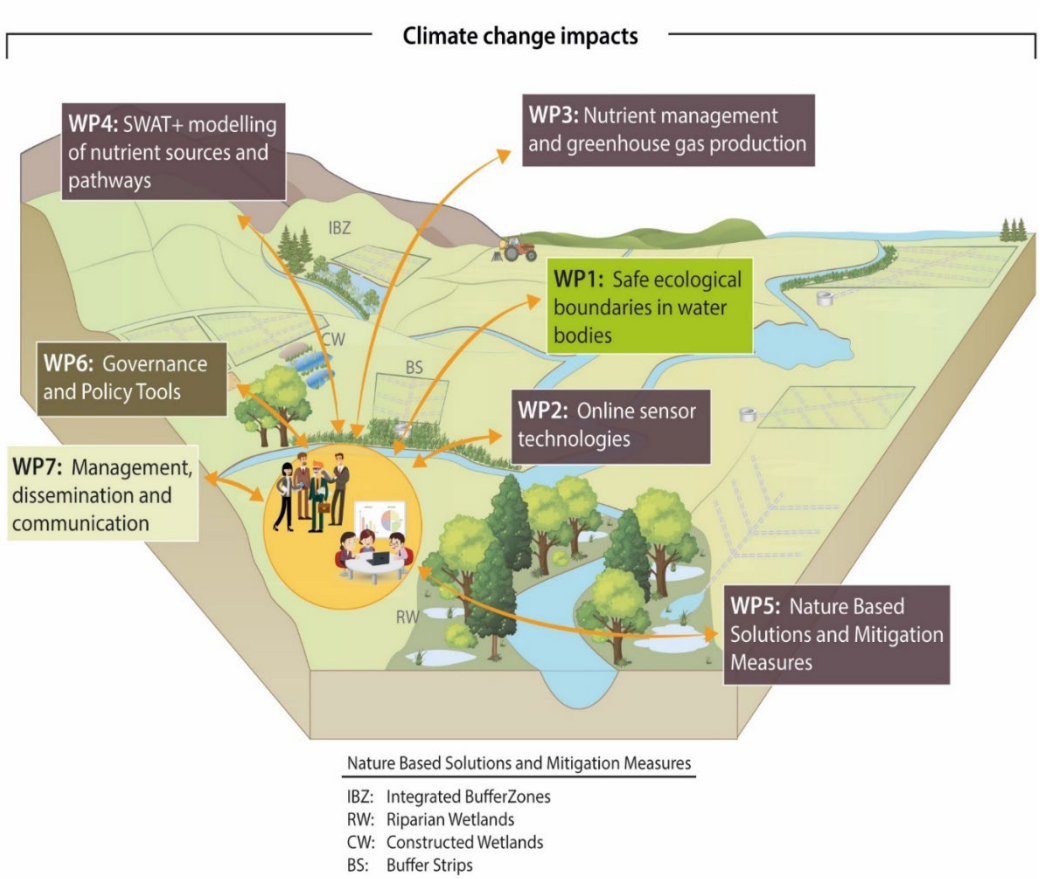

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Introduction

The main objective of WP5 is to foster the implementation of innovative Nature Based Solutions (NBSs) and mitigation measures (MMs) in the Nordic-Baltic region of Europe to reduce diffuse nutrient losses from agriculture and forestry under current and future climate conditions and stay within safe ecological boundaries in different water bodies under special consideration of stakeholder preferences. Safe ecological boundary values for nitrogen and phosphorus in different types of Nordic and Baltic rivers and lakes that are in line with good ecological status for sensitive biological quality elements (as required by the Water Framework Directive; Kelly et al., 2021) were identified in WP1 of the NORDBALT-ECOSAFE project (D1.1 and D1.2). Based on the safe ecological boundaries and observed nitrogen and phosphorus loads or concentrations, reduction needs can be estimated, which are essential for identifying and quantifying the need for implementation of nutrient mitigation measures and Nature Based Solutions.

The Nordic-Baltic region has a long tradition of developing and testing different mitigation measures within agriculture and forestry. It is therefore well-suited for the development of a novel decision-support tool guiding river basin managers and stakeholders in the selection of the most effective NBSs and MMs for reaching the required nutrient load reductions and their optimal placement in a river basin. The first step in the development of such a tool was to identify the NBSs and MMs that are most well-established in the Nordic-Baltic region and compiling them in a NBS and MM portfolio (D5.1). Based on the NBS and MM portfolio, a classification framework considering various factors that are essential for selecting, designing, and evaluating a particular measure was developed. In combination with the SWAT+ modelling in WP4, the classification framework can help to identify the most suitable measures and optimize their placement in a catchment.

In the next few chapters, the different sections of the classification framework will be briefly introduced:

1. Measures included in the classification framework
2. Transport pathways
3. Co-benefits and disservices
4. Official and subsidized measures
5. Implementation barriers

Also, the shortcomings of the classification framework and the info sheets accompanying it will be briefly discussed. Finally, an outlook will clarify how the classification framework will contribute to future tasks and deliverables in NORDBALT-ECOSAFE.

Measures included in the classification framework

The classification framework is based on the NBS and MM portfolio (D5.1), which included 33 common nutrient mitigation measures in the Nordic-Baltic region as identified from national catalogues, reports, and river basin management plans in the six countries represented in the project, the recent international literature, and stakeholder perceptions and preferences.

Some changes were made to the selection of measures for the classification framework. The measures “crop rotation”, “early seeding of winter crops”, “mulching”, “subsoiling”, “nitrification inhibitors to slurry”, and “paludi cultures” were removed, as each of them was only used in one

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country and no data or information was available for the different sections of the classification framework from any of the six NORDBALT-ECOSAFE countries. The name of the measure “reduced tillage and direct seeding” was changed to “direct sowing” and “reduced tillage – no tillage in autumn” was changed to “no or delayed tillage in autumn”. “Buffer strips with grass or trees” were divided into “Grass buffer strips” and “Buffer strips with trees”. Finally, “bank stabilization” was added as an in-stream mitigation measure. After all the changes, the classification framework included 29 measures.

The measures included in the classification framework are classified in three groups, agricultural/forest management measures, i.e. field measures (13 measures), transport control measures (10), and in-stream measures (6). The first group, the agricultural/forest management measures, includes the largest number of measures, as preventing and reducing nutrient pollution at the source is the foundation to managing water quality and transport control and in-stream measures cannot function efficiently if they are overloaded by nutrients or water flows.

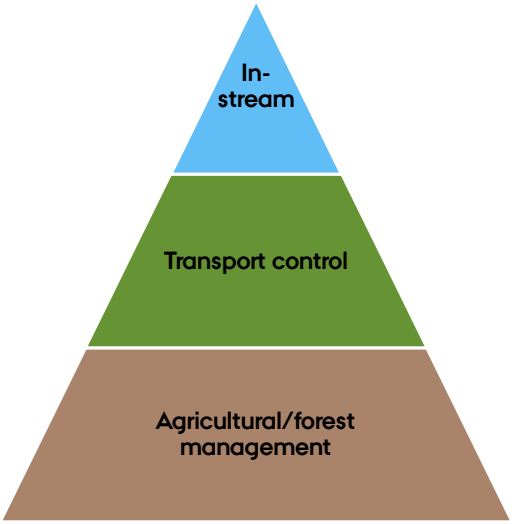

Figure 1: The three groups of NBSs and MMs included in the classification framework.

Transport pathways

Depending on the catchment characteristics, nutrients can be transported via surface runoff, tile flow, leaching from the root zone, groundwater flow, and streamflow. Catchment-scale hydrologic models like SWAT+ can be used to identify the dominant pathways in a specific area of interest (as will be done in NORDBALT-ECOSAFE WP4). However, for selecting the right measure, it is essential to not only know the dominant pathways, but also which measures affect which nutrient transport pathways. While the field mitigation measures aim at preventing and reducing nutrient pollution at the source, i.e. before the nutrients are transported, many of them are particularly efficient at preventing or reducing nutrient loads transported via a specific pathway. The in-stream measures mostly target streamflow but can have a small impact on other transport pathways as well. As the transport pathways targeted by the measures included in the classification framework are not expected to differ between the six countries involved in NORDBALT-ECOSAFE, they were not assessed for each country individually. The measures included in the classification framework and the pathways they affect are listed in Figure 2.

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Measure	Pathway				
	Surface runoff	Tile flow	Leaching from root zone	Groundwater flow	Stream flow
Field mitigation measures					
Catch crops		x	x	x	
Permanent set-aside	x	x	x	x	
Set-aside in rotation	x	x	x	x	
Permanent grassland, meadows and pastures	x	x	x	x	
Energy crops	x	x	x	x	
Afforestation	x	x	x	x	
Direct sowing	x	x	x	x	
No or delayed tillage in autumn	x		x		
Application of gypsum or structure lime			x		
Precision fertilization (fertilizer & manure)		x	x	x	
Reduced fertilizer use		x	x	x	
Manure application regulations (time and amount)	x	x	x	x	
Limits for N and P use in manure	x	x	x	x	
Transport mitigation measures					
Surface flow constructed wetlands (on fields)		x			
Restored wetlands		x		x	x
Bioreactors with wood chips		x			
Controlled drainage		x	x		
Inundation of meadows with drainage water		x			
Grass buffer strips	x				
Buffer strips with trees	x				x
Integrated and Saturated Buffer Zones	x	x			
Grassed waterways	x				
Grass cover/no tillage in areas with high flood and/or erosion risk	x				
In-stream mitigation measures					
Constructed wetlands					x
Retention ponds in forests	x				x
Re-meandering of river channels					x
Two stage ditches and channels					x
Bank stabilization					x
Stream bed re-naturalization					x

Figure 2: Measures included in the classification framework and nutrient transport pathways targeted by the measures

Co-benefits and disservices

A measure can reduce nutrient concentrations or loads in surface water bodies, but at the same time have a negative impact on other factors that are relevant for ecosystems and/or the environment. When selecting a measure, it is important to minimize disservices (Goméz Martín et al., 2020). Consideration of co-benefits can increase the cost-effectiveness of measures (Hashemi & Kronvang, 2020).

As the nutrient transport pathways, the potential co-benefits and disservices of the measures included in the classification framework are not expected to differ significantly between the six NORDBALT-ECOSAFE countries and were thus not assessed for each country individually. However, it is important to note that the classification framework only lists co-benefits and disservices that may potentially occur. Whether or not these co-benefits or disservices are relevant in a specific area of interest depends on the local environmental conditions and the design, implementation, and maintenance status of the measure.

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Measure	Co-benefits and disservices									
	Flood control	Drought mitigation	Soil health	Methane emissions	N2O emissions	Carbon sequestration	Consumption of fossil fuels	Sediment retention	Biodiversity	Phosphate emissions from soils
Field mitigation measures										
Catch crops	0	0	+	0	+	+	-	+	+	+
Permanent set-aside	0	0	+	0	+	+	-	+	+	0
Set-aside in rotation	0	0	+	0	0	0	-	+	0	0
Permanent grassland, meadows and pastures	+	0	+	0	+	+	-	+	+	+
Energy crops	0	0	0	0	0	+	-	+	+	+
Afforestation	0	0	+	0	+	+	-	+	+	+
Direct sowing	0	0	+	0	0	+	-	+	+	0
No or delayed tillage in autumn	0	0	+	0	0	0	-	+	+	0
Application of gypsum or structure lime	0	0		0	0	0	+	+	0	+
Precision fertilization (fertilizer & manure)	0	0	+	0	0	+	0	0	0	+
Reduced fertilizer use	0	0	0	0	+	0	0	0	0	+
Manure application regulations (time and amount)	0	0	0	0	+	0	0	0	0	+
Limits for N and P use in manure	0	0	0	0	+	0	0	0	0	+
Transport mitigation measures										
Surface flow constructed wetlands (on fields)	0	0	0	-	-	0	0	+	+	0
Restored wetlands	+	+	+	-	-	+	-	+	+	+
Bioreactors with wood chips	0	0	0	-	-	-	0	+	0	-
Controlled drainage	+	+	+	0	0	0	0	+	0	+
Inundation of meadows with drainage water	+	+	+	-	-	+	-	+	+	-
Grass buffer strips	0	0	+	0	0	+	-	+	+	0
Buffer strips with trees	0	0	+	0	0	+	-	+	+	0
Integrated and Saturated Buffer Zones	0	0	+	0	0	+	-	+	+	0
Grassed waterways	+	0	+	0	0	+	-	+	+	0
Grass cover/no tillage in areas with high flood and/or erosion risk	0	0	+	0	0	+	-	+	+	0
In-stream mitigation measures										
Constructed wetlands	0	0	n/a	-	0	0	n/a	+	+	0
Retention ponds in forests	+	0	n/a	0	0	0	n/a	+	+	0
Re-meandering of river channels	+	+	n/a	0	0	0	n/a	-	+	-
Two stage ditches and channels	+	0	n/a	0	0	0	n/a	+	+	0
Bank stabilization	0	0	n/a	0	0	0	n/a	+	0	0
Stream bed re-naturalization	0	0	n/a	0	0	0	n/a	0	+	0

Figure 3: Co-benefits and disservices of the nutrient mitigation measures included in the classification framework according to the expert knowledge of the NORDBALT-ECOSAFE consortium

The NORDBALT-ECOSAFE classification framework assesses ten potential co-benefits and disservices. The initial assessment was derived from Eriksen et al. (2020) and Andersen et al. (2020), but subsequently adjusted based on expert knowledge available within the NORDBALT-ECOSAFE consortium. Also, some variables were added (soil health, consumption of fossil fuels) and the effects of the measures on these were also estimated based on expert knowledge available within the consortium. Positive effects, i.e. co-benefits, are indicated by "+", negative effects, i.e. disservices, are indicated by "-", and "0" indicates that there is no or a marginal effect. Accordingly,

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"+" indicates a reduction of methane emissions, N_2O emissions, consumption of fossil fuels, and phosphate emissions, but an increase in flood control, drought mitigation, soil health, carbon sequestration, sediment retention, and biodiversity.

Official and subsidized measures

Nowadays, many countries have a catalogue of official measures that are endorsed and potentially subsidized by the government. Therefore, the NORDBALT-ECOSAFE classification framework includes a section assessing which measures are official measures at national or regional level and which measures are subsidized in the six NORDBALT-ECOSAFE countries.

Measure	Official measure_Subsidized					
	DK	NO	SE	FI	LV	PL
Field mitigation measures						
Catch crops	nat_yes	nat_yes	nat_yes	nat_yes	nat_yes	nat_yes
Permanent set-aside	nat_yes	no_no	no_no	no_no	no_no	nat_yes
Set-aside in rotation	nat_yes	no_no	no_no	nat_no	nat_yes	nat_yes
Permanent grassland, meadows and pastures	nat_yes	no_no	no_no	no_no	nat_yes	nat_yes
Energy crops	nat_yes	no_no	no_no	no_no	no_no	nat_yes
Afforestation	nat_yes	no_no	no_no	no_no	no_no	nat_yes
Direct sowing	nat_yes	nat_yes	no_no	nat_yes	nat_yes	nat_yes
No or delayed tillage in autumn	nat_no	nat_yes	nat_yes	nat_no	no_no	nat_yes
Application of gypsum or structure lime	no_no	nat_no	nat_yes	no_yes	nat_yes	no_no
Precision fertilization (fertilizer & manure)	nat_yes	nat_no	nat_yes	nat_no	nat_yes	no_no
Reduced fertilizer use	no_no	nat_no	no_no	nat_no	no_no	nat_yes
Manure application regulations (time and amount)	nat_yes	nat_no	nat_no	yes_no	nat_no	nat_yes
Limits for N and P use in manure	nat_yes	no_no	no_no	nat_no	nat_no	no_no
Transport mitigation measures						
Surface flow constructed wetlands (on fields)	nat_yes	no_no	nat_yes	no_no	no_no	no_no
Restored wetlands	nat_yes	no_no	no_yes	nat_yes	no_no	nat_yes
Bioreactors with wood chips	nat_yes	no_no	no_no	no_no	no_no	no_no
Controlled drainage	no_no	no_no	no_yes	nat_yes	no_no	no_no
Inundation of meadows with drainage water	nat_yes	no_no	no_no	no_no	no_no	no_no
Grass buffer strips	nat_no	nat_yes	nat_yes	nat_yes	nat_yes	nat_yes
Buffer strips with trees	nat_yes	reg_yes	no_no	no_no	no_no	nat_yes
Integrated and Saturated Buffer Zones	no_no	no_no	no_no	no_no	no_no	no_no
Grassed waterways	no_no	nat_yes	nat_yes	no_no	no_no	nat_yes
Grass cover/no tillage in areas with high flood and/or erosion risk	no_no	reg_yes	nat_yes	nat_yes	nat_yes	nat_yes
In-stream mitigation measures						
Constructed wetlands	no_no	nat_yes	nat_yes	nat_yes	nat_yes	nat_yes
Retention ponds in forests	no_no	reg_yes	nat_yes	nat_yes	no_no	nat_yes
Re-meandering of river channels	nat_yes	no_no	nat_yes	nat_yes	no_no	nat_no
Two stage ditches and channels	no_no	no_no	nat_yes	nat_yes	no_no	no_no
Bank stabilization	no_no	no_no	nat_yes	nat_yes	no_no	nat_no
Stream bed re-naturalization	nat_yes	no_no	nat_yes	nat_yes	no_no	nat_no

Figure 4: Measures that are official measures at national or regional level ("nat", "reg" or "no" before the underscore) and measures that are subsidized ("yes" or "no" after the underscore)

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Implementation barriers

Even when a measure has been identified as suitable based on the pathways, co-benefits, and disservices, its implementation can be hampered by various factors. Including an assessment of the most relevant implementation barriers in the six NORDBALT-ECOSAFE countries allows potential users of the classification framework to take these barriers into consideration before they slow down the implementation of a measure or make it less cost-effective. In this section of the classification framework, the two-digit country codes are used to indicate which barriers are most relevant in which country according to the expert knowledge available within the NORDBALT-ECOSAFE consortium.

Measure	Implementation barriers								
	Lack of knowledge about measure	Loss of agricultural land	Limited availability of suitable land	High economic investment	Lack of subsidies	Complicated administrative processes	Ineffective or unclear regulations and policies	Lack of design and implementation guidance	Regular maintenance needs
Field mitigation measures									
Catch crops	NO, LV			DK	NO	LV		LV	DK, PL
Permanent set-aside		DK, SE, PL		DK					
Set-aside in rotation		SE, PL							
Permanent grassland, meadows and pastures							LV		LV
Energy crops		DK, PL						PL	PL
Afforestation		PL							PL
Direct sowing	NO, LV, PL		SE	NO, LV, PL	NO	NO		NO	
No or delayed tillage in autumn			NO, SE		NO				NO
Application of gypsum or structure lime	FI, LV		SE, FI					LV	
Precision fertilization (fertilizer & manure)	LV			LV, PL				LV	
Reduced fertilizer use						PL			
Manure application regulations (time and amount)				LV, PL		LV			PL
Limits for N and P use in manure				LV		LV			
Transport mitigation measures									
Surface flow constructed wetlands (on fields)		DK, SE	SE	SE		DK, SE	SE		
Restored wetlands	PL	DK, PL				DK		PL	
Bioreactors with wood chips									
Controlled drainage	DK		SE	SE	DK		DK	DK	DK, PL
Inundation of meadows with drainage water		SE							
Grass buffer strips	DK, LV	DK, NO, SE, LV	NO, SE, PL	NO, LV	DK, NO	LV		NO	DK, NO, LV
Buffer strips with trees	NO	NO, PL	NO		NO		NO	NO	NO, PL
Integrated and Saturated Buffer Zones	SE				DK				
Grassed waterways	NO, PL	NO, SE, PL	SE	NO	NO		PL		NO
Grass cover/no tillage in areas with high flood and/or erosion risk	LV	SE, PL			NO	LV		NO, LV	
In-stream mitigation measures									
Constructed wetlands	NO, LV, PL	SE, FI, LV, PL	SE, LV	NO, SE, LV		SE, LV	SE	NO, LV, PL	NO, FI, LV, PL
Retention ponds in forests					SE				PL
Re-meandering of river channels		PL	PL	PL	PL	PL	PL	PL	PL
Two stage ditches and channels	SE, FI	(FI), PL	SE, FI	SE		SE			FI
Bank stabilization									
Stream bed re-naturalization	PL				PL		PL		

Figure 5: Implementation barriers according to the expert knowledge of the NORDBALT-ECOSAFE consortium

Shortcomings of the classification framework

Two factors that were not included in the NORDBALT-ECOSAFE classification framework, even though they can have a significant impact on the selection of a measure, are the implementation

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costs and the reduction efficiencies. According to Tanner et al. (2023), the implementation costs depend on various factors, including design, construction, operation and maintenance costs, and loss of productive land, all of which vary between countries and based on site-specific environmental characteristics. While there are several studies published in the scientific literature that report reduction efficiencies, their findings are often highly site-specific and cannot be easily transferred to other sites, which may differ considerably in relevant environmental factors such as soil types, slopes, and climate. Both the implementation costs and the reduction efficiencies were initially included in the spreadsheet that was used to collect information from the six countries, but the available data was sparse and not comparable between measures and/or countries. Therefore, it was decided to exclude these factors from the initial version of the classification framework. This finding indicates that there is a need for additional studies that estimate reduction efficiencies under different environmental conditions and for modelling studies that can upscale the knowledge gained from field studies.

While the initial version of the classification framework includes a lot of information that is useful for selecting a measure, it does not provide a relative scoring system for comparison of different practices.

Info sheets

A detailed analysis of the classification framework during the NORDBALT-ECOSAFE mid-term meeting revealed that there are large differences between the countries in how measures are designed and implemented. Since there are already many fact sheets about almost all nutrient mitigation measures available online, it was decided that a comparison between the six NORDBALT-ECOSAFE countries would add more to the existing body of knowledge than additional fact sheets about the measures in a local context. Therefore, the consortium selected three measures, for which example “info sheets” were developed (see Appendix). These info sheets are expected to replace the fact sheets that were originally intended to be developed for each measure included in the classification framework. The goal is to eventually have an info sheet for each measure included in the classification framework, but the final selection depends on the availability of data and information. Also, new insights gained from the modelling in WP4 will be included in the existing and future info sheets.

Outlook

The NORDBALT-ECOSAFE classification framework is intended to be a dynamic document and it will be updated continuously over the second half of the project to reflect new findings from the project (i.e., reduction efficiencies from SWAT+, stakeholder preferences identified in the 2nd round of regional workshops to be held in autumn 2024), the scientific literature, and other reports. Furthermore, if more comprehensive and comparable data on implementation costs become available over the remaining project period, they may be included in future versions of the classification framework. Finally, the development of a more advanced scoring system for selected measures, e.g. an adjusted version of the system introduced by Tanner et al. (2023), will be considered within the consortium.

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The classification framework will be an integral part of a novel management support system for selection and placement of NBSs and MMs within catchments based on geo-spatial analysis tool and SWAT+ outputs, which will be developed and tested in the six NORDBALT-ECOSAFE demonstration river basins. The river basin management support system will assist in discussions of future solutions with stakeholders in river basins and thereby support river basins managers and stakeholders in reaching ecologically safe concentrations and loadings for water bodies.

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Appendix

Info Sheet: Catch Crops

Info Sheet: Buffer Strips

Info Sheet: Surface Flow Constructed Wetlands (field)

Info Sheet: Surface Flow Constructed Wetlands (in-stream)

Overview of the entire classification framework

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Nutrient mitigation measures in the Nordic-Baltic region

CATCH CROPS

Catch Crops are used to reduce nitrate leaching from soils that would otherwise be bare during the autumn and winter. They are sown in late summer and take up inorganic nitrogen from the soil during their growth period in early autumn. Catch crops can either be harvested in late autumn and the biomass used for fodder or bioenergy or they can be incorporated into the soil in late autumn to early spring to improve soil health and recycle part of the nitrogen.

This info sheet is part of a series that summarizes a comparative assessment of nutrient mitigation measures in six Nordic-Baltic countries (Denmark, Norway, Sweden, Finland, Latvia, Poland) carried out in the project NORDBALT-ECOSAFE.

Catch Crops are approved as a national mitigation measure and subsidized in Denmark (DK), Norway (NO), Sweden (SE), Finland (FI), Latvia (LV), and Poland (PL).

Effects on nutrient removal

Nutrient removal efficiency is an important criterion for selecting a suitable measure. Catch Crops mostly reduce nitrogen leaching. Their nitrogen removal efficiency depends on the type of crop, time of planting, time and method of removal, and whether they are fertilized.

Table 1: Nitrogen removal efficiency of Catch Crops

	DK	*NO*	*SE*	*FI*	*LV*	*PL*
Nitrogen removal efficiency [kg/ha]	12-32*; 24-45**	22				
Nitrogen removal efficiency [%]		48	25	32		

* <80 kg N/ha from manure; **>80 kg N/ha from manure

The nitrogen removal efficiency of Catch Crops differs considerably between countries. In Denmark, it was estimated in kg N/ha, whereas for Sweden and Finland, percentages have been reported and for Norway both.

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Design and implementation

The design and implementation can differ significantly between countries, which can impact the nutrient removal efficiency and the suitability of the measure under certain environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 2: Catch Crops used in the six NORDBALT-ECOSAFE countries and their time of sowing and removal

	Crops	*Time of sowing*	*Removal*
DK	Oil radish, honeywort, rye, yellow mustard, spring barley, grasses	Before or on 20 August	Incorporated into the soil between 20 October and 1 March
NO	Grasses, grass mixed with legumes or clover, Italian ryegrass, perennial ryegrass, white clover, oil radish, winter vetch, honeywort, rapeseed, white mustard, westerwolds ryegrass,	Undersown (together with or sometime after main crop) or after harvest	Harvested or incorporated into the soil, not before 1 March if sown after harvest of main crops
SE	Grasses and grass mixed with N-fixating crops (max 15%) if undersown; white mustard, oil radish, radish, winter rye and westerwolds ryegrass if sown after the main crop	Undersown or after harvest (before or on 15 August)	Removed using herbicides or incorporated into soil after 10 October in the north and 20 October in the south of Sweden, after 1 January if winter rye or westerwolds ryegrass
FI	Ryegrass, other grasses, clover, or mix of these plants	Undersown or after harvest (before or on 15 August)	Removed using herbicides after 15 September or incorporated into soil after 1 October, minimum growing period of 6 weeks
LV	Rapeseed, westerwolds ryegrass, white mustard, oil radish, oats, phacelia, buckwheat, vetch, rye, field beans, peas, or fodder radish (mixture of at least two)	After harvest (before or on 1 September)	Incorporated into the soil between 31 October and sowing of the following main crop
PL	Perennial ryegrass, winter vetch, incarnate clover, mustard, phacelia, buckwheat, field peas	Before or on 15 August	Incorporated into the soil after 15 February

There is a lot of variability in the crops used as Catch Crops, but oil radish and different kinds of ryegrass, clover, and mustard are used in several countries. Most commonly, Catch Crops must be planted in August or undersown during or after sowing of the main crop. Removal methods include harvest, incorporation into the soil, and killing of the crop using herbicides. Removal can occur as early as 15 September (Finland) and as late as sowing of the following main crop (Latvia).

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Implementation barriers

Implementation barriers can hamper the use of a nutrient mitigation measure even if it has a high nutrient reduction efficiency and is suitable for the local environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 3: Barriers to the implementation of Catch Crops

	DK	*NO*	*SE*	*FI*	*LV*	*PL*
Lack of knowledge about measure		x			x	
Loss of agricultural land						
Limited availability of suitable land						
High economic investment	x					
Lack of subsidies		x				
Complicated administrative processes					x	
Ineffective or unclear regulations or policies						
Lack of design and implementation guidance					x	
Regular maintenance needs	x					x

Catch crops are very well established in most countries in the Nordic-Baltic region and compared to other nutrient mitigation measures, there are relatively few implementation barriers to the use of Catch Crops. However, in Latvia there is still a *lack of knowledge about the measure* and a *lack of design and implementation guidance*, which could possibly be addressed with knowledge from other Nordic-Baltic countries.

Co-benefits and disservices

When selecting a measure, it is important to avoid trade-offs or pollution swapping and to consider co-benefits, which can increase the cost-effectiveness of measures.

Table 4: Co-benefits and disservices of Catch Crops according to the expert knowledge of the NORDBALT-ECOSAFE consortium ("-" indicates a negative impact, "+" indicates a positive impact, and "0" indicates that there is no or a marginal impact)

Flood control	0
Drought mitigation	0
Soil health	+
Methane emissions	0
N_2O emissions	+
Carbon sequestration	+
Consumption of fossil fuels	-
Sediment retention	+
Biodiversity	+
Phosphate emissions from soils	+

Catch Crops can improve *soil health*, reduce *N2O emissions* and *phosphate emissions from soils*, and increase *carbon sequestration*, *sediment retention,* and *biodiversity*. A possible disservice is increased *consumption of fossil fuels* when the Catch Crops are sown and harvested or incorporated into the soil.

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Additional information

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Nutrient mitigation measures in the Nordic-Baltic region

BUFFER STRIPS

Buffer Strips are established between fields and surface water bodies. The permanent vegetation slows down surface runoff, which results in deposition of sediment and sediment-bound nutrients and infiltration of dissolved nutrients into the soil, where they can be removed or adsorbed to soil particles.

This info sheet is part of a series that summarizes a comparative assessment of nutrient mitigation measures in six Nordic-Baltic countries (Denmark, Norway, Sweden, Finland, Latvia, Poland) carried out in the project NORDBALT-ECOSAFE.

Buffer Strips are approved as a national mitigation measure and subsidized in Denmark (DK), Norway (NO), Sweden (SE), Finland (FI), Latvia (LV), and Poland (PL).

Effects on nutrient removal

Nutrient removal efficiency is an important criterion for selecting a suitable measure. The nutrient removal efficiency of Buffer Strips is highly dependent on their width and vegetation type. but can also be affected by their soil type and slope.

Table 1: Nutrient removal efficiency of Buffer Strips

	DK	*NO*	*SE*	*FI*	*LV*	*PL*
Nitrogen removal efficiency [%]		16; 31; 78-89				7-99
Phosphorus removal efficiency [%]	32-74	23; 34; 76-89	5	27-97		76-81

The phosphorus removal efficiency of Buffer Strips measured in Denmark, Norway, and Finland varies within very wide ranges. In Poland, it was relatively high, whereas it was much lower in Sweden. In Norway, one study found a relatively low and another one a relatively high phosphorus removal efficiency. Data on the nitrogen removal efficiency of Buffer Strips was only available for Norway and Poland, where it ranges from very low to very high.

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Design and implementation

The design and implementation can differ significantly between countries or regions of a country (Norway), which can impact the nutrient removal efficiency and the suitability of the measure under certain environmental conditions. Comparisons can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 2: Width, vegetation, and maintenance of Buffer Strips

	Width	*Vegetation*	*Maintenance*
DK	3 m along public water courses	Grasses or herbs	Annual cutting without removal of biomass required
NO	Mandatory: 2 m natural BS; optional: 5-6 m (meadows) or 10-12 m (fields) grass BS	Grasses, herbs, bushes, trees	Natural BS: optional cutting of individual trees; grass BS: Cutting with or without removal of biomass required
SE	6 m	Grasses, up to 15% N-fixating crops	Cutting of grass allowed (except 1 April to 30 June)
FI	3 m	Grasses	Annual cutting and removal of vegetation before 31 August, grazing allowed
LV	4 m along ditches; 8 m along streams and rivers	Grasses, wildflowers, hemp, sunflowers	Annual cutting and removal of vegetation before 15 September
PL	3 m	Not specified	no information

The buffer width is largest in Norway, and larger in Sweden and Latvia than the remaining countries. In most countries, the vegetation is limited to grasses, herbs, or wildflowers, but bushes and trees are allowed in Norway (but not subsidized) and Poland. In Sweden, the grass may be mixed with N-fixating crops, whereas in Latvia, oilseeds may be planted.

Implementation barriers

Implementation barriers can hamper the use of a nutrient mitigation measure even if it has a high nutrient reduction efficiency and is suitable for the local environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 3: Barriers to the implementation of Buffer Strips

	DK	*NO*	*SE*	*FI*	*LV*	*PL*
Lack of knowledge about measure	x				x	
Loss of agricultural land	x	x	x		x	
Limited availability of suitable land		x	x			x
High economic investment		x			x	
Lack of subsidies	x	x				
Complicated administrative processes					x	
Ineffective or unclear regulations or policies						
Lack of design and implementation guidance		x				
Regular maintenance needs	x	x			x	

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Loss of agricultural land is a relevant implementation barrier in most NORDBALT-ECOSAFE countries. *Limited availability of suitable land* and *regular maintenance needs* are also relevant barriers in several countries. Denmark, Latvia and especially Norway are facing more implementation barriers than Sweden, Finland, and Poland.

Co-benefits and disservices

When selecting a measure, it is important to avoid trade-offs or pollution swapping and to consider co-benefits, which can increase the cost-effectiveness of measures.

Table 4: Co-benefits and disservices of Buffer Strips according to the expert knowledge of the NORDBALT-ECOSAFE consortium ("-" indicates a negative impact, "+" indicates a positive impact, and "0" indicates that there is no or a marginal impact)

Flood control	0
Drought mitigation	0
Soil health	+
Methane emissions	0
N_2O emissions	0
Carbon sequestration	+
Consumption of fossil fuels	-
Sediment retention	+
Biodiversity	+
Phosphate emissions from soils	0

Buffer Strips have a positive impact on *soil health*, *carbon sequestration*, *sediment retention* and *biodiversity*, but can result in increased *consumption of fossil fuels* if the vegetation is cut more often than agricultural crops.

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Nutrient mitigation measures in the Nordic-Baltic region

SURFACE FLOW CONSTRUCTED WETLANDS (field)

Surface Flow Constructed Wetlands on fields (Field SFCWs) are engineered systems that replicate the processes occurring in natural wetlands. The main nutrient removal processes are denitrification and sedimentation. Field SFCWs in the Nordic-Baltic region typically receive flow from sub-surface drainage systems.

This info sheet is part of a series that summarizes a comparative assessment of nutrient mitigation measures in six Nordic-Baltic countries (Denmark, Norway, Sweden, Finland, Latvia, Poland) carried out in the project NORDBALT-ECOSAFE.

Field SFCWs are approved as a national mitigation measure and subsidized in Denmark (DK) and Sweden (SE).

Effects on nutrient removal

Nutrient removal efficiency is an important criterion for selecting a suitable measure. The nutrient removal efficiency of Field SFCWs depends on many factors, e.g., their design (wetland-catchment ratio, number of zones, vegetation), incoming flow and nutrient loads, temperature, and the Fe:P ratio.

Table 1: Nutrient removal efficiency of Field SFCWs

	DK	*SE*
Nitrogen removal efficiency [%]	22	20
Phosphorus removal efficiency [%]	45	33

The nitrogen removal efficiency of Field SFCWs in Denmark and Sweden is very similar, while the phosphorus removal efficiency is higher in Denmark than in Sweden.

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Design and implementation

The design and implementation can differ significantly between countries, which can impact the nutrient removal efficiency and the suitability of the measure under certain environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 2: Design and dimensions of Field SFCWs

	Design	*Dimensions*
DK	Four zones: 1 sedimentation pond and 3 additional ponds (0.85-1.15 m deep) separated by shallow vegetated lagoons (0.25-0.40 m deep)	Wetland area: 1-1.5% of catchment area
SE	Phosphorus retention SFCWs: a deep sedimentation pond and a shallow, vegetated pond; nitrogen retention SFCWs: One vegetated zone	Dependent on hydraulic load and nutrient concentration. A map tool is available for estimation at any location in Sweden.

There are very precise recommendations available for the design and dimensions of Field SFCWs in Denmark. In Sweden, the design depends on the primary purpose of the wetland and the dimensions is adjusted to the hydraulic load and nutrient concentration.

Implementation barriers

Implementation barriers can hamper the use of a nutrient mitigation measure even if it has a high nutrient reduction efficiency and is suitable for the local environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 3: Barriers to the implementation of Field SFCWs

	DK	*SE*
Lack of knowledge about measure		
Loss of agricultural land	x	x
Limited availability of suitable land		x
High economic investment		x
Lack of subsidies		
Complicated administrative processes	x	x
Ineffective or unclear regulations or policies		x
Lack of design and implementation guidance		
Regular maintenance needs		

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Loss of agricultural land and *complicated administrative processes* are implementation barriers in both countries. In Sweden, the implementation of Field SFCWs is also hampered by *limited availability of suitable land*, *high economic investments* (despite subsidies), and *ineffective or unclear regulations or policies*.

Co-benefits and disservices

When selecting a measure, it is important to avoid trade-offs or pollution swapping and to consider co-benefits, which can increase the cost-effectiveness of measures.

Table 4: Co-benefits and disservices of Field SFCWs according to the expert knowledge of the NORDBALT-ECOSAFE consortium ("-" indicates a negative impact, "+" indicates a positive impact, and "0" indicates that there is no or a marginal impact)

Flood control	0
Drought mitigation	0
Soil health	0
Methane emissions	-
N_2O emissions	-
Carbon sequestration	0
Consumption of fossil fuels	0
Sediment retention	+
Biodiversity	+
Phosphate emissions from soils	0

Field SFCWs can have a positive impact on *sediment retention* and *biodiversity* but can result in increased *methane* and *N_2O emissions*.

Additional information

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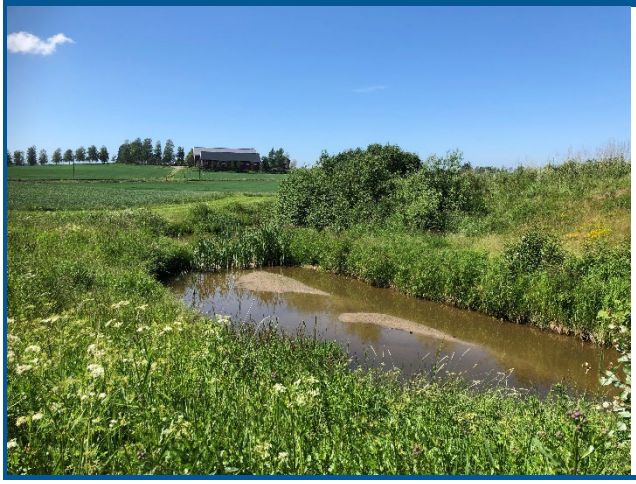
Nutrient mitigation measures in the Nordic-Baltic region

SURFACE FLOW CONSTRUCTED WETLANDS (in-stream)



In-stream Surface Flow Constructed Wetlands (In-stream SFCWs) are engineered systems that replicate the processes occurring in natural wetlands. The main nutrient removal processes are denitrification and sedimentation. In-stream Surface Flow Constructed Wetlands in the Nordic-Baltic region are constructed by damming or widening the natural stream and establishing different zones for the water to flow through.

This info sheet is part of a series that summarizes a comparative assessment of nutrient mitigation measures in six Nordic-Baltic countries (Denmark, Norway, Sweden, Finland, Latvia, Poland) carried out in the project NORDBALT-ECOSAFE.

In-stream SFCWs are approved as a national mitigation measure and subsidized in Norway (NO), Sweden (SE), Finland (FI), Latvia (LV), and Poland (PL).

Effects on nutrient removal

Nutrient removal efficiency is an important criterion for selecting a suitable measure. The nutrient removal efficiency of In-stream SFCWs depends on many factors including their design (wetland-catchment ratio, number of zones, vegetation), incoming flow and nutrient load and temperature.

Table 1: Nutrient removal efficiency of In-stream Surface Flow Constructed Wetlands

	NO	*SE*	*FI*	*LV*	*PL*
Nitrogen removal efficiency [%]			14-54	15	63
Phosphorus removal efficiency [%]	16; 22	33	34	32	19

The nitrogen removal efficiency of In-stream SFCWs is much higher in Poland than in Latvia and it varies within a relatively large range in Finland. The phosphorus removal efficiency is similar in Sweden, Finland, and Latvia, while lower efficiencies were observed in two studies in Norway and in Poland.

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Design and implementation

The design and implementation can differ significantly between countries, which can impact the nutrient removal efficiency and the suitability of the measure under certain environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 2: Design and dimensions of In-stream SFCWs

	Design	*Dimensions*
NO	Sedimentation pond (1.5-2 m deep), sprinkling zone, one or more vegetated zones (0.5 m deep)	Wetland area: approximately 0.1-1% of catchment area
SE	No official guidelines	No official guidelines
FI	Deep ponds (>1 m deep) at inlet and outlet, one or more shallow zones with islands in between	Wetland area: at least 1% of catchment area
LV	At least 50% of surface area must be vegetated, 0.5-1.5 m deep	Wetland area: 0.5-2% of catchment area
PL	Three zones: sedimentation and microbial activity, biogeochemical barrier for phosphate fixation, plant biofiltration	No official guidelines

There are very precise recommendations available for the design and dimensions of In-stream SFCWs in Norway. In Poland, the information about the design is specific to one case study. The required wetland area to catchment area ratio is highest in Latvia and lowest in Norway, where the size of the wetlands is often limited by the rough topography.

Implementation barriers

Implementation barriers can hamper the use of a nutrient mitigation measure even if it has a high nutrient reduction efficiency and is suitable for the local environmental conditions. Comparisons between countries can reveal potential to learn from other countries and increase the likelihood that a measure will be implemented.

Table 3: Barriers to the implementation of In-stream SFCWs

	NO	*SE*	*FI*	*LV*	*PL*
Lack of knowledge about measure	x			x	x
Loss of agricultural land		x	x	x	x
Limited availability of suitable land		x		x	
High economic investment	x	x		x	
Lack of subsidies					
Complicated administrative processes		x		x	
Ineffective or unclear regulations or policies		x			
Lack of design and implementation guidance	x			x	x
Regular maintenance needs	x		x	x	x

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There are many implementation barriers potentially hampering the use of In-stream SFCWs, especially in Latvia and Sweden. *Loss of agricultural land* and *regular maintenance needs* are implementation barriers in several countries. *Lack of knowledge about measure* and *lack of design and implementation guidance* are in Latvia and Poland, while updated and more practical information is needed in Norway. *High economic investment* is a relevant barrier in several countries as well (Norway, Sweden, and Latvia).

Co-benefits and disservices

When selecting a measure, it is important to avoid trade-offs or pollution swapping and to consider co-benefits, which can increase the cost-effectiveness of measures.

Table 4: Co-benefits and disservices of In-stream SFCWs according to the expert knowledge of the NORDBALT-ECOSAFE consortium ("-" indicates a negative impact, "+" indicates a positive impact, and "0" indicates that there is no or a marginal impact)

Flood control	0
Drought mitigation	0
Soil health	n/a
Methane emissions	-
N_2O emissions	0
Carbon sequestration	0
Consumption of fossil fuels	n/a
Sediment retention	+
Biodiversity	+
Phosphate emissions from soils	0

In-stream SFCWs can have a positive impact on *sediment retention* but result in an increase in *methane emissions.* Even though they can in some cases reduce fish migration, they have an overall positive impact on *biodiversity* as they provide a habitat for several endangered species (e.g., salamanders and dragonflies).

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NORDBALT ECOSAFE

Overview of the entire classification framework

Measure	Pathway					Co-benefits and disservices										Official measure?						Subsidized?						Implementation barriers								
	Leaching from root zone	Surface runoff	Tile flow	Groundwater flow	Stream flow	Flood control	Drought mitigation	Soil health	Methane emissions	N2O emissions	Carbon sequestration	Consumption of fossil fuels	Sediment retention	Biodiversity	Phosphate emissions from soils	DK	NO	SE	FI	LV	PL	DK	NO	SE	FI	LV	PL	Lack of knowledge about measure	Loss of agricultural land	Limited availability of suitable land	High economic investment	Lack of subsidies	Complicated administrative processes	Ineffective or unclear regulations and policies	Lack of design and implementation guidance	Regular maintenance needs
Field mitigation measures																																			
Catch crops	x		x	x		0	0	+	0	+	+	-	+	+	+	nat	nat	nat	nat	nat	nat	yes	yes	yes	yes	yes	yes	NO, LV			DK	NO	LV		LV	DK, PL
Permanent set-aside	x	x	x	x		0	0	+	0	+	+	-	+	+	0	nat	no	no	no	no	nat	yes	no	no	no	no	yes		DK, SE, PL		DK					
Set-aside in rotation	x	x	x	x		0	0	+	0	0	0	-	+	0	0	nat	no	no	nat	nat	nat	yes	no	no	no	yes	yes		SE, PL							
Permanent grassland, meadows and pastures	x	x	x	x		+	0	+	0	+	+	-	+	+	+	nat	no	no	no	nat	nat	yes	no	no	no	yes	yes							LV		LV
Energy crops	x	x	x	x		0	0	0	0	0	+	-	+	+	+	nat	no	no	no	no	nat	yes	no	no	no	no	yes		DK, PL						PL	PL
Afforestation	x	x	x	x		0	0	+	0	+	+	-	+	+	+	nat	no	no	no	no	nat	yes	no	no	no	no	yes		PL							PL
Direct sowing	x	x	x	x		0	0	+	0	0	+	-	+	+	0	nat	nat	no	nat	nat	nat	yes	yes	no	yes	yes	yes	NO, LV, PL		SE	NO, LV, PL	NO	NO		NO	
No or delayed tillage in autumn	x	x				0	0	+	0	0	0	-	+	+	0	nat	nat	nat	nat	no	nat	no	yes	yes	no	no	yes			NO, SE		NO				NO
Application of gypsum or structure lime	x					0	0		0	0	0	+	+	0	+	no	nat	nat	no	nat	no	no	no	yes	yes	yes	no	FI, LV		SE, FI					LV	
Precision fertilization (fertilizer & manure)	x		x	x		0	0	+	0	0	+	0	0	0	+	nat	nat	nat	nat	nat	no	yes	no	yes	no	yes	no	LV			LV, PL				LV	
Reduced fertilizer use	x		x	x		0	0	0	0	+	0	0	0	0	+	no	nat	no	nat	no	nat	no	no	no	no	no	yes						PL			
Manure application regulations (time and amount)	x	x	x	x		0	0	0	0	+	0	0	0	0	+	nat	nat	nat	yes	nat	nat	yes	no	no	no	no	yes				LV, PL		LV			PL
Limits for N and P use in manure	x	x	x	x		0	0	0	0	+	0	0	0	0	+	nat	no	no	nat	nat	no	yes	no	no	no	no	no				LV		LV			
Transport mitigation measures																																			
Surface flow constructed wetlands (on fields)			x			0	0	0	-	-	0	0	+	+	0	nat	no	nat	no	no	no	yes	no	yes	no	no	no		DK, SE	SE	SE		DK, SE	SE		
Restored wetlands			x	x	x	+	+	+	-	-	+	-	+	+	+	nat	no	no	nat	no	nat	yes	no	yes	yes	no	yes	PL	DK, PL				DK		PL	
Bioreactors with wood chips			x			0	0	0	-	-	-	0	+	0	-	nat	no	no	no	no	no	yes	no	no	no	no	no									
Controlled drainage	x		x			+	+	+	0	0	0	0	+	0	+	no	no	no	nat	no	no	no	no	yes	yes	no	no	DK		SE	SE	DK		DK	DK	DK, PL
Inundation of meadows with drainage water			x			+	+	+	-	-	+	-	+	+	-	nat	no	no	no	no	no	yes	no	no	no	no	no		SE							
Grass buffer strips		x				0	0	+	0	0	+	-	+	+	0	nat	nat	nat	nat	nat	nat	no	yes	yes	yes	yes	yes	DK, LV	DK, NO, SE, LV	NO, SE, PL	NO, LV	DK, NO	LV		NO	DK, NO, LV
Buffer strips with trees		x			x	0	0	+	0	0	+	-	+	+	0	nat	reg	no	no	no	nat	yes	yes	no	no	no	yes	NO	NO, PL	NO		NO		NO	NO	NO, PL
Integrated and Saturated Buffer Zones		x	x			0	0	+	0	0	+	-	+	+	0	no	no	no	no	no	no	no	no	no	no	no	no	SE				DK				
Grassed waterways		x				+	0	+	0	0	+	-	+	+	0	no	nat	nat	no	no	nat	no	yes	yes	no	no	yes	NO, PL	NO, SE, PL	SE	NO	NO		PL		NO
Grass cover/no tillage in areas with high flood and/or erosion risk		x				0	0	+	0	0	+	-	+	+	0	no	reg	nat	nat	nat	nat	no	yes	yes	yes	yes	yes	LV	SE, PL			NO	LV		NO, LV	
In-stream mitigation measures																																			
Constructed wetlands					x	0	0	n/a	-	0	0	n/a	+	+	0	no	nat	nat	nat	nat	nat	no	yes	yes	yes	yes	yes	NO, LV, PL	SE, FI, LV, PL	SE, LV	NO, SE, LV		SE, LV	SE	NO, LV, PL	NO, FI, LV, PL
Retention ponds in forests		x			x	+	0	n/a	0	0	0	n/a	+	+	0	no	reg	nat	nat	no	nat	no	yes	yes	yes	no	yes					SE				PL
Re-meandering of river channels					x	+	+	n/a	0	0	0	n/a	-	+	-	nat	no	nat	nat	no	nat	yes	no	yes	yes	no	no		PL	PL	PL	PL	PL	PL	PL	PL
Two stage ditches and channels					x	+	0	n/a	0	0	0	n/a	+	+	0	no	no	nat	nat	no	no	no	no	yes	yes	no	no	SE, FI	(FI), PL	SE, FI	SE		SE			FI
Bank stabilization					x	0	0	n/a	0	0	0	n/a	+	0	0	no	no	nat	nat	no	nat	no	no	yes	yes	no	no									
Stream bed re-naturalization					x	0	0	n/a	0	0	0	n/a	0	+	0	nat	no	nat	nat	no	nat	yes	no	yes	yes	no	no	PL				PL		PL		

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