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Assessing ecosystem services of wetlands in the Neman catchment in the perspective of their restoration

Ocena usług ekosystemów obszarów podmokłych w zlewni Niemna w perspektywie ich odtworzenia

Master Thesis
In the study program of Environmental Protection

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Oświadczenie promotora pracy

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Summary

Assessing ecosystem services of wetlands in the Neman catchment in the perspective of their restoration

The aim of the study was to evaluate selected regulating ecosystem services of wetlands in the Neman catchment in the perspective of their restoration. Ecosystem services were quantified as a trade-off between the management and environmental conservation. The following ecosystem services were analyzed: water retention, nitrogen removal, carbon sequestration. The analyses have indicated that restoration of drained peatlands would increase water retention in the study area by 120 M m^3 which gives approximately 0.7% of the total river runoff of Neman. The total loss of nitrogen from the upland areas in the Neman basin is 724.3 M kg TN · $year^{-1}$, of which 311.5 M kg TN · $year^{-1}$ is removed by wetland buffer zones. This allows to draw a conclusion, that restoration of peatlands could contribute to the reduction of nitrogen load reaching the Baltic Sea. The cost-benefit analysis proves that the costs incurred for the restoration are an investment for the future. The study opens up a new field for research on ecosystem services.

Key words – ecosystem services, wetlands, peatlands, restoration, water retention, nitrogen removal

Streszczenie

Ocena usług ekosystemów obszarów podmokłych w zlewni Niemna w perspektywie ich odtworzenia

Celem pracy była ocena wybranych regulujących usług ekosystemowych mokradeł w zlewni Niemna w perspektywie ich odtworzenia. Usługi ekosystemów zostały określone jako kompromis pomiędzy zarządzaniem a ochroną środowiska. Przeanalizowano następujące usługi ekosystemowe: retencja wody, usuwanie azotu, sekwestracja węgla. Analizy wykazały, że odtworzenie odwodnionych torfowisk zwiększyłoby retencję wody na badanym obszarze o 120 mln m^3, co daje około 0,7% całkowitego odpływu Niemna. Dostawa azotu ze zlewni Niemna wynosi 724,3 mln kg TN · rok^{-1}, z czego 311,5 mln kg TN · rok^{-1} jest usuwane przez bagienne strefy buforowe. Pozwala to na wyciągnięcie wniosku, że odbudowa torfowisk może przyczynić się do zmniejszenia ładunku azotu docierającego do Morza Bałtyckiego. Analiza kosztów i korzyści dowodzi, że koszty poniesione na odtworzenie torfowisk są inwestycją na przyszłość. Badanie otwiera nowe pole do badań nad usługami ekosystemów.

Słowa kluczowe – usługi ekosystemowe, mokradła, torfowiska, renaturyzacja, retencja wody, usuwanie azotu

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1. Introduction

Ecosystem services are fundamental for human well-being (Costanza et al., 2014). The degradation of natural ecosystems across the globe has contributed to the change in perception of nature and it was found that they may act as a source of certain economic benefits (Wichmann et al., 2016). The monetary valuation of ecosystem services gives an insight into the importance of conservation of nature and it is a useful measure in decision-making (Kaval, 2019).

A wetland is an ecosystem which is temporarily or constantly saturated or inundated by water. They may occur with or without peat and in this regard not all wetlands are peatlands (Joosten, 2016). The total area of wetlands across the globe is 12.1 million km^2 (Ramsar Convention on Wetlands, 2018). Wetlands are one of the most important and valuable ecosystems in the world and they are vital for human well-being (Clarkson et al., 2013; Xu et al., 2020). Human activity and expansion led to enormous losses of wetland ecosystems. The loss of wetlands in Europe is estimated to the amount of 80% of their original area (Verhoeven, 2014). Degradation of these ecosystems occurred mainly because of drainage, for agricultural and forestry purposes and for peat extraction. These actions negatively affect the quantity and quality of ecosystem services provided by wetlands and they lead to changes in soil properties, water conditions and vegetation cover (Similä et al., 2014; Glina et al., 2018). They also cause disrupted carbon cycle and increased fire risk. Therefore, it is crucial to protect natural wetlands and restore the degraded ones (Glina et al., 2018). Wetland restoration aims at the permanent re-establishment of the wetland ecosystem that was previously disturbed, including hydrological and biogeochemical processes, as well as the plant cover. This implies that rewetting of the drained wetlands is necessary for the process of restoration (Renou-Wilson et al., 2018). Overall, wetlands are critical for the delivery of ecosystem services and they contribute to 40.6% of the total global ES value (Xu et al., 2020). They are particularly important for human survival and sustainable development (Ramsar Convention on Wetlands, 2018).

Main goal of this thesis was an attempt to quantification of potential gains to be achieved in the process of restoration of wetlands in the transboundary catchment of the river Neman. This challenging task included an extensive work in data collection, analysis and development of original approaches to quantification of costs and benefits of wetland restoration, for the sake of society, ecosystems and the Baltic Sea.

2. The goal and scope of the study

The aim of the study was to evaluate selected regulating ecosystem services of wetlands in the Neman River catchment in the perspective of their restoration. Services provided by wetlands that will be analyzed are: water retention, nitrogen removal and carbon accumulation. Ecosystem services were quantified as a trade-off between the management and environmental conservation.

This assessment provided valuable information on importance of wetlands not only in the Neman catchment area, but also in the global scale. It showed environmental and economic benefits that people can gain from these ecosystems and how important it is to keep them in as natural state as possible. The work gave a view on the restoration of degraded wetlands and the changes these measures may bring to human well-being. In particular, research approach provided in the thesis covered the following steps:

- introduction to the subject of the study,
- description of the research area and its characteristics,
- description of the methodology used for the transformation and selection of the peatlands database for the purpose of the analyses,
- description of the methodology used to calculate selected ecosystem services,
- presentation of the obtained results,
- discussion on the results,
- conclusions drawn from the carried out analyses.

3. Material and methods

3.1. Role of wetlands

Wetlands provide many ecosystem services, including food, fresh water, raw materials and fuel supply (Clarkson et al., 2013). They increase biodiversity and they are a valuable habitat for many species (Xu et al., 2020). Wetlands take part in many processes in the water cycle, including maintaining groundwater levels in aquifers, storing water from precipitation events, regulating discharge and modulating both low and high stream flows (TEEB, 2013; Price et al., 2016; Bourgault et al., 2017; Jones et al., 2017). Their features and characteristics allow supporting human safety and well-being through attenuation of floods. Therefore, they may be a natural and cost-effective alternative for human-made infrastructure built for flood protection (TEEB, 2013; Ramsar Convention on Wetlands, 2018). Wetlands also provide other water-related ecosystem services, such as water quality regulation (Price et al., 2016). They are responsible for removal of nutrients, nitrogen and phosphorus, whose main source is from agriculture (Walton et al., 2020). This ability allows reducing nutrient loads in water locally, regionally and in larger scales, which further prevents the process of degradation and eutrophication in water bodies.

Another very important function of wetlands is climate regulation. Peatlands are the most important terrestrial ecosystems in terms of carbon storage (Joosten et al., 2016). Through their ability to sequester atmospheric CO_2, wetlands play a vital role in global climate change mitigation and they help in adapting to its impacts (Were et al., 2019). Besides providing mentioned regulating, supporting and provisioning ecosystem services, wetlands also deliver cultural ES. They may be used for recreation and ecotourism and they have aesthetic and educational values (Xu et al., 2020).

3.2. Research area

Research area of the study is the Neman River catchment. It is located in Eastern Europe and covers 5 countries: Lithuania (47.7% of the basin area), Belarus (46.4%), Russia (Kaliningrad Oblast) (3.2%), Poland (2.6%) and Latvia (0.1%) (Rimkus et al., 2013; Stonevičius et al., 2017). The estimated drainage area of the river varies between 95 753 and 98 200 km^2 (Domnin et al., 2014; Stonevičius et al., 2017). Based on HELCOM data and Polish official hydrological data, for the purpose of this study, it is assumed that the area of the basin is 95 753 km^2 and Latvia is not part of the catchment (Fig. 1). The Neman River (954 km) has its source in Belarus and its mouth in the Curonian Lagoon, which is separated from the Baltic Sea by the Curonian spit.

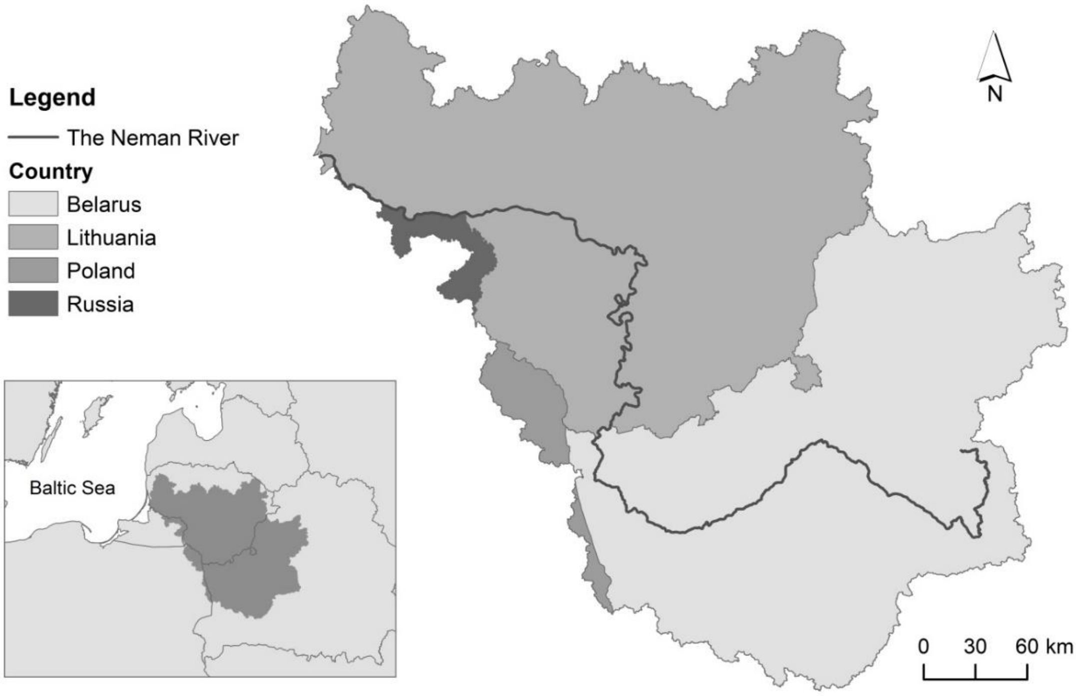

Fig. 1. The Neman River catchment drainage area (CCM River and Catchment Database © European Commission - JRC, 2007)

Fig. 2. A drained peatland in Polish part of the Neman basin (photo: Krystian Kamiński)

The river flows through Belarus and Lithuania, partially forming border between these countries and between Lithuania and Russia. Hydrographic network of the Neman catchment is extensive. Neman has many tributaries along its length, which also have tributaries of higher orders. Tylzha and Shesupe are the main tributaries of the left bank of the Neman River, while

Minija, Jura, Nevėžis, Vilia and Merkys are the main tributaries of the right bank (Domnin et al., 2014). Average discharge of Neman at the confluence to the Baltic sea reaches some 535 m^3/s (Glazaciovaite et al., 2012).

The Neman River catchment has continental climate (Dubra et al., 2013). Mean annual air temperature varies between 5.5°C and 6.5°C, and the variations among the coldest and warmest months range within 22–33°C (Sileika et al., 2006; Dubra et al., 2013). January is the coldest month in the basin area, with temperature from –9 to –4.5°C. The hottest month is July, with mean temperature from 17°C to 19°C, with a maximum 34–37°C (Dubra et al., 2013). The annual precipitation in the Neman catchment ranges between 520 and 900 mm (Sileika et al., 2006; Rimkus et al., 2013). The annual evaporation varies from 450 to 600 mm (Rimkus et al., 2013). One of the most important factors influencing intensity of liquid precipitation in the Neman basin is the distance from the Baltic Sea, especially during winter (Stonevičius et al., 2017). Based on the Global Average Annual Surface Runoff data computed for years 1950-2000, the annual average surface runoff in the studied area is 166 mm (Fekete et al., 2002).

The Neman River catchment is mainly covered by sand and sandy clay, predominantly in the northwest and southeastern parts of the basin (Stonevičius et al., 2017). The landscape of the area was formed during quaternary period and the retreat of the glacier contributed to the uneven terrain (Sileika et al., 2006; Stonevičius et al., 2017). The whole basin is covered by 100–200 m thick layer of sandy-gravel moraine and it is intersected by the Baltic Moraine Ridge (Sileika et al., 2006). In the eastern section of the area the altitudes range from 150–200 m and gradually decrease towards the sea, ending with a few meters above the sea level in the Neman delta area (Stonevičius et al., 2017).

However, based on the SOTER database (Soil and Terrain Database for Central and Eastern Europe, SOVEUR, version 1.1) (Hengl et al., 2017), most of the Neman catchment is covered by sandy loam (68.7%) and loam (23.7%) (Fig. 3). Loamy sand and silty loam take 7.2% and 0.3% of the basin, respectively. Area covered by sand, clay loam and silty clay-loam is minor.

Agriculture is the dominant form of land use in the Neman River catchment, taking about 57% of its area (NCM, 2017). Approximately 35% of the basin is covered by forests, mainly coniferous. Lakes cover about 1.5% of the catchment and about 20% of the area is covered by swamps, bogs and wet forests (Rimkus et al., 2013).

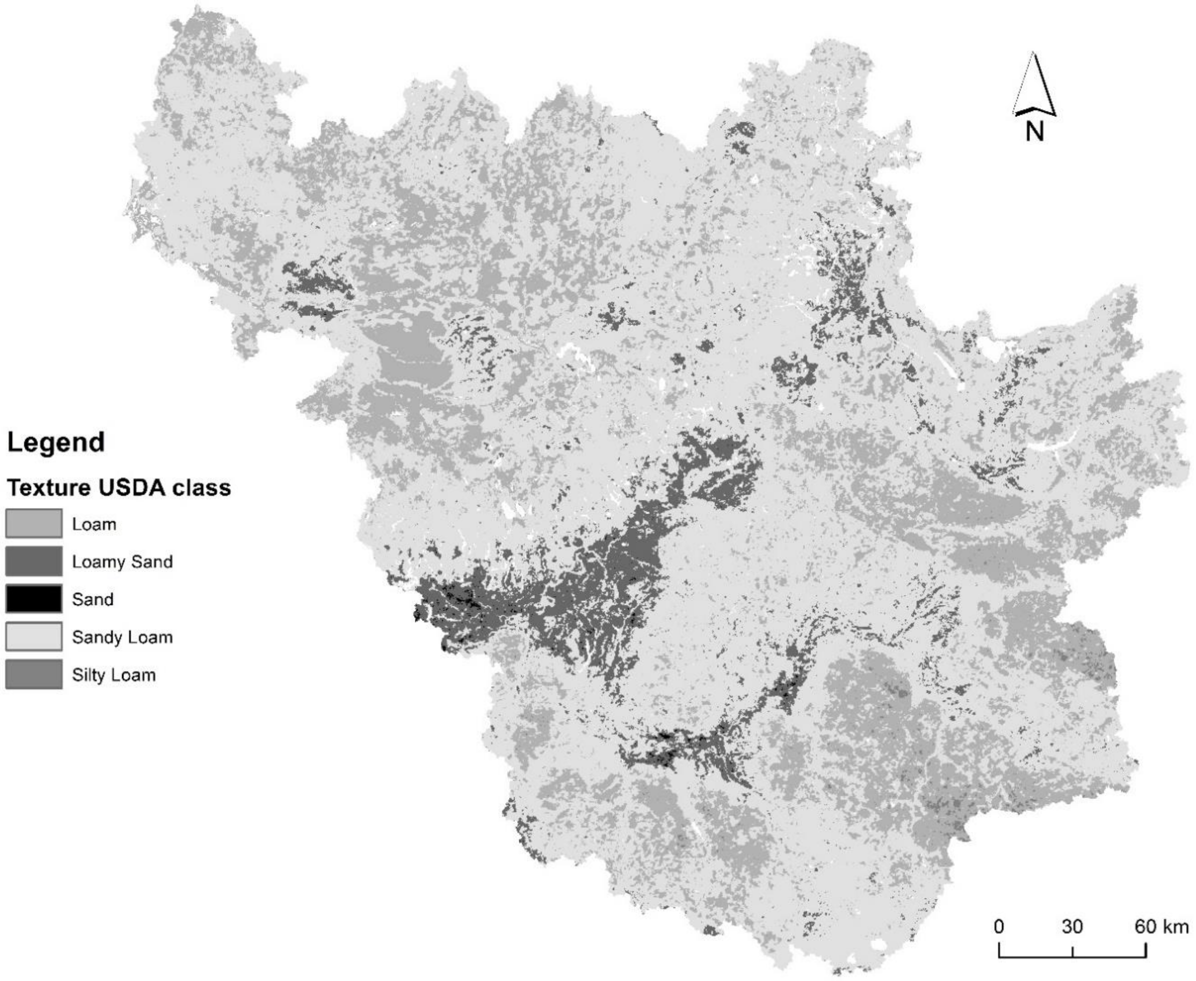

Fig. 3. Map of USDA soil textural classes in the Neman catchment (Soil and Terrain Database for Central and Eastern Europe, SOVEUR, version 1.1) (Hengl et al., 2017)

According to the MODIS-based Global Land Cover (Broxton et al., 2014), agricultural areas cover approximately 68% of the Neman basin, of which 33% are croplands and 35% are croplands with natural vegetation mosaic (Fig. 4). Based on the data, about 30% of the research area is covered by forests, including mixed forests (24%) and evergreen needle leaf forests (6%). The area taken by deciduous needle leaf forests and deciduous broadleaf forests is very small. Water and urban areas cover approximately 0.4% and 0.6%, respectively. Permanent wetlands may also be found in the catchment, taking about 0.4% of its surface. Grasslands cover only about 0.2% of the area.

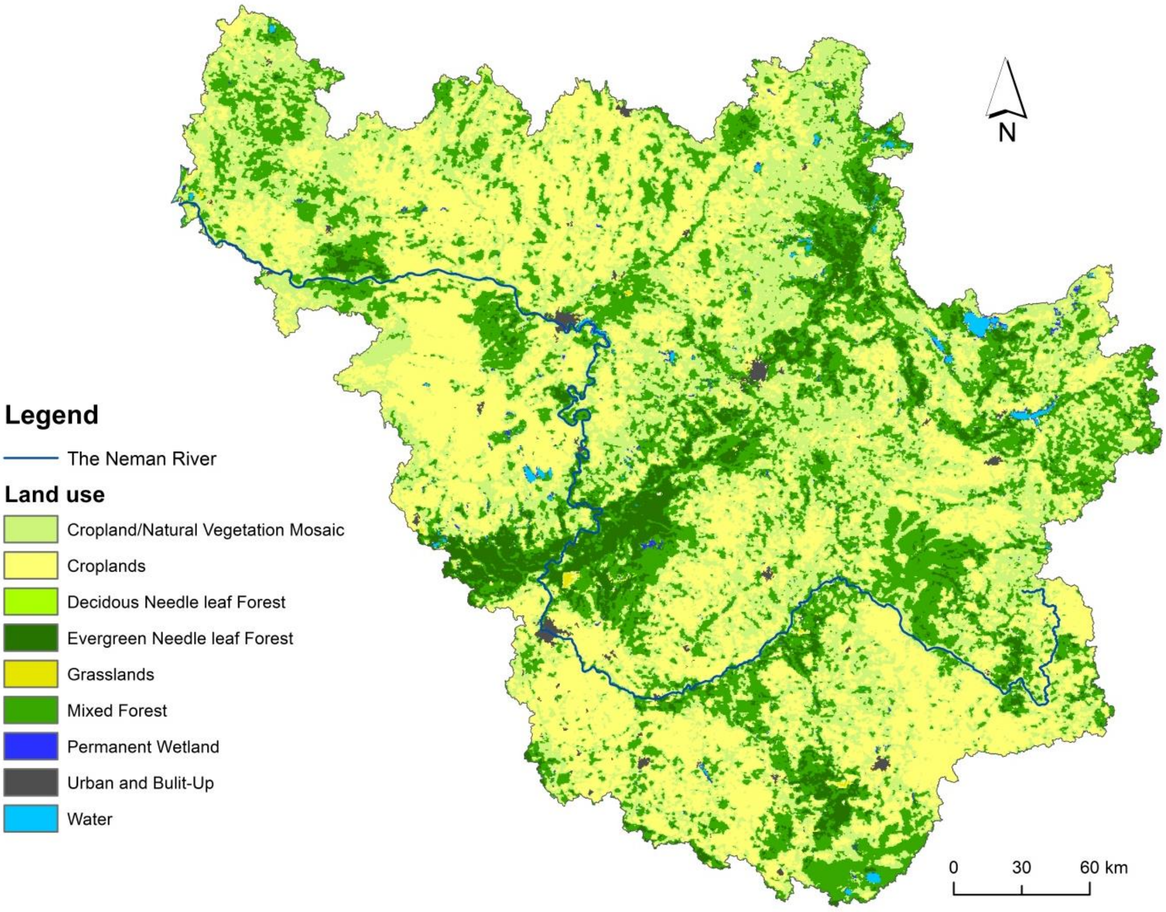

Fig. 4. Land use in the Neman catchment (Broxton et al., 2014)

Fig. 5. A fen in Kaliningrad Oblast, Russia

3.3. Data input and analysis

The basic data for the study was obtained from HELCOM (CCM River and Catchment Database © European Commission - JRC, 2007). Polish borders of the catchment were further corrected based on the Polish official hydrological data. Wetlands database was collected from the partners of the DESIRE Project, supported by Interreg Baltic Sea Region (Development of Sustainable (adaptive) peatland management by Restoration and paludiculture for nutrient retention and other ecosystem services in the Neman river catchment).

Calculations and analysis of the studied peatlands were done using GIS software. To carry out the analysis, peatlands database had to undergo certain alterations (Fig. 6).

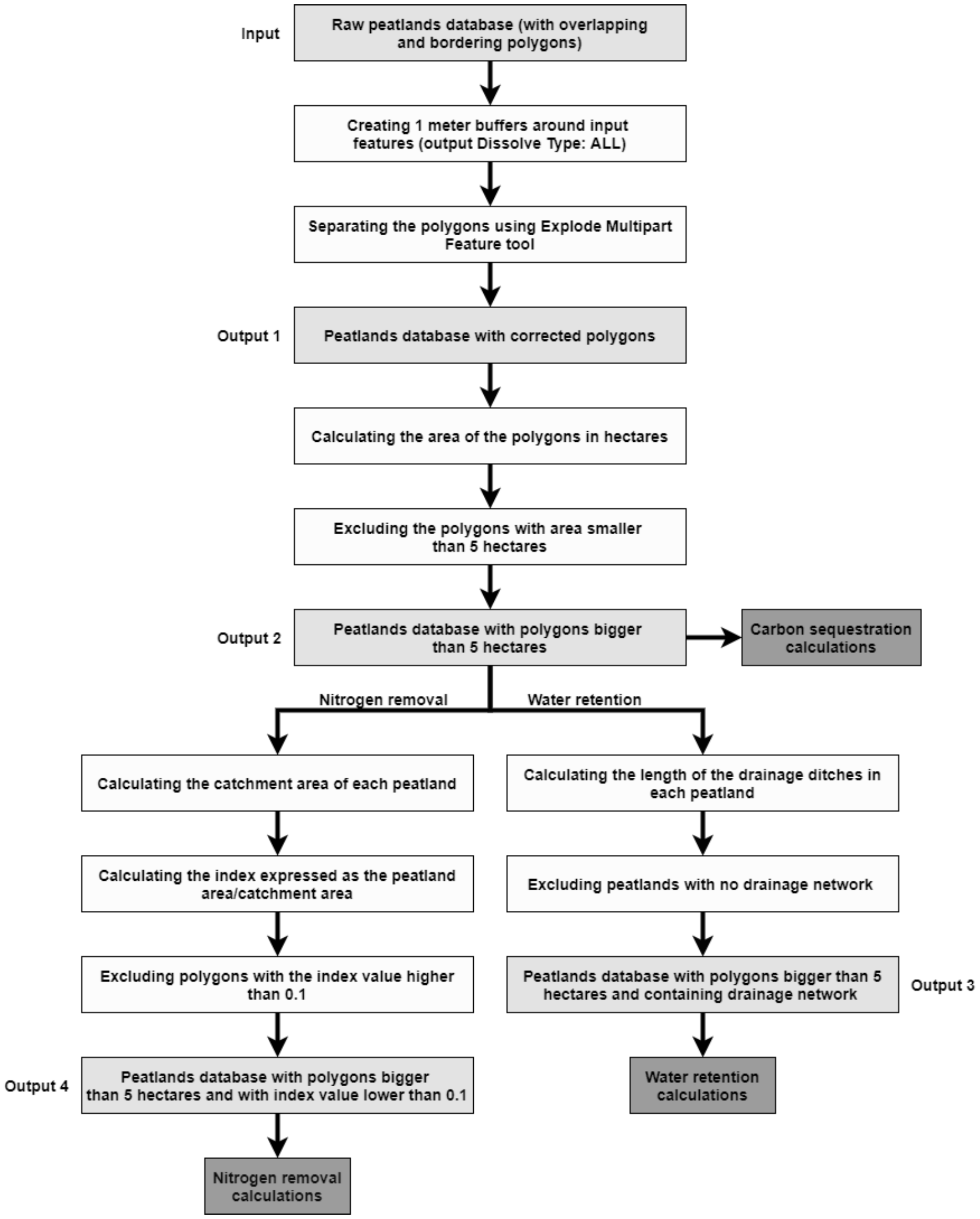

Fig. 6. Diagram showing the process of peatlands database transformation

3.4. Evaluation of selected ecosystem services

3.4.1. Water retention

Wetland's ability to store water plays a vital role in the ecosystem and it is very beneficial for people. This ability allows wetlands to perform their biochemical, biological and hydrologic functions and it determines provisioning of other ecosystem services, such as habitat for animals, removal of contaminants and flood protection (Lane and D'Amico, 2010; Bourgault et al., 2017; Jones et al., 2017). Peatlands are referred to as "sponge" due to their water storage capacity (Craft, 2016; Price et al., 2016). Unfortunately, due to the drainage of these ecosystems, this capacity is being reduced, which prevents wetlands from performing their functions. Therefore, restoration measures in degraded wetlands are needed to recover their water retention ability (Jones et al., 2017).

Quantification of water storage capacity is a useful measure for the proper management of wetlands and establishing their restoration plans (Jones et al., 2017). Damming the drainage ditches is one of the most common methods used for rewetting degraded peatlands. This method of restoration causes a rise in the groundwater level, which increases soil retention in nearby areas. The volume of water stored due to damming, which is water retained in the ditch and water retained as soil retention, can be represented by the formula 3.1 (Grygoruk et al., 2018):

$$V = a \cdot h \cdot l \cdot \left(\frac{b}{2} + \frac{r}{3} \cdot p\right) \qquad (3.1)$$

where:

V – water retained due to damming up on the ditches in m^3,

a – coefficient correcting the actual damming capacity on the ditch,

h – stacking (damming) height in m,

l – stacking (damming/backwater) range upstream in m,

b – average width of the ditch in m,

r – the average radius of water level rise in a cross-sectional view in meters from the ditch,

p – average soil porosity.

The parameters used in the equation are graphically presented in Figure 7.

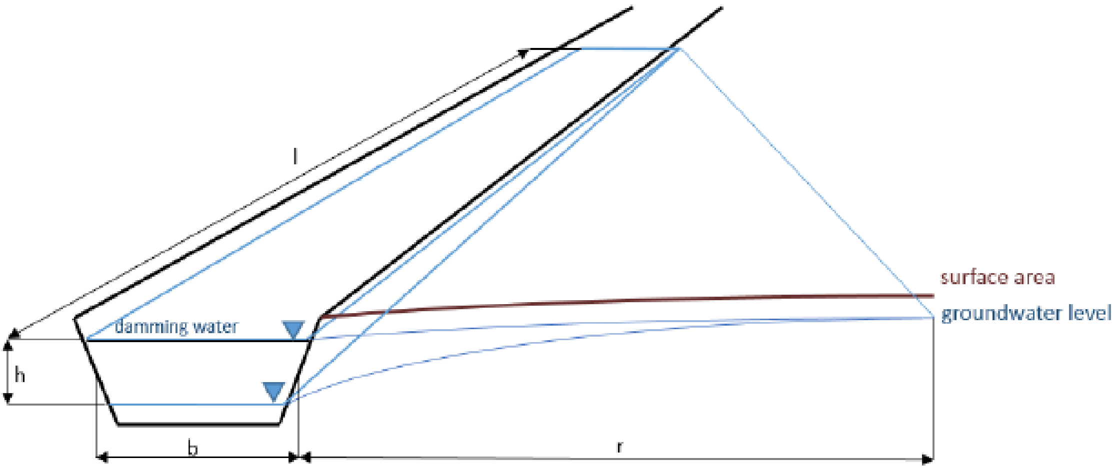

Fig. 7. Schematic drawing of water conditions for damming the ditches (Grygoruk et al., 2018)

For the purpose of calculations certain assumptions were needed to be applied (Tab. 1) (Grygoruk et al., 2018). It is assumed that the drainage ditches located within wetlands have hydrotechnical structures, such as dams. Value of h represents damming height and the value of l is assumed to be the length of the ditches significant in a studied area. The variable r stands for the maximum trench influence on the water level in the area and is dependent on the initial groundwater table, the soil type and the slope. Peat soil porosity ranges from 71 to 95.1% (Rezanezhad et al., 2016). In the study, the porosity of the peat in examined wetlands was assumed as 83%. The coefficient correcting the actual damming capacity on the ditch (a) is 0.8 [-]. It was also assumed that the average width of the ditch is 2 meters and the range of the ditch influence is 50 meters, which is an adequate value for areas with light soils and small topographic slope (Grygoruk et al., 2018). The length of the ditches in Lithuanian, Polish and Russian peatlands was calculated individually for each polygon based on the drainage network data. Due to the lack of this data for Belarus, the length of the ditches in Belarusian peatlands was computed based on the average drainage density calculated in wetlands with full data. The calculations were carried out in three scenarios, with different stacking height values: 0.1, 0.3 and 0.5 meters. The monetary unit value used for the valuation of water retention in the studied peatlands was assumed as 0.53 EUR $\cdot$ m^{-3} $\cdot$ $year^{-1}$ (Grygoruk et al., 2013).

Tab. 1. Parameters and its values used for the calculation of water retention

Parameters	**Value**	**Unit**
Correction coefficient (a)	0,8	-
Stacking height (h)	0.1; 0.3; 0.5	m
Average width of the ditch (b)	2	m
Range of the ditch influence (r)	50	m
Porosity (p)	0,83	-

Restoration scenario of peatlands in the study implies the use of dams reinforced with wood, which are built every 20 cm of slope. The average cost of building a wooden dam is 110 EUR (Landry and Rochefort, 2012). The durability of a dam was assumed as 40 years.

3.4.2. Nitrogen removal

Human activities lead to an excessive increase in the nutrient content of water bodies, which generates serious problems in aquatic ecosystems. Increased loads of nitrogen are mainly caused by anthropogenic factors, such as excessive fertilization, animal farming and land use change (Kiedrzyńska et al., 2014; Vybernaite-Lubiene, 2018; Liu et al., 2020). Nitrogen may find its way to the water ecosystems directly from the source or through atmospheric deposition, due to releases of compounds containing nitrogen to the atmosphere (Hayden and Ross, 2005). Water pollution with nitrogen induces eutrophication, which is a severe problem in the Baltic Sea (Kiedrzyńska et al., 2014; Vybernaite-Lubiene, 2018). It is important to prevent nutrient inputs to surface waters and for this purpose wetland buffer zones work effectively. Wetland Buffer Zone (WBZ) is a wetland area located next to water bodies, such as rivers and lakes. They are responsible for capturing runoff containing nutrients from upland areas and therefore limiting water nutrient pollution through its removal or storage (Walton et al., 2020).

Nitrogen in wetlands is mainly removed through the process of denitrification and by assimilation by plants and microbes (Hayden and Ross, 2005). The process of denitrification is carried out by microbes in anaerobic conditions or under conditions of limited oxygen availability. It is based on the reduction of nitrates and nitrites to nitrogen oxides (NO, N_2O) and dinitrogen (N_2) (Kucharski et al., 2015).

According to Swedish Environmental Protection Agency, wetlands highly contribute to nitrogen removal and wetland restoration is a cost-effective measure for reducing loads of nitrogen reaching the Baltic Sea (SEPA, 2008).

The amount of nitrogen load reaching wetland buffer zones is dependent on the share of agricultural land, sandy soil content and annual runoff. It was calculated based on the following equation (Lewandowska, 2019):

$$N_{\text{loss per ha}} = 1.124 \cdot \exp\left(-3.08 + 0.758 \cdot \ln(A) - 0.003 \cdot S + 0.0249 \cdot D\right) \tag{3.2}$$

where:

$N_{\text{loss per ha}}$ – the N loss from the upland area in kg · ha^{-1},

A - yearly runoff in mm,

S - % of sandy soil,
D - % of agricultural area.

The total N loss was calculated using the equation:

$$N_{\text{loss, total}} = N_{\text{loss per ha}} \cdot \text{direct upland area (ha)}$$

Runoff data was obtained from Global Average Annual Surface Runoff data computed for years 1950-2000 (Fekete et al., 2002). Sand distribution in the researched peatlands was calculated based on the data from European Soil Data Centre (Hiederer, 2013). Percentage of agricultural area in each wetland was derived from MODIS-based Global Land Cover Climatology (Broxton et al., 2014).

It is assumed that the direct upland with a wetland is defined as the upland area, from which nitrogen is transported from during rain events (Lewandowska, 2019). Direct upland area was calculated as a catchment area of each peatland, based on the digital elevation model and computed flow accumulation. The efficiency of nitrogen (TN) removal by wetland buffer zones was assumed as 43% (Walton et al., 2020). The monetary unit value used for the valuation of nitrogen removal in the studied peatlands was assumed as 26 EUR $\cdot$ kg^{-1} (Collins and Gillies, 2013).

3.4.3. Carbon sequestration

Peatlands are often referred to as carbon sinks (Joosten et al., 2016; Villa and Bernal, 2018). After oceans, they are the biggest natural carbon stock in the world, containing 450 Gt of carbon (Joosten et al., 2016; Harenda et al., 2018). On average, they store 1125 tons of C per hectare, which is a highest amount of carbon held in any terrestrial ecosystem (Joosten et al., 2016).

Carbon sequestration in wetlands is the process which involves the capture of atmospheric carbon dioxide (CO_2) and long-term storage of carbon in peat as soil organic matter. Input of C is mainly mediated by wetland vegetation through the process of photosynthesis (Villa and Bernal, 2018; Were et al., 2019). Carbon accumulation and storage ability is highly dependent on the water content in peat (Harenda et al., 2018). It may be released again to the atmosphere as CO_2 or methane (CH_4) through the process of mineralization of organic matter and this process is accelerated due to the drainage of wetlands (Joosten et al., 2016; Villa and Bernal, 2018). Degradation and draining of peatlands contribute to highly increased greenhouse gases emissions and that is why restoration and rewetting of these ecosystems is required (Joosten et al., 2016).

The annual methane release in peatlands is minor in comparison with the CO_2 uptake. For the calculation of carbon sequestration, the estimated average carbon uptake (minus CH_4 release) of value 191 g C · m^{-2} · $year^{-1}$ was used (Fortuniak et al., 2017). The monetary unit value used for the valuation of carbon accumulation in peatlands was assumed based on the social cost of carbon (SCC) as 26.4 EUR · t^{-1} CO_2 (Wang et al., 2019).

4. Results

4.1. Peatlands database

After the preliminary modification of raw peatlands database and selection of peatlands with area higher than 5 hectares (Fig. 6), it was found that there are 14780 peatlands to be analyzed. They cover approximately 10% of the Neman catchment and their area is 9 477 km^2. The distribution of peatlands in the Neman basin is shown on the map below (Fig. 8).

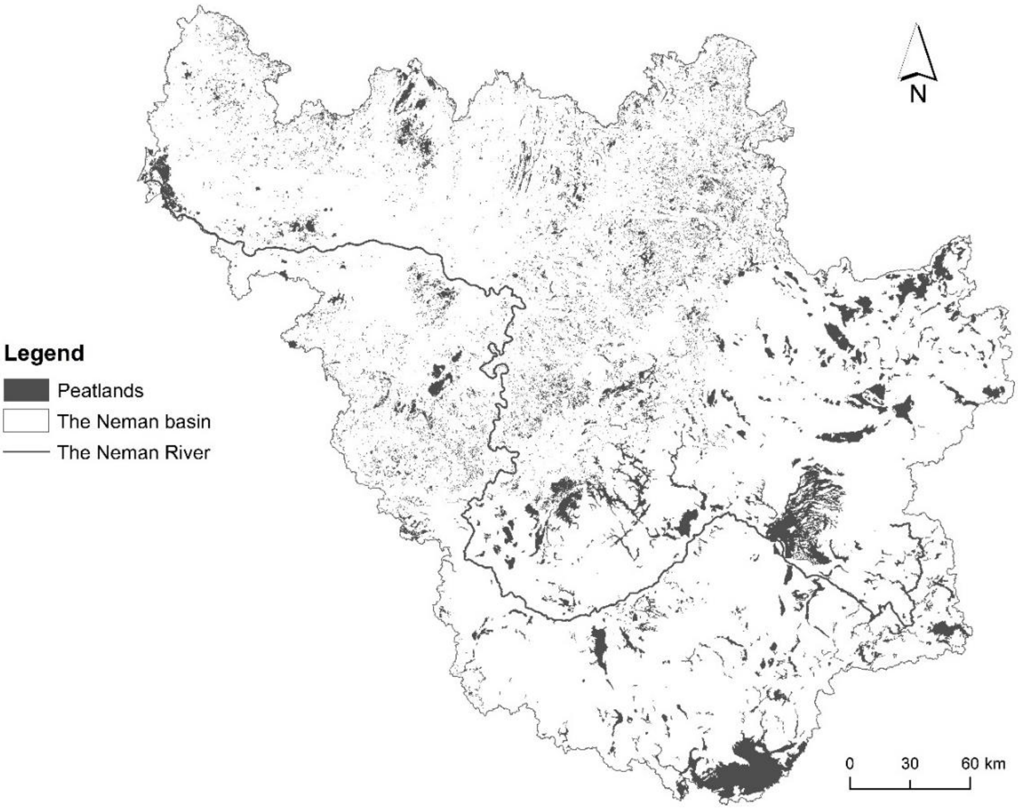

Fig. 8. Peatlands in the Neman catchment

Accuracy and the level of detail of the presented map results from the fact of data availability and attributes that could have been obtained in order to perform the analyses planned in this thesis. Additional modifications of the peatlands database were carried out to estimate water retention and nitrogen removal (Fig. 6). Water retention calculations were made for peatlands intersected by drainage ditches. For the calculations of nitrogen removal, it was necessary to determine the area of wetland buffer zones of peatlands and to select those that should be analyzed (Fig. 9).

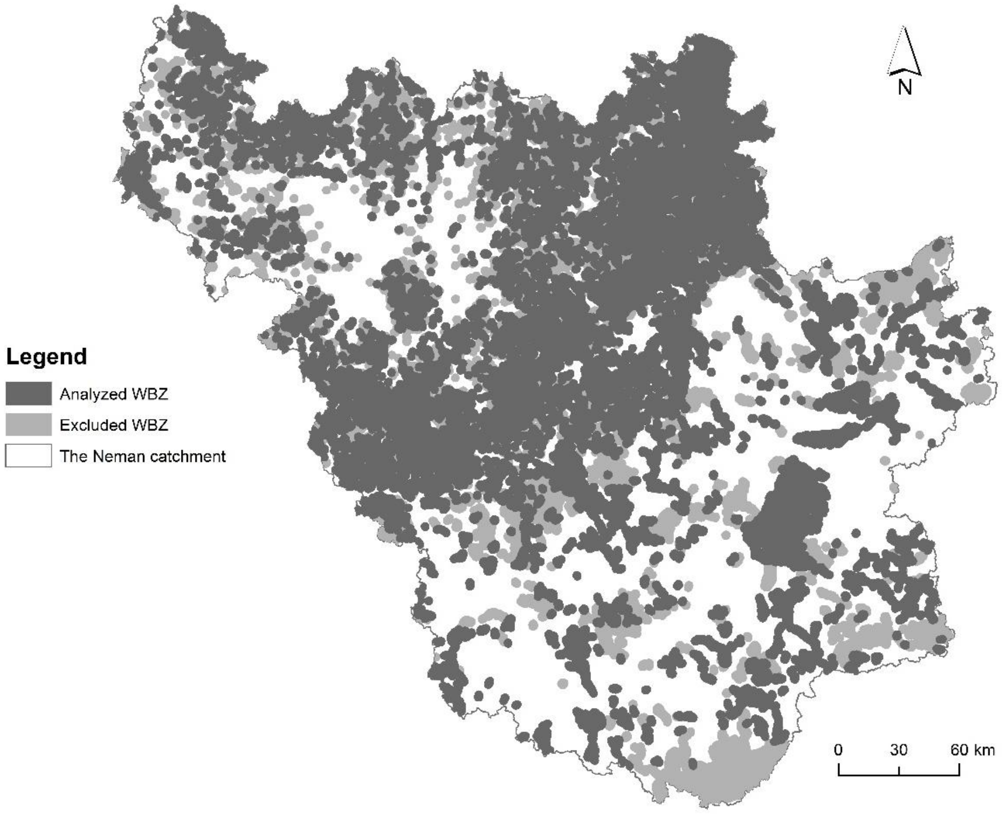

Fig. 9. Map of selected wetland buffer zones for the analysis of N removal

4.2. Water retention

The first stage of the analysis (Fig. 6) showed that approximately 64.3% of peatlands in the research area is impacted by drainage (9 507 out of 14 780 peatlands). For these peatlands, a scenario of restoration using dams reinforced by wood was applied. Water retention was calculated for each peatland, in m^3 and $m^3 \cdot ha^{-1}$ (Tab. 2).

The volume of water stored on one hectare of peatland due to the damming of the drainage ditches ranges from 0.005 to 439.1 $m^3 \cdot ha^{-1}$ when the stacking height of the dams equals 0.1 meter, from 0.01 to 1 317.4 $m^3 \cdot ha^{-1}$ when the stacking height equals 0.3 meter and from 0.02 to 2 195.7 $m^3 \cdot ha^{-1}$ when the stacking height equals 0.5 meter. The average volume of water stored on one hectare of peatland due to the damming is 62.2 m^3 · ha^{-1} when the stacking height of the dams equals 0.1 meter, 186.5 m^3 · ha^{-1} when the stacking height equals 0.3 meter and 310.9 m^3 · ha^{-1} when the stacking height equals 0.5 meter (Tab. 2, Fig. 10).

Water retention in peatlands ranges from 0.1 to 1.4 M m^3 when the stacking height of the dams equals 0.1 meter, from 0.3 to 4.2 M m^3 when the stacking height equals 0.3 meter and from 0.5 to 7 M m^3 when the stacking height equals 0.5 meter. The average volume of water stored in peatlands due to the damming is 2 540 m^3 when the stacking height of the dams equals 0.1 meter, 7 650 m^3 when the stacking height equals 0.3 meter and 12 700 m^3 when the stacking height equals 0.5 meter (Tab. 2, Fig. 11).

Tab. 2. Minimum, maximum and mean retained water volume for different stacking heights.

Stacking height [m]	**Retained water volume [m^3 · ha^{-1}]**			**Retained water volume [m^3]**		
	Min	Max	Mean	Min	Max	Mean
0,1	0,005	439,1	62,2	0,1	1 399 508	2 540
0,3	0,01	1 317,4	186,5	0,3	4 198 523	7 620
0,5	0,02	2 195,7	310,9	0,5	6 997 538	12 700

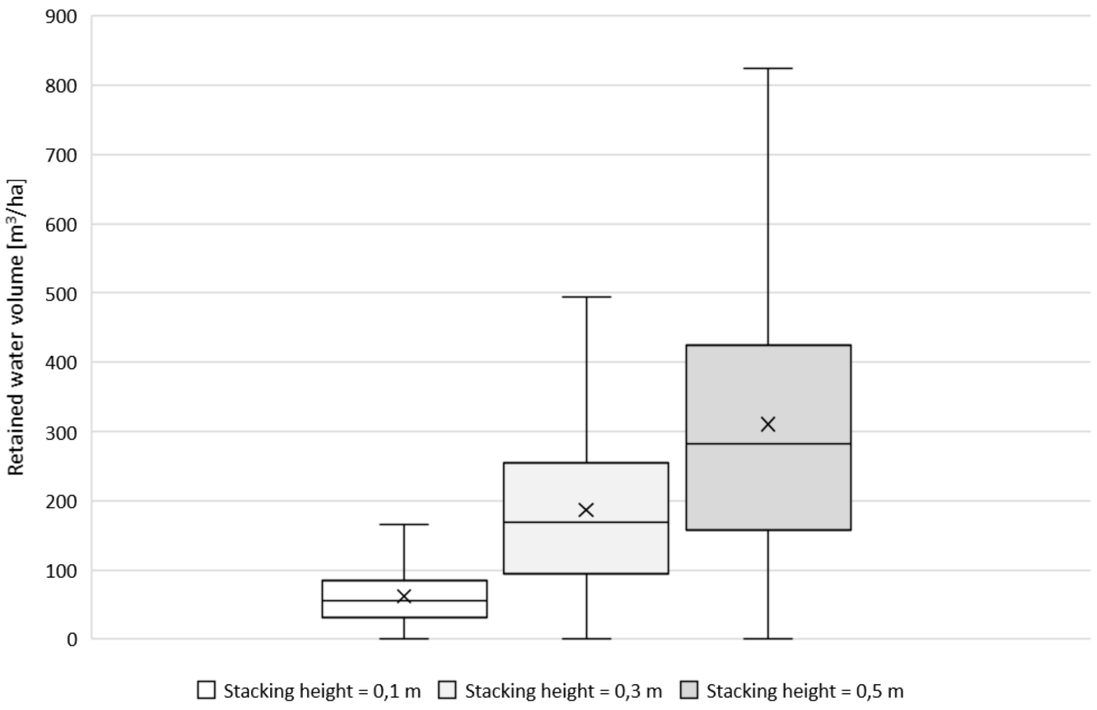

Fig. 10. Boxplots comparing retained water volume in m^3 · ha^{-1} for different stacking heights (outliers excluded)

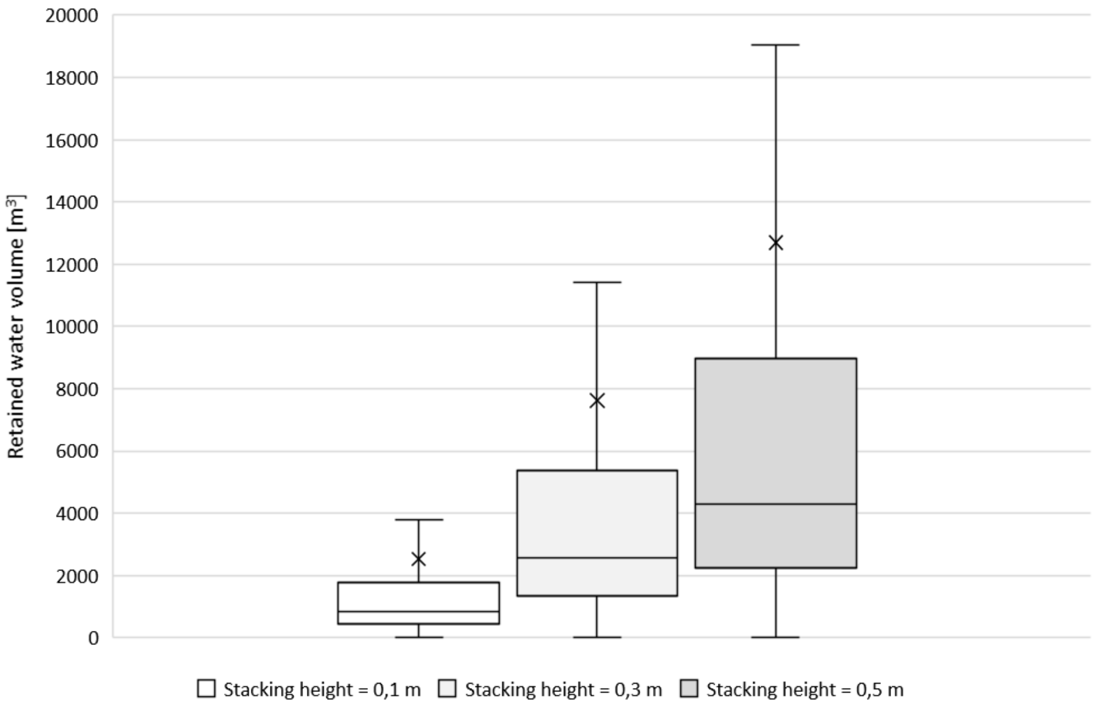

Fig. 11. Boxplots comparing retained water volume in m^3 for different stacking heights (outliers excluded)

After summing up the retained water volume from all the peatlands, the approximate total volume of water is 24.1 M m^3 when the stacking height equals 0.1 meter, 72.4 M m^3 when the stacking height equals 0.3 meter and 120.7 M m^3 when the stacking height equals 0.5 meter. It follows that the total water retention value is 12.8 M, 38.4 M and 64 M EUR · year^{-1}, respectively for the stacking heights equal 0.1, 0.3 and 0.5 meter (Tab. 3).

Tab. 3. Total retained water volume and total water retention value

Stacking height [m]	**Total retained water volume [m^3]**	**Total water retention value [EUR · year^{-1}]**
0,1	24 147 146	12 797 987
0,3	72 441 438	38 393 962
0,5	120 735 731	63 989 937

The total cost of dams that are needed to be built in order to restore degraded peatlands in the Neman catchment is approximately 5.8 M EUR · year^{-1}. The estimated costs of constructing dams in each country are presented in the Table 4.

Tab. 4. Estimated cost of dams by country and the total cost

Country	Estimated cost of dams [EUR · year^{-1}]
Belarus	1 530 430
Lithuania	4 022 279
Poland	173 759
Russia	79 060
Total	5 805 528

After deduction of restoration costs, the net water retention value is 7 M EUR · year^{-1} when the stacking height equals 0.1 meter, 32.6 M EUR · year^{-1} when the stacking height equals 0.3 meter and 58.2 M EUR · year^{-1} when the stacking height equals 0.5 meter (Tab. 5).

Tab. 5. Total water retention value in comparison to the net water retention value

Stacking height [m]	Total water retention value [EUR · year^{-1}]	Net water retention value [EUR · year^{-1}]
0,1	12 797 987	6 992 460
0,3	38 393 962	32 588 435
0,5	63 989 937	58 184 409

4.3. Nitrogen removal

After the designation and selection of wetland buffer zones for nitrogen removal calculations (Fig. 6) it was found that 6732 out of 14780 peatlands can be analyzed. Nitrogen removal rate was calculated for each of these WBZ. The catchment area of each peatland was computed based on the flow accumulation (Fig.12).

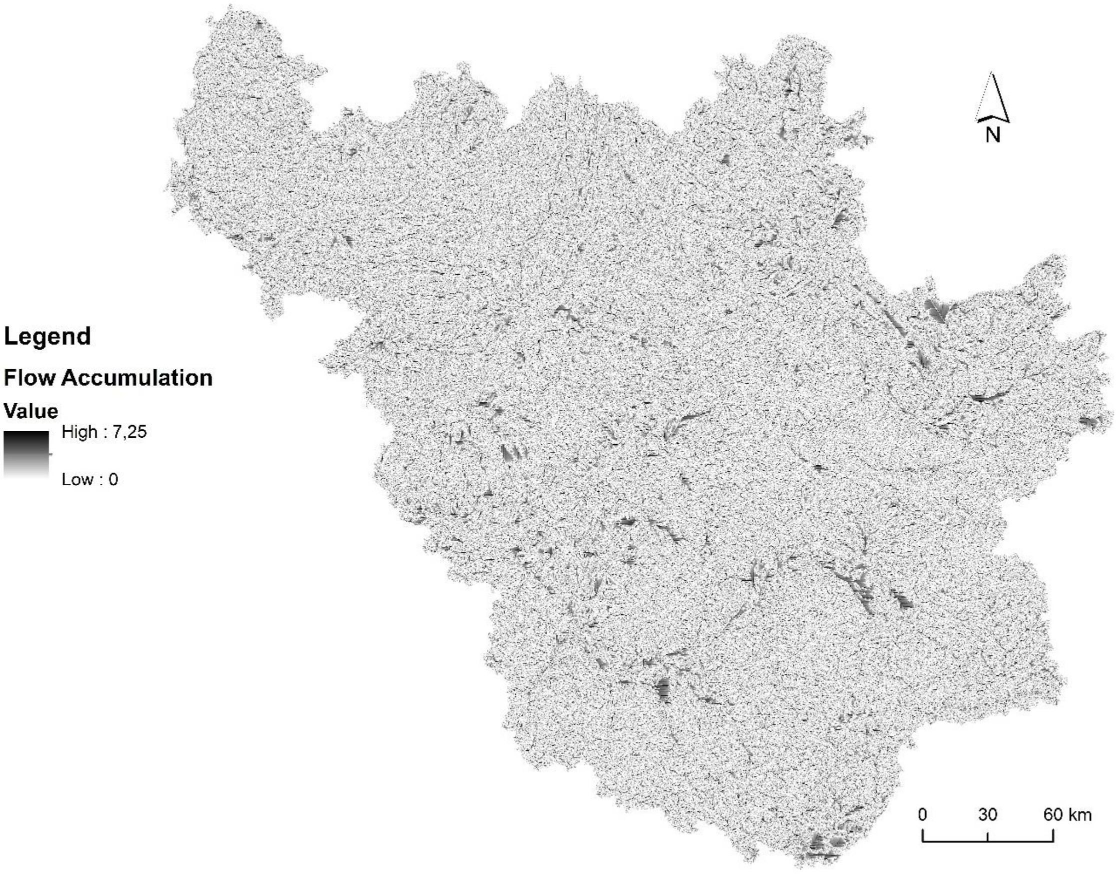

Fig. 12. Log-transformed flow accumulation map of the study area

The annual nitrogen loss from one hectare of the WBZ ranges from 0.98 to 57.2 kg TN · ha^{-1} · year^{-1}, with the average of 15.7 kg TN · ha^{-1} · year^{-1}. The annual N loss from upland areas ranges from 83.1 to 8.4 M kg TN · year^{-1}, with the average of 107 597 kg TN · year^{-1}. Nitrogen removal rate by wetland buffer zones ranges from 35.7 to 3.6 M kg TN · year^{-1}, with the average of 43 267 kg TN · year^{-1} (Tab. 6, Fig. 13, Fig. 14).

Tab. 6. Minimum, maximum and mean values of N losses and N removal

-	**N loss [kg · ha^{-1} · year^{-1}]**	**N loss [kg · year^{-1}]**	**N removal [kg · year^{-1}]**
Min	0,98	83,1	35,7
Max	57,2	8 409 398	3 616 041
Mean	15,7	107 597	46 267

Fig. 13. A boxplot showing the range of nitrogen losses from upland areas in kg · ha^{-1} · year^{-1} (outliers excluded)

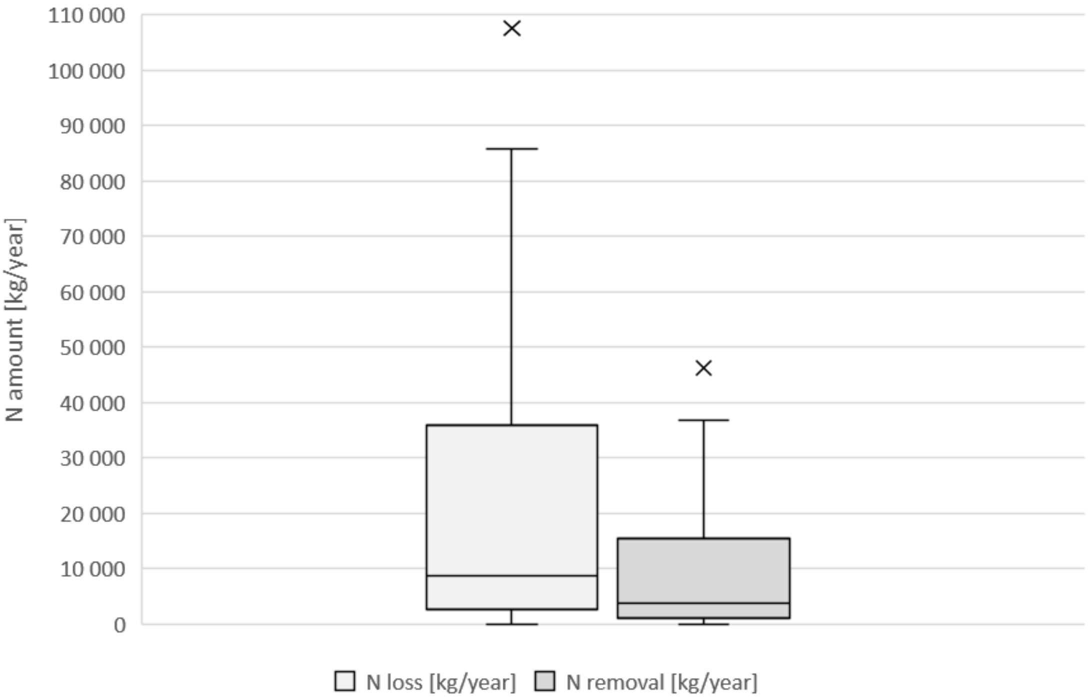

Fig. 14. Boxplots comparing nitrogen losses to the nitrogen removal rate in kg · year^{-1} (outliers excluded)

The total loss of nitrogen from the upland areas in the Neman basin is 724.3 M kg TN · year^{-1}, of which 311.5 M kg TN · year^{-1} is removed by wetland buffer zones. The total value of N removal in analyzed WBZ is 8098 M EUR · year^{-1} (Tab. 7).

Tab. 7. Total N loss, N removal and N removal value

Total N loss [kg · year^{-1}]	**Total N removal [kg · year^{-1}]**	**Total N removal value [EUR· year^{-1}]**
724 339 834	311 466 129	8 098 119 349

Based on the calculations and peatlands area in the Neman catchment, the average N loss from upland areas is 1637 kg TN · ha^{-1} · year^{-1}.

It was found that approximately 70.6% (4753 out of 6732) of wetland buffer zones is drained. They were included in the calculations, but on the assumption that they remove nitrogen at the same rate as WBZ not impacted by drainage. They are responsible for 79.5% (6434 M EUR · year^{-1}) of the total nitrogen removal value.

4.4. Carbon accumulation

The calculations of carbon sequestration were carried out for all peatlands in the Neman basin (14780 peatlands). The estimated average carbon uptake (minus CH_4 release) is 191 g C · m^{-2} · year^{-1} (Fortuniak et al., 2017), which corresponds to 1.91 t C · ha^{-1} · year^{-1}.

The total amount of carbon sequestered by peatlands in the study area is 1.8 M t C · year^{-1}. The monetary value of this ecosystem service is approximately 47.8 M EUR · year^{-1} (Tab. 8).

Tab. 8. Total carbon sequestration in tones · year^{-1} and its value in EUR · year^{-1}

Total carbon sequestration [t C · year^{-1}]	**Total value of carbon sequestration [EUR · year^{-1}]**
1 810 020	47 784 522

5. Discussion

The carried out analyses and the results obtained from the calculations of water retention, nitrogen removal and carbon sequestration in peatlands in the Neman catchment area allow to draw certain conclusions and to make comparisons with other studies. The value of ecosystem services derived from the calculations amounts to: 75 EUR · ha^{-1} · year^{-1} for water retention, 154.3 EUR · ha^{-1} · year^{-1} for nitrogen removal and 50.4 EUR · ha^{-1} · year^{-1} for carbon sequestration (Fig. 15). The value of all analyzed ecosystem services in the research area is 279.7 EUR · ha^{-1} · year^{-1}.

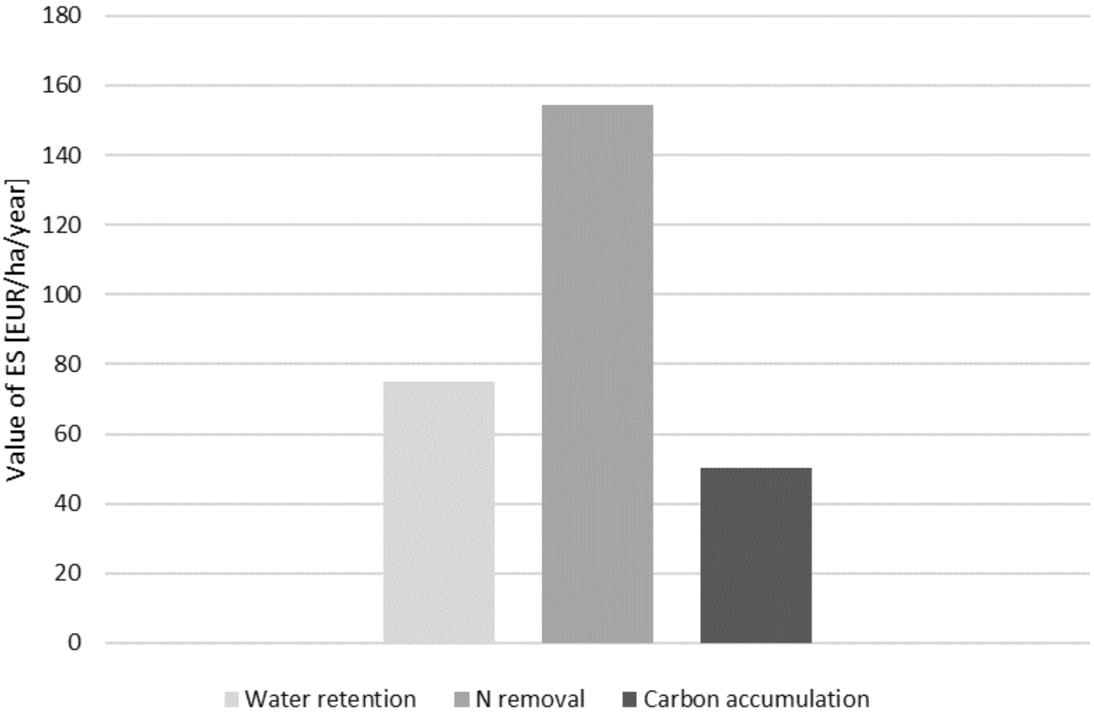

Fig. 15. A graph comparing the values of analyzed ES in EUR · ha^{-1} · year^{-1}

Calculations of water retention show that the difference in the water storage capacity is significant with an increase of used stacking height. The most suitable damming height used for restoration of peatlands should be estimated individually, e.g. based on the peat depth (Similä et al., 2014). Restoration of drained peatlands in the Neman catchment with the biggest stacking height scenario (0.5 meter) would increase the water storage capacity by 120.7 M m^3 and it accounts for 26% of water volume that can be stored in the Kaunas reservoir (with total storage capacity equal to 462 M m^3) (Gailiusis et al., 2003). The average discharge from the Neman River is 535 m^3 ·s^{-1} (Glazaciovaite et al., 2012), which corresponds to 16871 M m^3 · year^{-1}. Restoration of peatlands would increase retention by 0.7% in the scale of the whole catchment area.

The cost-benefit analysis proves that the costs incurred for the restoration of drained peatlands in the Neman basin are an investment for the future. The total value of retained water with the biggest stacking height scenario (64 M EUR · year^{-1}) exceeds 11 times the costs of restoration (5.8 M EUR · year^{-1}). The highest costs associated with the construction of dams are expected on the Lithuanian side (4 M EUR · year^{-1}). It should also be stressed that the average values of the slope in each peatland are overestimated, therefore the number of dams needed for the restoration of all drained peatlands and their cost is miscalculated and it would probably be lower. Also the costs of dam construction used in this study, although well described by Landry and Rochefort (2012) seem to be underestimated. The net value of water retention, after deduction of the costs, is 58.2 M EUR · year^{-1}. The costs are insignificant in comparison with the possible benefit, especially that peatlands in natural state provide many other valuable ecosystem services (Bourgault et al., 2017). Overall, the results may correspond with the statement of Jones et al. (2017) that quantification of restorable wetland water storage capacities is a useful measure for the proper wetland management, and it can help prioritize restoration of these ecosystems.

The rate of nitrogen removal by wetland buffer zones varies due to different factors, such as average runoff and share of agricultural area and sandy soils. Agricultural areas cover most of the Neman catchment and they contribute to high loads of nitrogen reaching WBZ, due to the use of fertilizers. The average calculated load of nitrogen that reaches WBZ in the research area is 1637 kg TN · ha^{-1} · year^{-1}, which is over 3 times higher than the load estimated by Walton et al. (2020) (523 kg TN · ha^{-1} · year^{-1}). The difference may result from higher values of certain parameters of the equation used for the calculation of N loss, but also from the overestimation of the size of the catchment area of particular peatlands.

The calculations of nitrogen removal were carried out on the assumption that no peatland is impacted by drainage. In reality, approximately 70.6% of analyzed peatlands is drained. They are responsible of removal of 79.5% of nitrogen (247.5 M kg TN · year^{-1}). Therefore, restoration of these peatlands would increase the actual value of N removal by 6434 M EUR · year^{-1}, assuming that drained peatlands do not have the ability to remove nitrogen.

In years 2012–2016, the mean annual supply of Total Nitrogen (TN) received from the Neman River catchment to the river mouth was 44 208 ± 12 677 t TN · year^{-1}. Nitrates (NO^{3-}) contributed to almost half (48%) of the TN amount. The contribution of nitrites (NO^{2-}) was minor (Vybernaite-Lubiene, 2018). Despite the probability that the values of nitrogen removal by WBZ in the Neman catchment are overestimated, it can be assumed that the restoration of peatlands would significantly contribute to the reduction of nitrogen load reaching the Baltic Sea.

The rate of carbon sequestration in wetlands in the Neman catchment, as well as the nitrogen removal, was estimated on the assumption that no peatland is impacted by drainage.

The total mass of carbon sequestered by peatlands in the research area is 1.8 M t C · year^{-1}. As a comparison, the mass of emitted fossil carbon dioxide in Lithuania in the year 2016 was 13.7 M tons (Worldometers). It should be noted that the calculated value of carbon sequestration (47.8 M EUR · year^{-1}) is an imprecise estimate, due to the widely differentiated SCC values (Melaku Canu et al., 2015; Wang et al., 2019; Gallant et al., 2020). While natural peatlands act as a carbon sink, the degraded sites emit CO_2 in the process of oxidation and therefore, they may contribute to the global warming phenomenon. Rewetting and restoration of degraded peatlands, as well as conservation of the pristine peatlands are crucial for the adaptation to the climate change (Bonn et al., 2016). However, according to Gallant et al. (2020) mainly preservation of existing wetlands may be economically justified, and wetland restoration may be assumed cost-effective if carbon sequestration value is considered in conjunction with other ecosystem services.

The results obtained in this study are estimates and should be assumed to be of some error. Uncertainties may arise from input data quality, certain simplifications and adopted values. To establish more accurate results, a more in-depth analysis is recommended. This opens up a new field for research on ecosystem services.

6. Conclusions

Extensive analyses provided in the framework of this thesis allowed to formulate a number of conclusions addressing the challenges listed in the Introduction and Goal and Scope of the thesis:

1. Restoration of degraded peatlands in the Neman basin would increase water retention by 120 M m^3 which gives approximately 0.7% of the total river runoff of Neman. It should be stated that this number accounts for groundwater retention of degraded wetlands to be rewetted only.
2. On the basis of adopted assumptions, the total income from retained water due to damming, which amounts to 64 M EUR · year^{-1}, exceeds 11 times the costs of restoration (5.8 M EUR · year^{-1}). The cost-benefit analysis proves that the costs incurred for the restoration of drained peatlands in the Neman basin remain an investment for the future, especially that the costs are insignificant in comparison with the possible benefit.
3. It can be assumed that the restoration of peatlands would significantly contribute to the reduction of nitrogen load reaching the Baltic Sea, despite the probability that obtained

results are overestimated. Wetland buffer zones in the Neman catchment can reduce this load by 311.5 M kg TN · year^{-1}.

4. Valuation of wetland ecosystem services is a useful measure for the proper wetland management and establishment of restoration plans.
5. The results obtained in this study are estimates and should be assumed to be of some error. Uncertainties may arise from input data quality, certain simplifications and adopted values.
6. To establish more accurate results, a more in-depth analysis is recommended, especially by using better quality data for restoration cost estimation, high resolution peatland map of the Neman catchment and advanced differentiation of N removal that reach wetlands by groundwater flow and surface runoff, considering different mechanisms of N removal processes.

Results provided in this thesis allow one to consider wetland restoration in the Neman catchment as a useful tool for environmental management. Facts provided in this thesis provide direct quantitative description of potential gains one can get from appropriate management and restoration of wetlands in the catchment scale.

7. References

Bonn A., Allott T., Evans M., Joosten H., Stoneman R., 2016. Peatland restoration and ecosystem services: nature-based solutions for societal goals. In A. Bonn, T. Allott, M. Evans, H. Joosten, R. Stoneman (Eds.), Peatland Restoration and Ecosystem Services: Science, Policy and Practice, 19−43. Cambridge: Cambridge University Press.

Bourgault M. A., Larocque M., Garneau M., 2017. Quantification of peatland water storage capacity using the water table fluctuation method. Hydrological Processes 31(5), 1184–1195.

Broxton P. D., Zeng X., Sulla-Menashe D., Troch P. A., 2014. A Global Land Cover Climatology Using MODIS Data. Journal of Applied Meteorology and Climatology 53, 1593–1605.

CCM River and Catchment Database © European Commission - JRC, 2007. A pan-European River and Catchment Database. European Commission - JRC, Luxembourg, (EUR 22920 EN), 120 pp.

Clarkson B. R., Ausseil A. E., Gerbeaux P., 2013. Wetland ecosystem services. In Dymond JR ed. Ecosystem services in New Zealand – conditions and trends, 19−43. Manaaki Whenua Press, Lincoln, New Zealand.

Collins A. R., Gillies N., 2013. Constructed Wetland Treatment of Nitrates: Removal Effectiveness and Cost Efficiency. JAWRA Journal of the American Water Resources Association 50(4), 898–908.

Costanza R., de Groot R., Sutton P., van der Ploeg S., Anderson S. J., Kubiszewski I., Farber S., Turner R. K., 2014. Changes in the global value of ecosystem services. Global Environmental Change 26, 152–158.

Craft C., 2016. Peatlands. Creating and Restoring Wetlands, 161–192.

Domnin D., Chubarenko B., Karmanov K., Pilipchuk V., Korzun A., Nagornova N., Oblomkova N., Saukkoriipi J., Salminen E., 2014. Assessment and quantification of nutrient loads to the Baltic Sea from Kaliningrad Oblast and transboundary rivers, and the evaluation of their sources. HELCOM 2014, BASE project 2012-2014.

Dubra V., Abromas J., Dumbrauskas A., 2013. Impact of Ice Regime in the Nemunas River and the Curonian Lagoon on Floods in the Delta Area. Rural Development 6, 239–244.

Fekete B. M., Vorosmarty C. J., Grabs W., 2002. High-resolution fields of global runoff combining observed river discharge and simulated water balances. Global Biogeochemical Cycles 16(3), 15-1 to 15-10.

Fortuniak K., Pawlak W., Bednorz L., Grygoruk M., Siedlecki M., Zieliński M., 2017. Methane and carbon dioxide fluxes of a temperate mire in Central Europe. Agricultural and Forest Meteorology 232, 306–318.

Gailiusis B., Kriauciuniene J., Rimaviciute E., 2003. Modelling the Effect of the Hydroelectric Pumped Storage Plant on Hydrodynamic Regime of the Kaunas Reservoir In Lithuania. Hydrology Research, 34(5), 507–518.

Gallant K., Withey P., Risk D., van Kooten G. C., Spafford L., 2020. Measurement and economic valuation of carbon sequestration in Nova Scotian wetlands. Ecological Economics 171, 106619.

Glazaciovaite, E., Dailidiene, I., Osadcij, I., 2012. Bottom relief and water discharge changes in Nemunas delta due to climate change during the last century. IEEE/OES Baltic International Symposium (BALTIC).

Glina B., Bogacz A., Mendyk Ł., Bojko O., Nowak M., 2018. Effectiveness of restoration of a degraded shallow mountain fen after five years. Mires and Peat 21, 1–15.

Grygoruk M., Mirosław-Świątek D., Chrzanowska W.,1 Ignar S., 2013. How Much for Water? Economic Assessment and Mapping of Floodplain Water Storage as a Catchment-Scale Ecosystem Service of Wetlands. Water 5, 1760-1779.

Grygoruk M., Osuch P., Trandziuk P., 2018. Delineation of key zones for water retention enhancement in the Polish part of the Oder catchment. Analysis of potential water retention in land reclamation systems and its possible role in mitigating winter low flows of Oder. Report. German League for Nature and Environment. 109 pp.

Harenda K. M., Lamentowicz M., Samson M., Chojnicki, B. H., 2018. The Role of Peatlands and Their Carbon Storage Function in the Context of Climate Change. GeoPlanet: Earth and Planetary Sciences, 169–187

Hayden M. J., Ross D. S., 2005. Denitrification as a Nitrogen Removal Mechanism in a Vermont Peatland. Journal of Environmental Quality 34, 2052–2061.

Hengl T., Mendes de Jesus J., Gerard B. M. Heuvelink G. B. M., Ruiperez Gonzalez M., Kilibarda M., Blagotić A., Shangguan W., Wright M. N., Geng X., Bauer-Marschallinger B., Guevara M. A., Vargas R., MacMillan R. A., Batjes N. H., Leenaars J. G. B, Ribeiro E., Wheeler I., Mantel S., Kempen B., 2017. SoilGrids250m: Global gridded soil information based on machine learning. PLOS ONE 12(2), e0169748.

Hiederer R., 2013. Mapping Soil Properties for Europe - Spatial Representation of Soil Database Attributes. Luxembourg: Publications Office of the European Union, 47pp., EUR26082EN Scientific and Technical Research series, ISSN 1831-9424.

Jones C. N., Evenson G. R., McLaughlin D. L., Vanderhoof M. K., Lang M. W., McCarty G. W., Golden H. E., Lane C. R., Alexander L. C., 2017. Estimating restorable wetland water storage at landscape scales. Hydrological Processes 32(2), 305–313.

Joosten H., 2016. Peatlands across the globe. In A. Bonn, T. Allott, M. Evans, H. Joosten, R. Stoneman (Eds.), Peatland Restoration and Ecosystem Services: Science, Policy and Practice, 19−43. Cambridge: Cambridge University Press.

Joosten H., Sirin A., Couwenberg J., Laine J., Smith P., 2016. The role of peatlands in climate regulation. In A. Bonn, T. Allott, M. Evans, H. Joosten, & R. Stoneman (Eds.), Peatland Restoration and Ecosystem Services: Science, Policy and Practice, 63−76. Cambridge: Cambridge University Press.

Kaval P., 2019. Integrated catchment management and ecosystem services: A twenty-five year overview. Ecosystem Services 37, 100912.

Kiedrzyńska E., Jóźwik A., Kiedrzyński M., Zalewski M., 2014. Hierarchy of factors exerting an impact on nutrient load of the Baltic Sea and sustainable management of its drainage basin. Marine Pollution Bulletin 88, 162–173.

Kucharski J., Barabasz W., Bielińska E. J., Wyszkowska J., 2015. Właściwości biologiczne i biochemiczne gleby. In Mocek A. (Eds.), Gleboznawstwo, 232−280. Wydawnictwo Naukowe PWN SA.

Landry J., Rochefort L., 2012. The drainage of peatlands: impacts and rewetting techniques. Peatland Ecology Research Group, Département de phytologie, Université Laval.

Lane C. R., D’Amico E., 2010. Calculating the Ecosystem Service of Water Storage in Isolated Wetlands using LiDAR in North Central Florida, USA. Wetlands, 30(5), 967–977.

Lewandowska M., 2019. Potential for wetland restoration in Odense River catchment and nitrogen removal. A GIS-based analysis of Odense River catchment.

Lithuania CO_2 Emissions. Worldometers. Access: 25.07.2020. Retrieved from: https://www.worldometers.info/co2-emissions/lithuania-co2-emissions/

Liu C., Hou L., Liu M., Zheng Y., Yin G., Dong H., Liang X., Li X., Gao D., Zhang Z., 2020. In situ nitrogen removal processes in intertidal wetlands of the Yangtze Estuary. Journal of Environmental Sciences 93, 91–97.

Melaku Canu D., Ghermandi A., Nunes P. A. L. D., Lazzari P., Cossarini G., Solidoro C., 2015. Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: An ecological economics approach. Global Environmental Change 32, 87–95.

NCM Project, 2017. Neman & Pregola River Basin Monitoring Plan. Creation of a Sustainable, NGO-led River Monitoring Network on the Neman and Pregola Rivers, NCM Project ref # 15-01306

Price J., Evans C., Evans M., Allott T., Shuttleworth, E., 2016. Peatland restoration and hydrology. In A. Bonn, T. Allott, M. Evans, H. Joosten, & R. Stoneman (Eds.), Peatland Restoration and Ecosystem Services: Science, Policy and Practice, Ecological Reviews, pp. 77-94. Cambridge: Cambridge University Press.

Ramsar Convention on Wetlands, 2018. Global Wetland Outlook: State of the World’s Wetlands and Their Services to People. Ramsar Convention Secretariat, Gland, Switzerland.

Renou-Wilson F., Wilson D., Rigney C., Byrne K., Farrell C., Müller C., 2018. Network Monitoring Rewetted and Restored Peatlands/Organic Soils for Climate and Biodiversity Benefits (NEROS). EPA Research Report (2012-B-MS-9).

Rezanezhad F., Price J. S., Quinton W. L., Lennartz B., Milojevic T., Van Cappellen P., 2016. Structure of peat soils and implications for water storage, flow and solute transport: A review update for geochemists. Chemical Geology 429, 75–84.

Rimkus E., Stonevičius E., Korneev V., Kažys J., Valiuškevičius G., Pakhomau A., 2013. Dynamics of meteorological and hydrological droughts in the Neman river basin. Environmental Research Letters 8, 045014.

SEPA, 2008. Swedish Environmental Protection Agency. The Costs of Environmental Improvements in the Baltic Sea and Skagerrak. Economic Marine Information. Report 5876, December 2008.

Sileika A. S., Stålnacke P., Kutra S., Gaigalis K., Berankiene L., 2006. Temporal and Spatial Variation of Nutrient Levels in the Nemunas River (Lithuania and Belarus). Environmental Monitoring and Assessment 122, 335–354.

Similä M., Aapala K., Penttinen J., 2014. Ecological restoration in drained peatlands – best practices from Finland. Publisher: Metsähallitus, Natural Heritage Services, Vantaa.

Stonevičius E., Rimkus E., Štaras A., Kažys J., Valiuškevičius G., 2017. Climate change impact on the Nemunas River basin hydrology in the 21st century. Boreal Environment Research 22, 49–65.

Verhoeven J. T. A., 2014. Wetlands in Europe: Perspectives for restoration of a lost paradise. Ecological Engineering 66, 6–9.

Villa J. A., Bernal B., 2018. Carbon sequestration in wetlands, from science to practice: An overview of the biogeochemical process, measurement methods, and policy framework. Ecological Engineering 114, 115–128.

Vybernaite-Lubiene I., Zilius M., Saltyte-Vaisiauske L., Bartoli M., 2018. Recent Trends (2012–2016) of N, Si, and P Export from the Nemunas River Watershed: Loads, Unbalanced Stoichiometry, and Threats for Downstream Aquatic Ecosystems. Water 10, 1178.

Walton C. R., Zak D., Audet J., Petersen R. J., Lange J., Oehmke C., Wichtmann W., Kreyling J., Grygoruk M., Jabłońska E., Kotowski W., Wiśniewska M. M., Ziegler R., Hoffmann C. C., 2020. Wetland buffer zones for nitrogen and phosphorus retention: Impacts of soil type, hydrology and vegetation. Science of the Total Environment, 138709.

Wang P., Deng X., Zhou H., Yu S., 2019. Estimates of the social cost of carbon: a review based on meta-analysis. Journal of Cleaner Production 209, 1494–1507.

Were D., Kansiime F., Fetahi T., Cooper A., Jjuuko C., 2019. Carbon Sequestration by Wetlands: A Critical Review of Enhancement Measures for Climate Change Mitigation. Earth Systems and Environment 3, 327–340.

Wichmann S., Brander L., Schäfer A., Schaafsma M., Van Beukering P., Tinch D., Bonn A., 2016. Valuing peatland ecosystem services. In A. Bonn, T. Allott, M. Evans, H. Joosten, R. Stoneman (Eds.), Peatland Restoration and Ecosystem Services: Science, Policy and Practice, 19−43. Cambridge: Cambridge University Press.

Xu X., Chen M., Yang G., Jiang B., Zhang J., 2020. Wetland ecosystem services research: A critical review. Global Ecology and Conservation 22, e01027.

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