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Master Thesis

Impacts of railway infrastructure on riverine ecosystems in Austria – how to define hot spots of sensitive river sections

submitted by

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Abstract

Although railway infrastructure becomes more important for sustainable transport development, the expansion of railway networks has effects on the natural environment and exerts intense pressure to resources like soil and water. For example, it is well documented, that road infrastructures cause habitat fragmentation for several species like birds, frogs, fish, amphibians and plants.

This thesis's main method to investigate different impacts of railway infrastructure on riverine ecosystems in Austria was to do a GIS based analysis with various given datasets. Based on available environmental data, information about fish regions, fish metrics, Fish Index Austria FIA, different habitat types, ecosystem cartographies but also birdwatching data is analyzed. The railway data is provided by the Austrian Federal Railways including the Trans-European Transport Network (TEN-T), a network of high prioritized main routes.

To close the information gap about interferences between railway infrastructure and freshwater ecosystems, all relevant data about riverine ecosystems and railway networks in Austria are combined with one another. The first result are intersections like bridges, culverts and crossing routes, of which 1,038 exists in Austria. Some of them are located in very sensitive areas with high endangered fish species or birds. From that, hot spots can be derived, where to look precisely and where further and detailed surveys are needed. As part of the plans, sensitive areas should be protected against negative effects of these intensively used and important traffic infrastructures by taking effective compensatory measures.

Keywords: *riverine ecosystems***,** *hydromorphological impacts, railway infrastructure, river basin management, spatial analysis, sensitive river sections, conservation planning, sustainable transport*

Content

1. Introduction

Freshwater ecosystems are a basic requirement for life on earth. Early human settlements were located near rivers to scoop water and grow food on fertile soil (Fang and Jawitz 2019). Besides that, rivers served several purposes over the course of time: for cleaning and disposal, as transport routes, for power generation and as industrial production resource (Haidvogl 2018). The more intense land use became the more heavily rivers were regulated. The purpose of the channelization was to reclaim land for settlements and protect it from floods, but also to supply water and energy constantly (Petts 2006). Depending on the change of energy source from wood to fossil fuels in the eighteenth and nineteenth centuries, the enlarged regulation of rivers was enabled (Haidvogl 2018). This regulation measures also drained land, which enabled the broadening of human settlements and the cultivating of land.

Since the start of industrialization, mainly fossil fuel-based shipping and the act of reclaiming land has led to straightening of rivers and its morphology. According to Rockström et al. (2009), the changing of land use is to blame for degradation of ecosystems and habitat loss. Even Jäger et al. (2007) and Freitas et al. (2010) described transport infrastructure as a key to change land use. In addition, scientific papers showed that the construction of sewage-treatment facilities, flood protection measures and hydroelectric power stations have an impact on the hydromorphological river character, particularly interruptions in the river continuity (BMLUW 2010). Predominantly morphological and chemical-physical influences have been detected, which often are interacting (Schinegger et al. 2018). Here, i.e. hydropeaking hydropower plants affect rivers in numerous ways.

The technical development of railway systems is closely interwoven with the development of industrial production. The invention of steam and diesel-powered locomotives enabled people to swift goods in large quantities and higher speed, which was needed for maintaining industrialization (Cornwell 1976). Railway infrastructure became an important land-based transport infrastructure. It was mainly built in wetland areas and near rivers, where wheels were disadvantageous, because they sank in when the ground was wet (Stephan and Aufmkolk 2020). Railways are the most efficient means of freight transport in swampy terrain. Compared to the road, they have the advantage that the tracks can be laid quickly, are weather-resistant due to the track ballast body (frost damage) and have a better load distribution than wagon wheels. Moorbahnen are still in use today (Foos 2016). Another aspect is, that early railways were mainly built in riverside areas, because here the gradients were very low.

1.1. Transport infrastructure as a driver for pressures

Based on the DPSIR[1] scheme the past centuries have demonstrated that there are numerous external driving forces that can exert pressures on rivers and related ecosystems. Depending on the natural resilience and the degradation of the ecosystems, these affect the habitats and their inhabiting biota to a greater or lesser extent. Schinegger et al. (2013) could demonstrate that fish metrics respond specifically to water quality pressures and hydromorphological pressures. In all river types multiple pressures could be identified. Trautwein et al. (2012) showed that multiple land-use categories have effects on fish. The strongest correlation was between agriculture land use and European Fish Index

[1] DPSIR = short for driving forces, pressures, states, impacts and responses; an interdisciplinary tool with unknown author to conduct complex root cause research on environmental research issues

(EFI), which is a fish-based assessment method to observe the biological status of waterbodies (Breine et. al. 2005).

The interactions between riverine ecosystems and transport infrastructures have hardly been researched scientifically until the first decade of the 21st century. Since then various studies by researchers from America and Europe have been published. The amount of papers and studies dealing with interactions between transport and ecology is increasing since the IENE (short for Infra Eco Network Europe) initiative was formed. IENE[2] is a formalized non-profit network of experts both of ecology and transportation. In the year 2003, the first Conference, which title was "*Habitat fragmentation due to transport infrastructure & COST-341 action*", was the starting point for further debates about habitat fragmentation caused by infrastructure (Iuell et al. 2003). Their goal is to provide an independent area for exchanging knowledge and promote ecologically sustainable pan-European and international transport infrastructure. This comes about through researching on ecological problems, developing methods for the prioritization of mitigation and compensation measures.

The book "*Railway Ecology*" edited by Borda-de-Água et al. (2017) is one of the few available well-founded scientific works about railway effects on wildlife. It provides a wide scoped overview about the topic in general, but also specific monitor methods and case studies all over the world. The main aspects addressed are

(1) habitat fragmentation caused by transportation infrastructures with a focus on snails (Acsensao and Capinha 2017), birds and insects (Lucas et al. 2017), deers (Noro et al. 2012), frogs (Clauzel et al. 2013) and fish (Vo et al., 2015)

(2) changes of birds behavior around high speed railway (Malo et al. 2017), some species of bats and birds orientate themselves to linear structures (Vandevelde and Penone 2017)

(3) train collisions with wildlife (Seiler and Olsson 2017), seasonal movement routes of wild animals are cutted off by railway tracks, which leads to higher mortality (Noro et al. 2012)

Research studies about effects of railways on ecology are still underrepresented in science (Popp 2017).

Bekker et al. (2002) draws up measures for the prevention, mitigation and compensation of fragmentation effects caused by new road infrastructure. Karlson (2013) summed up the spatial assessments of fragmentation and disturbance trough transport infrastructure of grassland and forest birds in Sweden. But not only animals are affected by human infrastructure. Red listed ferns and flowering plants were recorded to be transferred by trains in Slovakia (Májeková et. al. 2015) and neophyta are increasingly growing along railway verges (Wermelinger 2020).

1.2. Impacts of railway infrastructures on riverine ecosystems

Austria has to achieve the quality target of the WFD, which is, that all surface waterbodies have to reach the "good ecological status", comprising over biological, hydromorphological and physical-chemical quality elements. Not everything that is likely to cause a bad quality status is well documented yet. According to the public consultation for the Water Fitness Check (European

[2] IENE = Infrastructure & Ecology Network Europe, www.iene.info

Commission 2019), transport was among the sectors with the largest number of replies pointing to incoherence between the transport sector and water legislation (124 replies out of 251). Transport sector predominantly means traffic and transport infrastructure like streets and railways. But, large rivers, like the Danube or the Rhine River, are navigable rivers. Obtaining a good navigation status results in changes of morphology and hydrology. But not only large rivers are affected by transport infrastructure developments, also small-scaled rivers suffer from impacts of human travel behavior.

Railway infrastructures are barriers for biota. Seasonal movement routes of wild animals and amphibians are cutted off by railway tracks. Some effects are documented mainly through terrestrial statistics of wild animals and surveys on fragmentation. There are yearly statistic overviews of animal-vehicle crashes, i.e. for roe deer, hare and fox, available (KFV 2020). Austrias nature conservancy associations document and publish observation data collected by voluntary helpers on www.naturbeobachtung.at. Less obvious, but not to be underestimated, is the effects on riverine ecosystems. In the COST-341 action handbook (Iuell et al. 2003) it is mentioned that every new infrastructure has to undergo detailed analyses during the environmental impact study. This also includes fragmentation impact assessment. The handbook shows, how barrier mapping could be done. Nevertheless, there is a lack of simple and uniform methods to display the interrelations of basic transportation infrastructure data regarding riverine ecosystems. Even a harmonization of EU-wide statistics is necessary. It can serve as a basis for evaluation of the objectives of the EU Water Framework Direction (WFD, European Commission 2000).

In Austria, mainly hydromorphological pressures combined with water-quality pressures could have been detected and are scrutinized well. For example, Schinegger et al. (2018) investigated the response of fish communities to single and multiple human stressors in the Drava and Mura catchments. Impacts on river morphology caused by human activities like flow regulations or dams are well documented in this study, too. Not only instream dams but also linear dams, straightenings and river bank stabilization are affecting lateral river connectivity and thus aquatic ecosystems (Habersack 2007). Often, railway infrastructure is a direct and an indirect driver of these pressures. Mount et al. (2011) developed a GIS-based modelling of fish habitats and road crossings for British Columbia. They quantified potential barriers for modelled fish habitats to improve the efficiency of fish passage remediation. Further, Diebel et al. (2014) investigated road crossings as barriers for stream connectivity for stream-resident fish using the example of the Pine-Popple River in Wisconsin. They can affect riverside and sensitive areas directly by the stream, i.e. in the form of bridge foundations or culverts built in the river. Bridges and culverts represent barriers to fish migration, too (Cooper et. al. 2017; Seliger and Zeiringer 2018). Crossings can also have an indirect effect on the river system, i.e. through emissions of dangerous substances or vibrations spreaded into the air and soil and their effects in fish assemblages (Pletterbauer and Unfer, 2015).

The most scientific studies mainly focus on road infrastructure and less on **railway issues**. There is no doubt, that the building and the maintenance of transport infrastructures have influence on the natural hydromorphological development of rivers, too. And indeed, small-scaled buildings like bridges and culverts are barriers for fish movements (Wightman and Taylor 1976; Dane 1978; Saremba 1984; Cooper et.al. 2017; Seliger and Zeiringer 2018). With special regard to long-term effects of interactions between railway infrastructure and riverine ecosystems, well founded scientific studies are rare. The study published by Clauzel et al. (2013) is a graph-based model about effects of a high-speed railway line on the distribution of the European tree frog in Eastern France. Clauzel et al. (2013) identified potential railway lines with the lowest impact on the species distribution. Múrias et al. (2017)

monitored shorebirds behavior and breeding during different construction phases of a new railway line. They found that the abundance was most reduced close to railways during post-construction phase. Godinho et al. (2017) dealt with a similar problem. They observed bird exclusion effects in a wetland caused by a railway bridge.

However, there is no explicit data on this matter, which shows that the ecological status of waterbodies is directly affected by land transport. It can be assumed, that land-based travelling could conflict with the objectives of the WFD. Although there are some studies available, it is recalled that there is a general lack of proper data and analysis methodologies for environmental assessment in general and especially with reference to transportation in Europe and European rivers (European Commission 2019).

1.3. Hypotheses

To close the information gap about interferences between railway transport and freshwater ecosystems, this thesis advances two hypotheses, which are to be tested and specified by additional questions:

- There are waterbodies in Austria where railway infrastructure exerts pressures on rivers. These are mainly of hydromorphological character.
  a) How many distinctive crossing points are there in Austria?
  b) How many of them are hydromorphologically stressed?
  c) Are there river sections, which are hydromorphologically stressed? As a result, can restrictions on fish passability also be expected?
- Besides waterbodies, there are other sensitive ecosystems which are affected by railway infrastructures. Here, protected areas, key habitats for aquatic and semi-aquatic animals and endangered species play a major role.
  a) Are there locations near railroads where several protected areas can be found and which are therefore particularly sensitive to impacts? Where are they located in Austria?
  b) Can certain ecological hot spots be defined from this multitude of different protected areas? Where can they be found in Austria?

This thesis aims to investigate the interrelations and interactions between railway networks and riverine habitats in Austria. It is going to show where railways directly and indirectly infringe upon riverine ecosystems and sensitive areas. It points out, what existing infrastructures means to the hydromorphological status of water bodies. The results may help to provide scientific and methodical fundaments to be considered for future railway plannings/management, river basin management as well as freshwater conservation planning activities.

3. Method

The used methods to localize different impacts are both numerous and analytic, based on GIS data and literature sources. At the beginning, suspected interactions between riverine ecosystems and railway infrastructures were verified by an intensive literature research. Next, basic spatial analyses about interfaces between railway network and aquatic ecosystems as well as a spatial prioritization of ecologically very sensitive water sections is conducted – both based on various GIS datasets at Austrian national scale (see Figure 1). Out of that, various maps were created, which show intersections, fragmentation sites, ecological hot spots, which are affected by railway infrastructure. By adding detailed data like bird areas and fish regions, it can be derived, which of these areas deserve more protection. Some species are particularly important, because they have diverse habitat requirements and their continued existence is vulnerable to threats. This applies, for example, to the European grayling that needs a heterogeneous river bank structure to reduce drift and stranding caused by hydropeaking (Auer et. al. 2016).

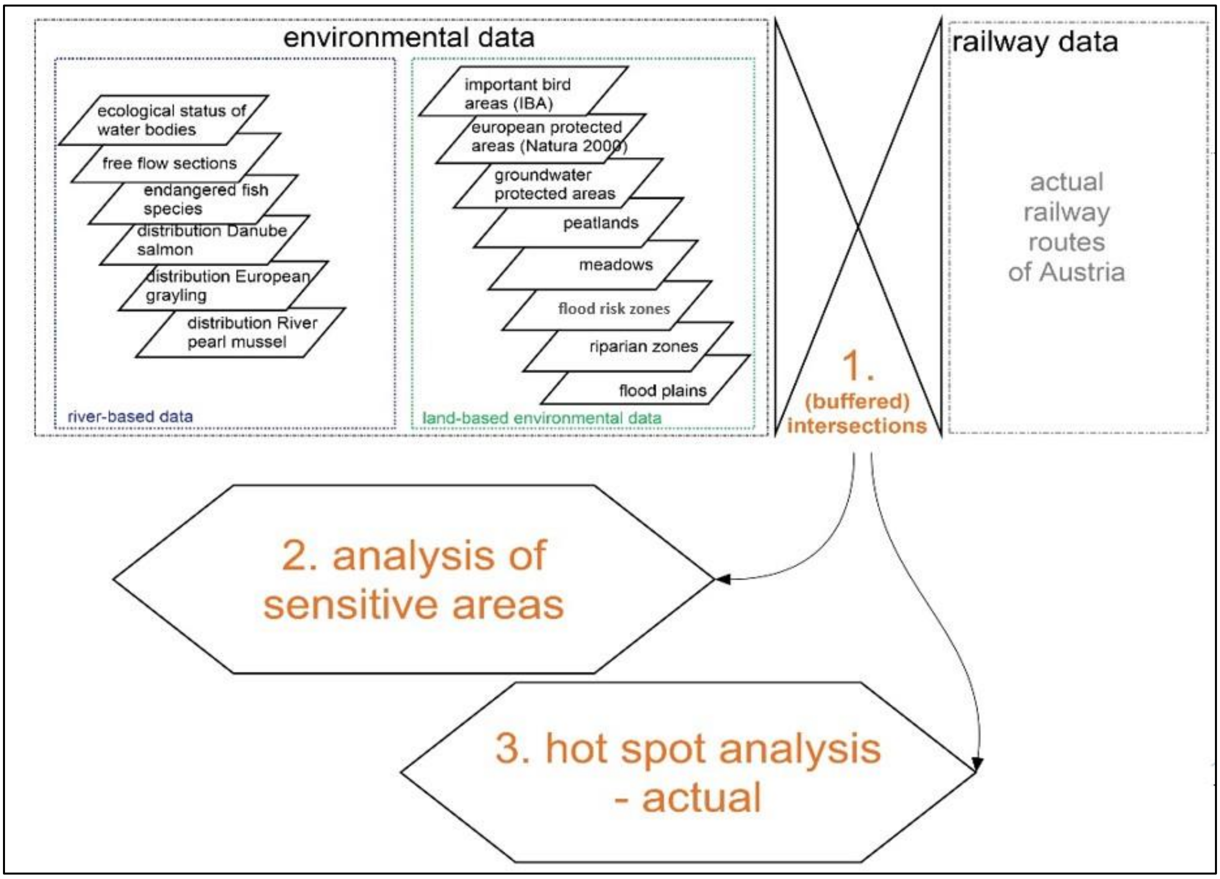

Figure 1: Schematic workflow

3.1. Spatial analysis

After brainstorming potential impacts and potential ecosystems, all required environmental data were collected and available GIS files were checked (metadata, completeness, useful attributes, transformation, etc.). For the spatial analysis ArcGIS 10.7.1 by ESRI was used. All spatial data were analyzed by displaying and intersecting in ArcGIS.

Intersections

Since there is no general overview about the interconnection between railway network and riverine ecosystems in Austria available, first of all a descriptive analysis had to be done. For this GIS-based shapefiles of railway network from the Austrian Federal Railways and river network according to RBMP 2015 were overlayed and combined with one another. Further, also the following datasets (see Figure 1 (1)) were used:

- European Protected Areas (Natura2000)
- Groundwater Protected Areas (ESG 2020)
- Riverine and riparian habitats like peatlands, floodplain forests (UBA, 2012) and actual and potential riparian zones (Copernicus datasets)
- flood risk areas (HQ30, HQ100, HQ300) (WFD)
- Important Bird Areas (BirdLife Austria 2020)
- Distribution areas of European teal, Common sandpiper and Common snipe (BirdLife Austria 2020)
- Distribution areas of Danube salmon (Hofpointner, 2013), European grayling (FDA 2015) and River pearl mussel (Ofenböck 1991)
- River sections with critically endangered, endangered and vulnerable fish species (Scharfling 2015, Seliger 2019 and Scheikl et. al. 2020)
- Free flowing sections (Scheikl et. al. 2020)

The reason why these were selected is described in Chapter 4.

The railway network file reflects the existing rail network in great detail. Each individual rail was mapped as a polyline. There are numerous shunting sidings near the station. Any linear or areal intersection or superimposition with other natural polygons would not have yielded useful results. Further use of this basic data was not useful in this state and therefore had to be generalised first. This step made sense especially for the railway station areas.

Identification of sensitive river sections along the railway network

All intersections between railway infrastructures and the result data sets are the basis for an analysis of sensitive river sections. The spatial intersections of the railway network with datasets described in Chapter 6 alone do not provide information about overall sensitive river sections along the railway network. For this reason, any points of contact of and distances with the railways were combined and superimposed. The resulting set of polygons enables a priority ranking based on various criteria. They are related to ecological status (Criteria *"Ecological status*") of rivers in Austria and the amount of superimposed valuable ecological habitats ("*Amount of overlapping polygons"*). They are intersections of the railway network (with a buffer distance of 50 metres) with the output datasets from Chapter 3 (see Figure 1 (2)).

Depending on how many polygons of all criteria meet at a certain point, they were filtered out according to their amount (see *Figure 2*) and summed up. The higher the "*Amount of overlapping polygons"*, the higher the value of these areas from an ecological point of view. Depending on the ecological status of waterbodies, the analysis results are differentiated into "*River sections with a preserving and protection need*" and "*River sections with potential for improvement*" (see Table 4 and Table 5). Thus, on the one hand waterbodies with a very good or good ecological status are designated as "*River sections with a preserving and protection need*" - regardless of whether additional areas worthy of protection are also located there. This comes, because according to the WFD all rivers have to reach the good ecological status. There is a no-deterioration principle for waterbodies with a good or a very good ecological status. Depending on if there are also designated protected areas from the list above, the level of conservation status increases. On the other hand, waterbodies with a moderate or worse ecological status are designed as "*River sections with riverine ecosystem connectivity*" - especially if there are protected areas or riverine and riparian habitats in the vicinity. In order to achieve a good ecological status for these waterbodies as well, it is important to restore their ecological functioning. This can be achieved, for example, by linking and connecting ecologically valuable ecosystems in the surrounding area, provided that the spatial conditions are suitable. Even here: The higher the amount of polygons, the higher the potential for improvement.

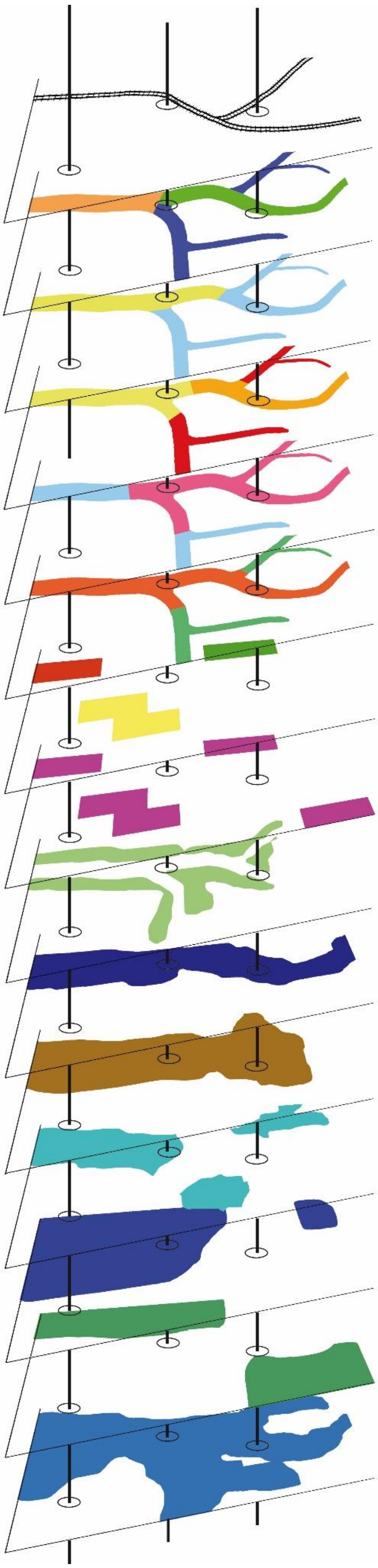

Figure 2: Schematic illustration of the Identification of sensitive river sections along the railway network

Hot spot analysis

The Identification of sensitive river sections along the railway network in Chapter 7 is a good method to get an overview of all riverine areas that are particularly valuable from an ecological point of view. An attempt has already been made to conduct a rough ranking of ecological sensitivity. The result is numerous area sections without any particular highlighting of hotspots. From the sensitive area analysis, areas are to be filtered out that require immediate protection status.

Out of the ranking, sensitive hot spots are to be found that should experience priority protection and preservation of ecological functioning. Therefore, a so called "Hot spot-analysis" was conducted to derive an initial priority ranking of areas where all selected criteria occur along the railway network. The hot spot analysis is to be understood as a supplement to the Identification of sensitive river sections along the railway network from Chapter 7. Hot spots are areas that are of particular importance due to their increased value of differently rated character traits out of the datasets from Chapter 3 and 4. The analysis in Chapter 7 determined whether a specific criterion applied or not. For example, a polygon was assessed according to whether or not the fish species Danube salmon occurred in this area. For the selection of the polygons, it was therefore decisive whether a criterion applied or not (yes/no). In the hot spot analysis, it is also taken into account that a criterion is likely to have a higher occurrence or a lower occurrence of Danube salmon. Areas of hot spots thus contain an additional valuation of the actual criterion. If a criterion (e.g. occurrence of Danube salmon) has several characteristics (dominant species or rare species), these were evaluated differently (Value 1 or Value 2). The values are to be understood as an allocation of points. The higher the value, the more points are awarded. Hot spots are highlighted as a cumulative view of thematically related criteria.

First, a grid analysis was carried out for the aquatic ecosystems. However, no useful results could be achieved. This is due to the fact that the amount of data was too large for flood plains. Therefore, the method of analysis was changed. Then, a vector analysis was carried out (ArcGIS tool: "*Intersect*"). Within the main influencing parameters, a weighting was made. The higher the degree of protection of the individual habitats, the more points (value) were awarded. When stacking on top of each other all of the relevant shapefiles classified points of contact along the railway network are resulting. The map demonstrates where hot spots of sensitive areas can be found (see Figure 1 (3)).

Originally, it was planned to also integrate the distribution areas of the river pearl mussel, but due to the limited tool possibilities, there would have been no tangible results, because there were too few common routes. Here, too, the raster analysis was abandoned and a vector analysis with the tool "*intersect*" was applied in order to obtain meaningful results. Therefore, the analysis combines river sections with endangered, critically endangered and vulnerable fish, especially river sections with Danube salmon and European grayling population with railways.

3.2. Statistical analysis

All available and produced GIS information was imported into proper data processing software for further analysis. Fish data are available as tables and were used for statistical analysis in Microsoft Excel. All railway infrastructures are going to be analyzed with regard to their importance on affecting habitat types. This step focused on the main expected hydromorphological impact.

4. Environmental data

4.1. River-based data

According to the EU-WFD, surface and groundwater bodies have to achieve a good ecological status until 2027. In addition, artificial and heavily modified waterbodies have to reach a good ecological potential. Every EU member state was required to file a report about the quality of its national water network and issue a programme of measures to improve the quality status. The first of three six-year planning cycles started in 2009, the second programme started in 2015 and the third in 2021. In Austria the reporting water network consists of rivers with a basin area size greater than 10km^2. In this master thesis, the reporting water network according to WFD was selected for all analyses.

There are no proper information about the ecological status of waterbodies for rivers with river basin areas smaller than 10 km². To answer the hypotheses the reporting water network is sufficient. This is due to the fact that the railway network is predominantly found in river basins larger than 10 km² (see Figure 3). Approximately 140,000 railway kilometres run through river basin areas larger than 500 km² (see Figure 4).

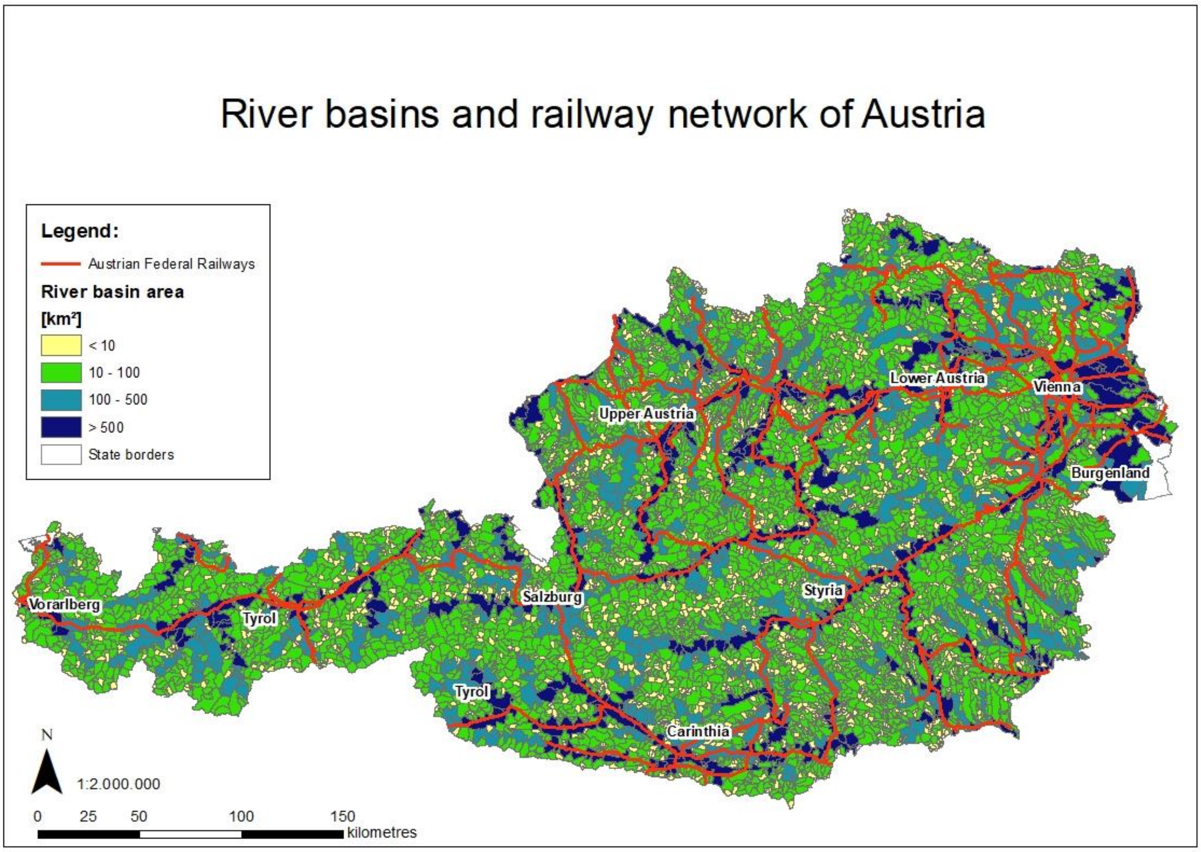

Figure 3: River basins and railway network of Austria

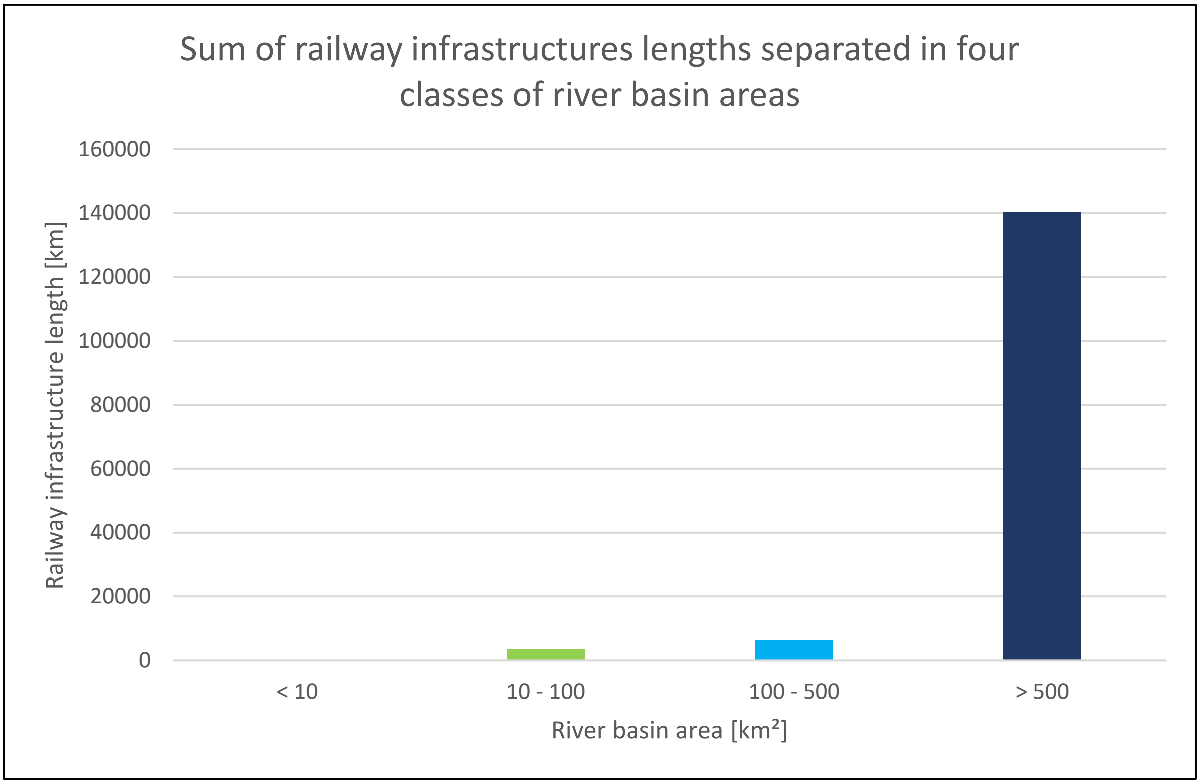

Figure 4: Sum of railway infrastructures lengths separated in four classes of river basin areas

4.1.1. Ecological status of waterbodies

The main environmental database that was analysed for this thesis, is provided by the Federal Ministry for Agriculture, Regions and Tourism. This comprises many data from the River Basin Management Plan (RBMP)[3] 2015 of Austria (BMLFUW 2015). According to the RBMP 2015, the assessed water network of Austria comprises 32,201 river kilometres, of which 38 % are assigned with a very good or a good ecological status, 31.5 % with a moderate status and about 18 % with a poor or bad status (see Figure 5).

[3] german: Nationaler Gewässerbewirtschaftungsplan (NGP 2015)

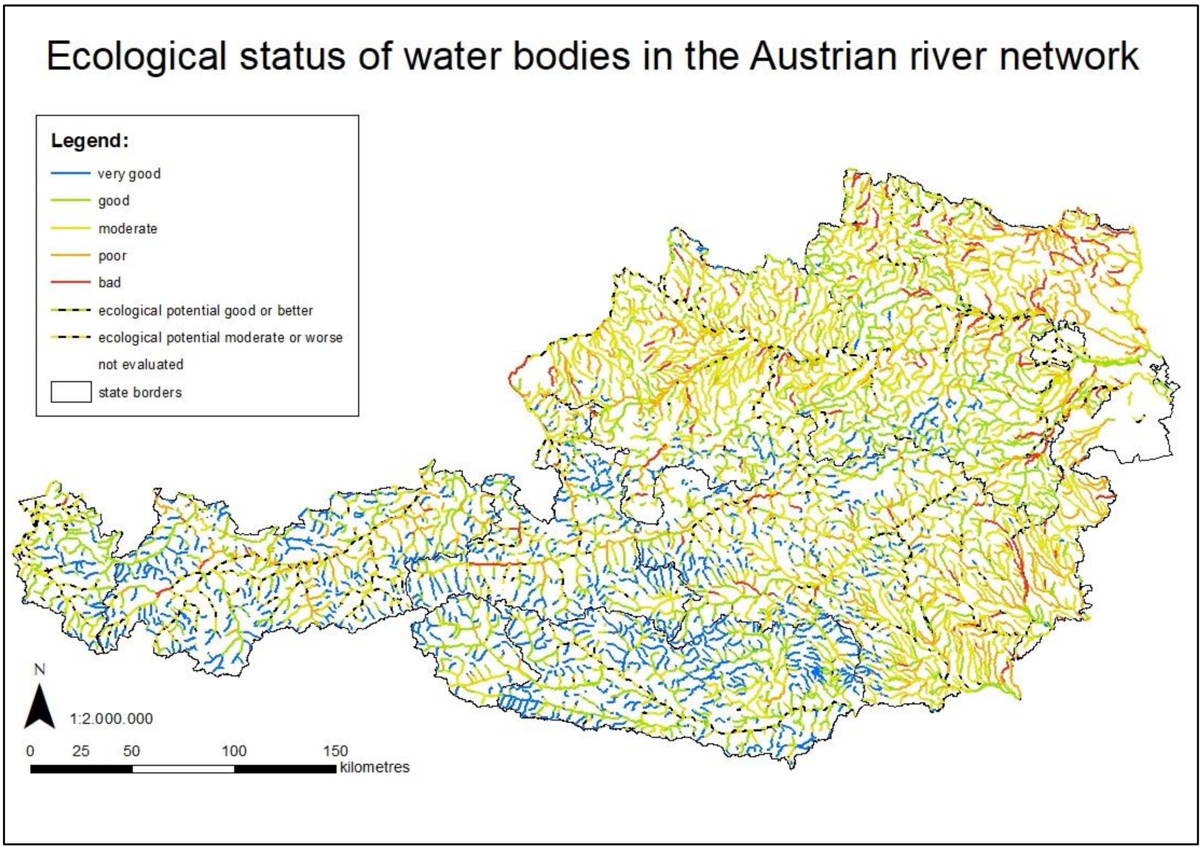

Figure 5: Ecological status of waterbodies in the Austrian river network (BMLFUW, 2015)

Category	Ecological status of water	Colour code	Ecological status	Biological status regarding material pollution*	Biological status regarding hydromorphological stress
Natural waters	very good		14,8 %	18,7 %	18,9 %
	good		22,9 %	58,0 %	24,5 %
	moderate		31,5 %	19,0 %	29,7 %
	poor		13,1 %	3,1 %	17,2 %
	bad		4,6 %	0,1 %	6,5 %
Artificial and heavily modified waters	ecological potential good or better		1,8 %	-	3,1 %
	ecological potential moderate or worse		10,2 %	-	-
No evaluation			1,1 %	1,1 %	3,1 %

* No differentiation is made between natural and artificial/significantly modified water bodies in the sub-states.

Figure 6: Status assessment of surface watercourses in Austria, indicated as percentage of the watercourse length (BMLFUW, 2015)

The ecological status is composed of two types of pressures. These are on the one hand the organic and nutrient pollution and on the other hand the hydromorphological pressures (see Figure 7).

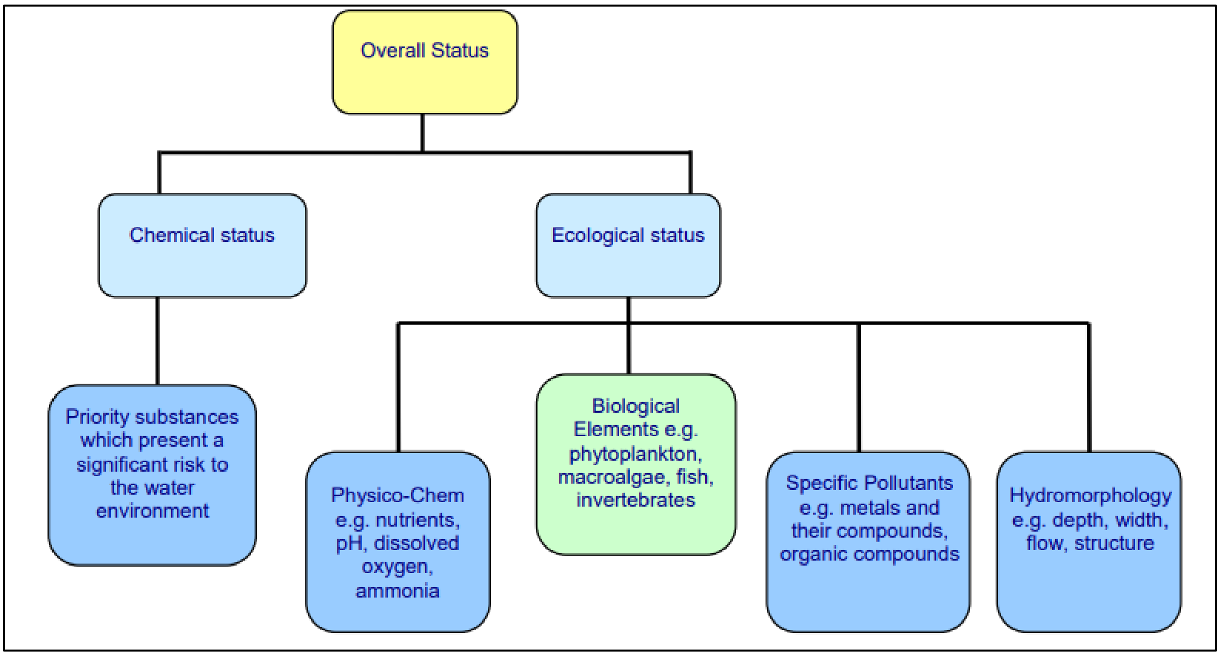

Figure 7: Compounds of the ecological status of waterbodies (Environmental Agency 2009)

Pollution is defined as organic contamination and nutrient pollution from point sources or loads from diffuse sources. To capture point sources, an electronic registry[4] was installed to record emissions from point sources like wastewater treatment plants with a capacity > 2000 population equivalents and industrial direct dischargers, i.e. International Pollution Prevention and Control (IPPC) plants. While the wastewater treatment pipeline has helped improve water quality in recent years, most diffuse inputs of nitrogen and phosphorus are emitted from agricultural and forestry uses. In addition, inputs of various herbicides and other pollutants like Polycyclic Aromatic Hydrocarbons (PAHs), heavy metals or ubiquitous substances from the area, which also reach Austria via long-distance transport, such as mercury, Polybrominated diphenyl ethers (PBDE) or tributyltin compounds were determined (BMLFUW 2017) in groundwaterbodies or are transferred to surface waterbodies. Railroad corridors are seen as emitters of some of these chemical substances for the further analyses (see also chapter 6.3).

In addition, waterbodies are subject to increasing hydromorphological pressures. These result from numerous and different measures, i.e. on drainage or regulation for flood protection, hydropower generation or inland navigation (mainly waterways), but it is also human settlements that lead to a change in the natural structure of aquatic ecosystems. In the River Basin Management Plan, human settlements are seen as a source of water pollution and as a driver that can influence pressures on the natural hydromorphological structures of surface waters. Railroad infrastructure are part of human settlements and can therefore alter the river´s hydromorphology.

[4] German: Emissionsregisterverordnung-Oberflächenwässer (EmRegV-OW) BGBl. II Nr. 207/2017

There are very few water sections left that have remained untouched from any influence. In the study published by Scheikl et al. (2020) only 17 % of Austrians reporting water network were defined as free flow sections, where no non-passable transverse structures, residual flow sections or dams exist (see Figure 8). Therefore, these must be preserved and not affected by additional stressors. This should be considered when new infrastructure links are to be built.

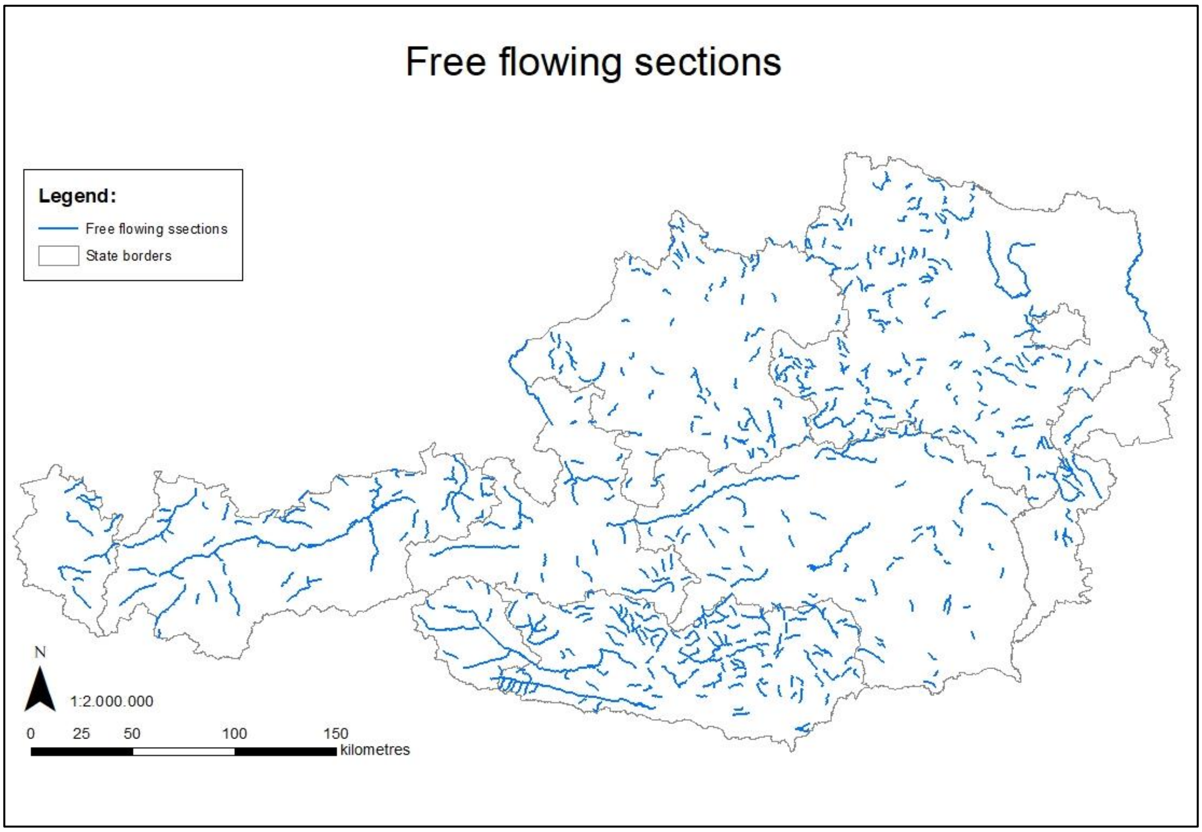

Figure 8: Free flowing river sections in Austria (Scheikl et al. 2020)

4.1.2. Fish data

Fish are representative indicators of the ecological status of waterbodies. International and national literature has already proven many correlation, especially with regard to hydromorphological and water quality pressures (Schmutz et al. 2015, Schinegger et al. 2018, López-López and Sedeño-Díaz 2014 and many more). As shown in chapter 1.1 it can be assumed that railway infrastructure is also a driver of these pressures, which then have an impact on waterbodies and ecology. This is reflected in the occurrence of fish species compositions that are no longer present or still present (but not in the original quantities). Waterbodies are divided into so-called fish regions. The Quality Ordinance Ecology[5] defines fish regions as biocoenotic regions that represent the longitudinal classification of running waterbodies which is based on the sequence of typical biocommunities. The fish habitat is subdivided into the biocoenotic regions of epirhithral, metarhithral, small hyporhithral, stone-loach brook, gudgeon brook, large hyporhithral, small epipotamal, medium epipotamal, large epipotamal

[5] german: Qualitätszielverordnung Ökologie Oberflächengewässer

and metapotamal. From this - depending on whether the expected fish populations occur in sufficient density and species composition or not - the ecological status of the waterbody is derived.

For the analysis direct fishing data from the Fish Database Austria (FDA 2015) (data based on measured fish population surveys) on the one hand and indirect data (derivation of potential fish species occurrence or index values) on the other hand were processed.

Direct fishing data:

- Distribution of endangered fish species
- Actual distribution of the Danube salmon
- Distribution of the European grayling

Indirect data:

- Ecological status of waterbodies: The ecological water status is determined from different assessments (see chapter 4.1.1)
- Potential fish species occurrence of Danube salmon

The Red List of threatened species contains 84 fish species, of which six are critically endangered, 18 endangered and 15 vulnerable (see Table 1). Scheikl et. al. (2020) extracted all threatened fish assemblages and mapped potential river sections (see Figure 9).

Table 1: Endangered, critically endangered and vulnerable fish species of the Red List Austria (Wolfram, G., Mikschi, E., 2007)

ENDANGERED	
Abramis ballerus (Linnaeus, 1758)	Zope
Abramis sapa (Pallas, 1814)	Zobel
Aspius aspius (Linnaeus, 1758)	Schied, Rapfen
Carassius carassius (Linnaeus, 1758)	Karausche
Cyprinus carpio Linnaeus, 1758	Karpfen
Gobio kesslerii Dybowski, 1862	Kesslergründling
Hucho hucho (Linnaeus, 1758)	Huchen
Lampetra planeri (Bloch, 1784)	Bachneunauge
Leucaspius delineatus (Heckel, 1843)	Moderlieschen
Leuciscus idus (Linnaeus, 1758)	Nerfling, Seider, Aland
Leuciscus souffia Risso, 1826	Strömer
Proterorhinus marmoratus (Pallas, 1814)	Marmorierte Grundel
Rutilus meidingeri (Heckel, 1851)	Perlfisch
Rutilus pigus (La Cepède, 1803)	Frauennerfling
Sabanejewia balcanica (Karaman, 1922)	Balkan-Goldsteinbeißer
Sander volgensis (Gmelin, 1788)	Wolgazander
Vimba elongata (Valenciennes, 1844)	Seerüssling
Zingel streber (Siebold, 1863)	Streber

CRITICALLY ENDANGERED	
Acipenser ruthenus Linnaeus, 1758	Sterlet
Barbus sp. (petenyi-Gruppe)	Semling, Hundsbarbe, Nudelbarbe

Coregonus sp. „Kröpfling“	Kröpfling
Gobio uranoscopus (Agassiz, 1828)	Steingressling
Misgurnus fossilis (Linnaeus, 1758)	Schlammpeitzger
Umbra krameri Walbaum, 1792	Hundsfisch

VULNERABLE	
Cobitis sp.,	Steinbeißer
Coregonus arenicolus Kottelat, 1997	Sandfelchen
Coregonus atterensis Kottelat, 1997, Reinanke	Attersee-Reinanke
Coregonus danneri Vogt, 1908	Riedling
Coregonus renke (Paula Schrank, 1783), Renke, Reinanke	Traunsee-Reinanke
Eudontomyzon mariae (Berg, 1931)	Ukrain. Bachneunauge
Gymnocephalus baloni Holčík & Hensel, 1974	Donaukaulbarsch
Gymnocephalus schraetser (Linnaeus, 1758)	Schrätzer
Lota lota (Linnaeus, 1758)	Aalrutte, Quappe, Trüsche
Rhodeus amarus (Bloch, 1782)	Bitterling
Silurus glanis Linnaeus, 1758	Wels, Waller
Thymallus thymallus (Linnaeus, 1758)	Äsche
Tinca tinca (Linnaeus, 1758)	Schleie
Vimba vimba (Linnaeus, 1758)	Rußnase
Zingel zingel (Linnaeus, 1766)	Zingel

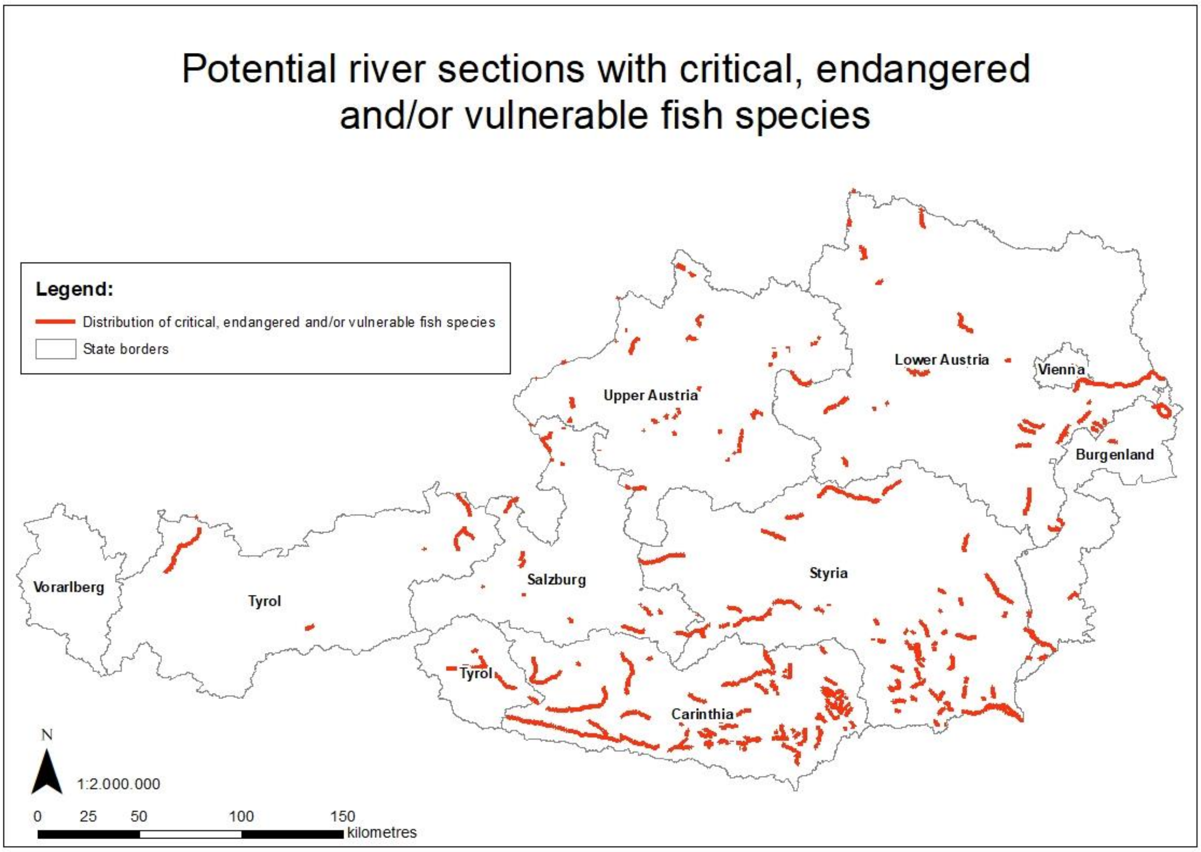

Figure 9: Potential river sections with critical, endangered and/or vulnerable fish species (Scheikl et. al., 2020)

To prove that fish assemblages can be affected by railways Austrians threatened fish species seemed particulary interesting. This is, because fish assemblages are a good indicator for river ecology, especially with regard to the hydromorphological condition. Schinegger et al. (2011) showed that not only the European grayling (Thymallus thymallus) but also the Danube salmon (Hucho hucho) are effected by hydromorphological and water quality pressures. For this reason these two fish species were chosen for detailed analysis. Out of this general available data two fish assemblages were extruded and cartography mapped.

Danube salmon (Hucho hucho)

An online fish lexicon describes the Danube salmon as an endemic fish species in the Danube catchment area. There it mainly inhabits submontane alpine rivers. However, it is detectable here in large hyporhitral and epipotamal rivers due to its average size of about 150 cm and about 60 kg. It prefers fast-flowing, cold, clear, and oxygen-rich waters with a diverse bed structure: The bottom of the water should be mostly gravelly. For adults, deep pools or quiet covers in the shade of overhanging trees should be available. Juvenile fish live mainly near gravel banks and sections adjacent to the main current with alternating shallow and deeper areas, as well as in areas of small feeders (WESO 2022).

During the spawning season in March and April, Danube salmons begin to migrate. They leave their traditional habitats and migrate upstream to smaller and shallower tributary waters or use the lower end of gravel bars – provided that the migration conditions of this middle distance swimmer (Jungwirth et. al 2003) are not limited, i.e. due to lack of fish ladders or hydrological impairments, that cause residual flows and thus lack of swimming & spawning habitats.

Hofpointner (2013) described the Danube salmon and its distribution in seven out of nine federal states in Austria. Only in Vorarlberg and Burgenland, no individual could be detected based on inadequate habitats/river regions and the occurrence in the Danube catchment only (see Figure 10).

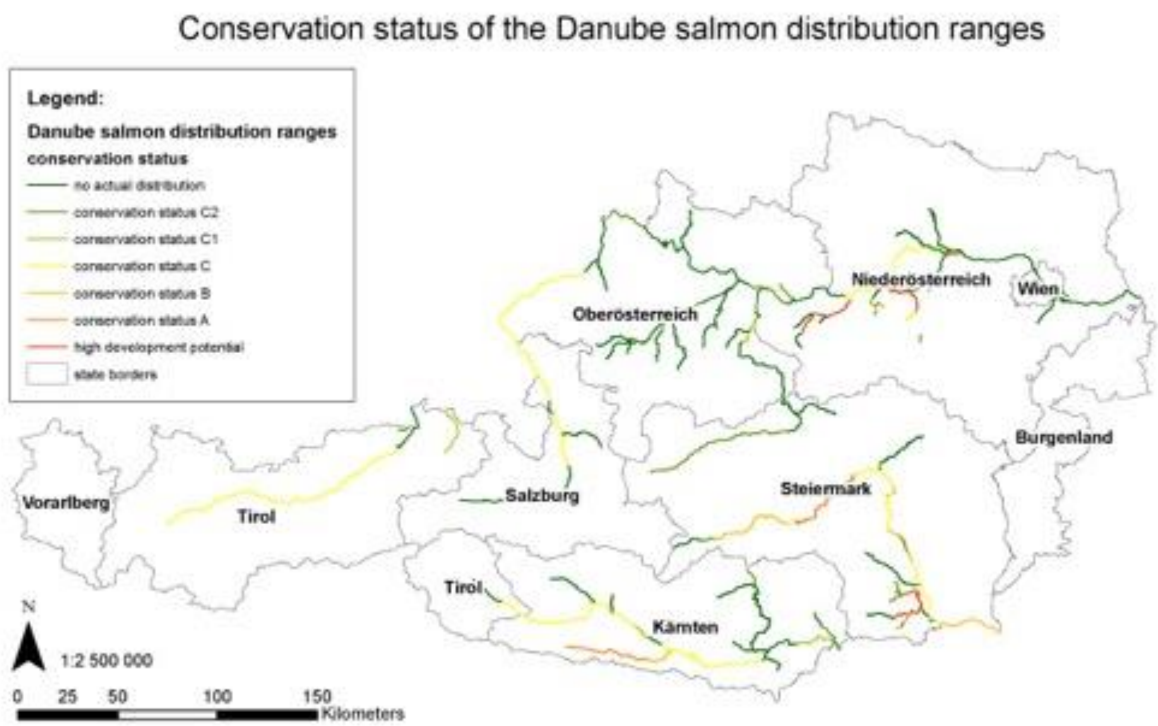

Figure 10: Conservation status of the Danube salmon distribution ranges (Hofpointner, 2013)

As Figure 10 shows, the historical range of the Danube salmon has been drastically limited by changes of stream characteristics. River channelization and the construction of transverse and longitudinal structures prevent the natural river morphological dynamics and the formation of a watercourse-typical substrate composition. Necessary habitats for assured reproduction and survival of this fish species are increasingly disappearing.

European grayling (Thymallus thymallus)

The European grayling is still common in every federal state of Austria. As Figure 11 shows the highest density of species occurrence extends to Upper Austria (Oberösterreich).

Even the European grayling belongs to the family of salmonids and is found in middle mountainous regions. Similar to the Danube salmon, the Grayling requires clear, cool water as a habitat and for spawning it needs shallow gravel bars. Heger (2011) sums up the most important information about this fish species: During the spawning act, structures such as dead wood provide visual cover and sought out as resting places. In case of danger, the Grayling does not seek cover under the stones like trouts. Without adequate structures they become easy prey for its predators like the cormorant especially in small rivers. The early larval stages stay on the water surface near the shore, while older larvae and small juveniles occupy sites near the water bottom at the edge of the main channel (shallow water zones). At night, they shift their habitats to the hyporheic interstitial[6], where they rest on the ground. Adult Grayling mostly inhabit mid-stream habitats and reside in larger streams and from late fall on, in deep water holes.

[6] Hyporheic interstitial = hyporheic zone: The region beneath and alongside the bed of a stream or river where the stream water and groundwater mix (Source: www.oxfordreference.com)

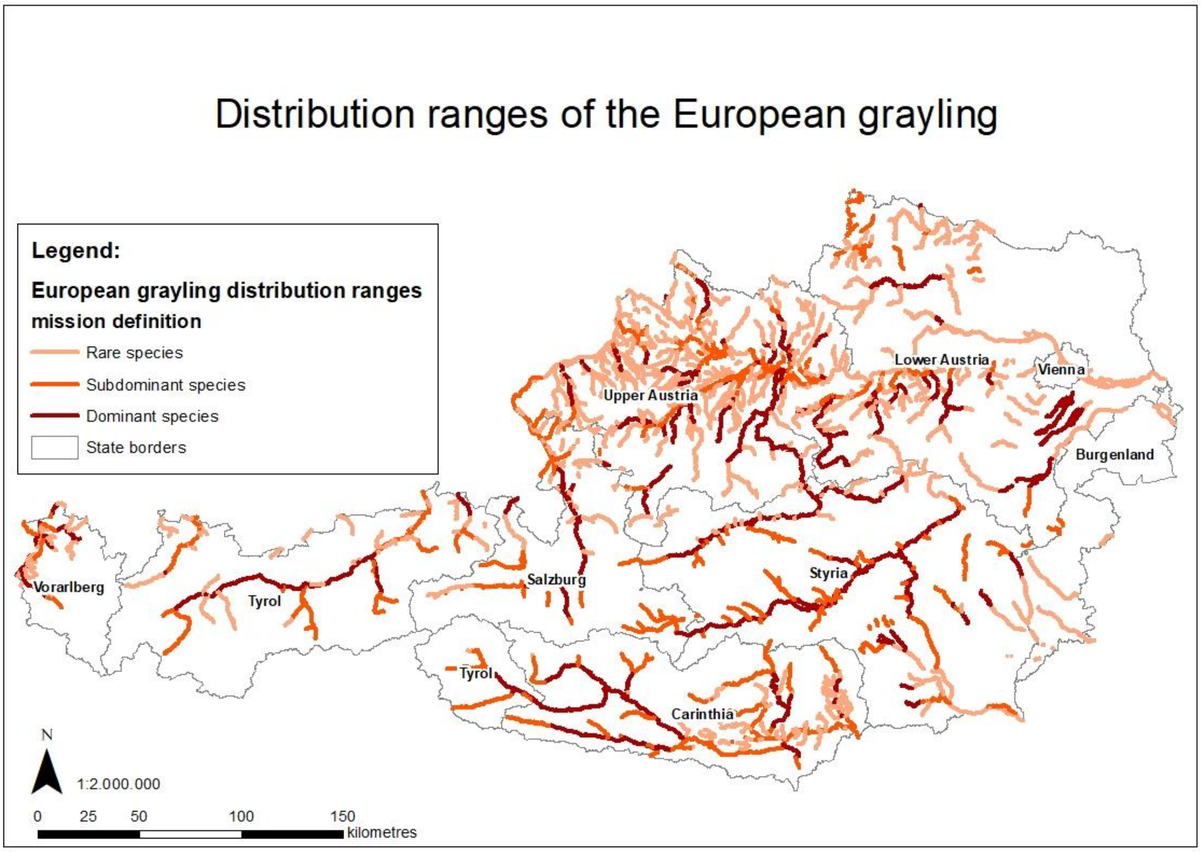

Figure 11: Distribution ranges of the European grayling (FDA, 2015)

In contrast to the Danube salmon, the Grayling is widespread in Austria. Due to its size it is a short distance swimmer (Jungwirth et. al 2003) and also inhabits smaller hyporhithral rivers that can meet its habitat requirements. But it could also be demonstrated that populations are declining significantly in Austria due to several causes. Even for the grayling, watercourse regulations, hydropower plants, water pollution, water warming and predators (Jungwirth et. al., 1995) are reasons through which population reduction may occur. Thus, changes in the river morphology, sediment abstraction, and hydrology of flowing waters due to power plants, weirs or bank and riverbed regulations have severely restricted the possibilities for natural reproduction of grayling locally (Wiesbauer et al. 1991; Uiblein & Jagsch 1994; Persat 1996).

4.1.1. River pearl mussel (Margaritifera margaritifera)

River pearl mussels are threatened with extinction worldwide (Moog et al. 1993). As seen in Figure 12 he specifies remnants in the northern Upper Austria, especially in the regions Mühlviertel and Waldviertel. The River pearl mussel has adapted in a special way to the special conditions of near-natural, low-calcium streams. They react very sensitive to changes in water quality, increasing inputs of fine sediments and altering feeding conditions due to changing land use. In addition, Gumpinger et al. (2002) found that also fish stocking, interruptions of flowing water conditions by impoundments (dams), protective hydraulic engineering and direct human destruction (pearl predation) have effects on reproduction and must be held responsible for the decline in species.

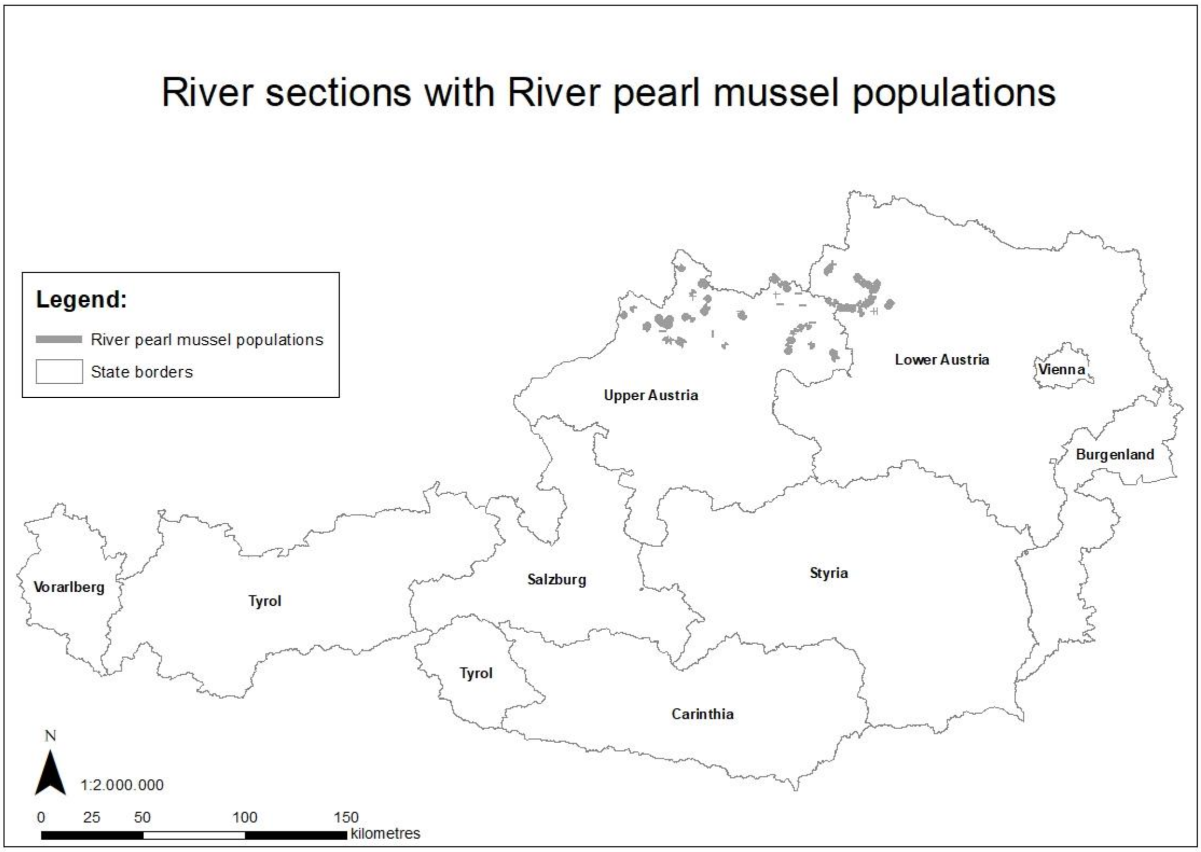

Figure 12: River sections with River pearl mussel populations (Moog et. al. 1993)

4.2. Other environmental data

4.2.1. Important bird areas and selected particularly endangered water birds

The BirdLife NGO designates Important Bird Areas (IBA), which are sites that are home to particularly endangered bird species (see Figure 13). Numerous threatened bird species throughout Europe find suitable resting or breeding places there or use them as wintering habitat (Berg 2009). The IBA and Red List provide an essential basis for the designation of bird sanctuaries under the EU Birds Directive (Directive 2009/147/EG). Red List species have also been sighted in these areas.

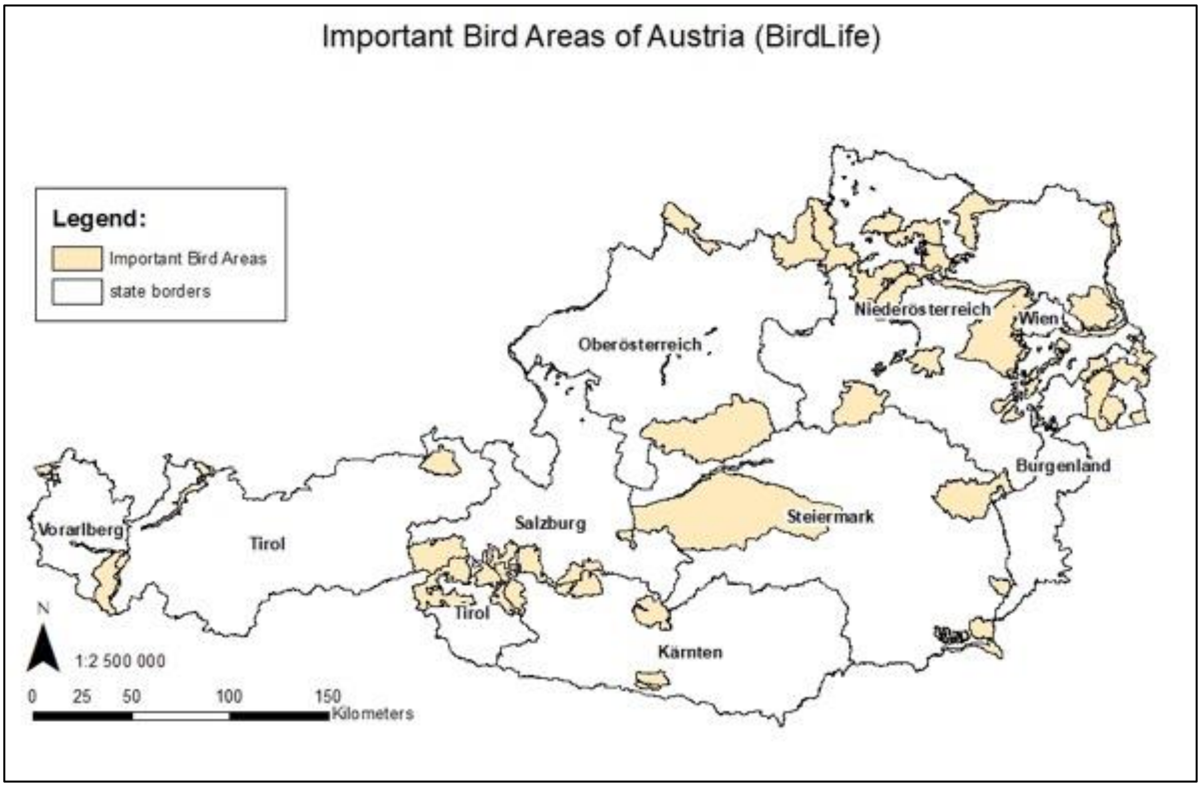

Figure 13: Important Bird Areas (BirdLife)

Three of these particularly endangered water bird species were selected for further analysis: Eurasian teal, Common sandpiper and Common snipe. All three were selected as priority waterbird species by BirdLife Austria as part of the Diversity Life III project (BirdLife Austria 2017). They are designated as Red List species and their conservation value was classified as very high. Dvorak (2021) provided the GIS dataset for further scientific processing within the framework of this Master thesis.

Eurasian teal (Anas crecca)

The smallest of the European ducks is native to all waters. It lakes to stay at small ponds, shallow water areas and can also be found in peatlands. It eats almost everything it finds in the silt and mud of the shore zones. Bauer et al. (2005) found out that the population declines due to habitat loss. Especially impairments to suitable breeding waters due to hunting and intensified agriculture. Even the destruction of peatlands (peat cutting) and drainage of land has negative effects on the population. Rewetting measures in nature reserves led to an increase in the breeding population regionally (Bauer et. al. 2005). Figure 14 shows the distribution areas of this bird in Austria.

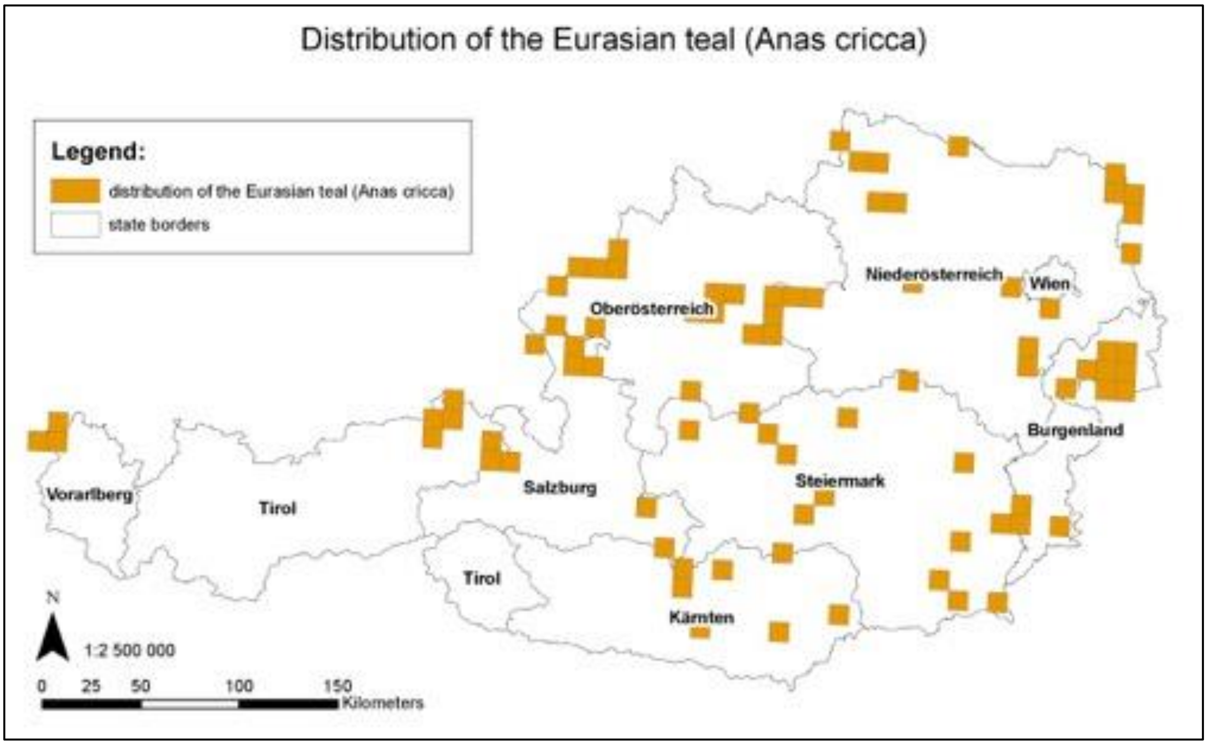

Figure 14: Map of the distribution of the Eurasian teal (Anas crecca)

Common sandpiper (Actitis hypoleucos)

The Common sandpiper is a wader and its home are stony river banks. For breeding it needs low vegetation and gravel banks on the shore or shallow riverbeds. Common sandpipers feed on small crustaceans, mollusks, spiders and insects that are to be found on the riverbank. It is endangered, because natural and undeveloped riverbanks with gravel bars have become rare (Hammer 2006). In Austria there are still some populations left (see Figure 15).

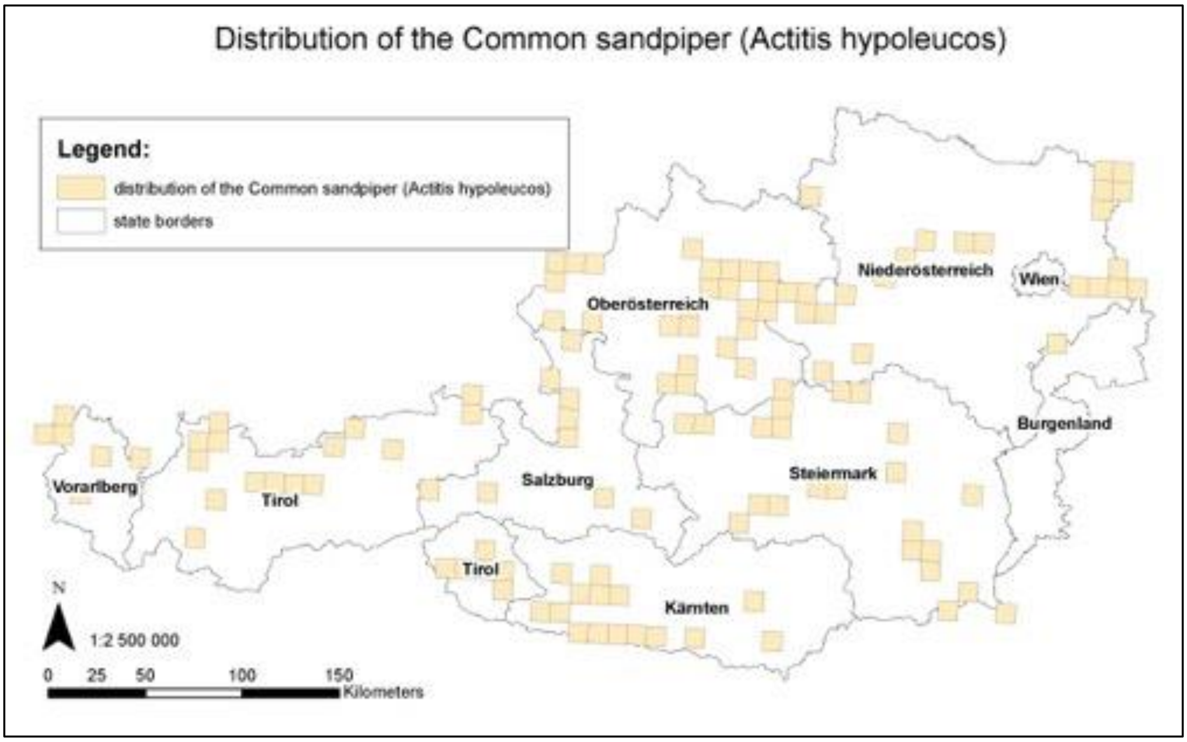

Figure 15: Map of the distribution of the Common sandpiper (Actitis hypoleucos)

Common snipe (Gallinago gallinago)

The Common snipe breeds mainly in wet floodplain forests, marshes and swamps in a hollow on the ground. Therefore it prefers dense vegetation. During the migratory season they rest on muddy areas, at ponds and ditches and at the edges of waterbodies. It has a long beak which it needs to poke at the mud for food, i.e. gnats, beetles and hoverflies. The loss of bods and wet grassland is causing a population decrease (NABU 2012). In northern, eastern and in the far west of Austria there are remnants of these species left (see Figure 16).

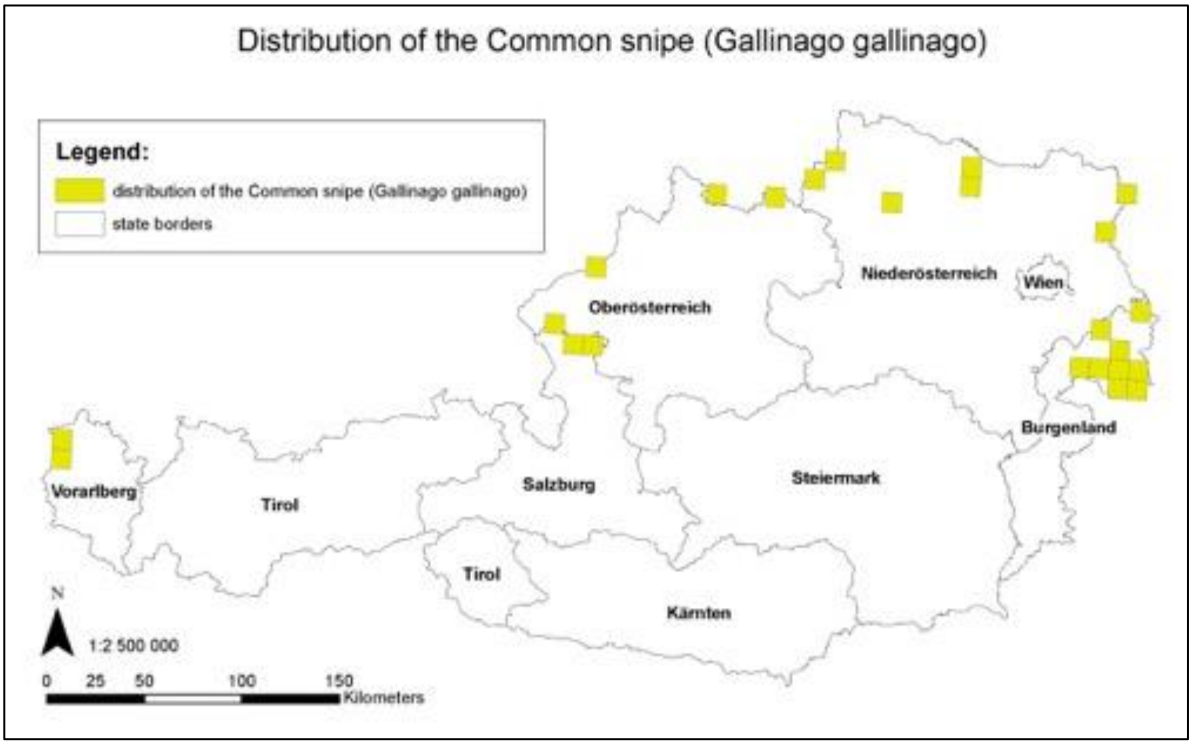

Figure 16: Map of the distribution of the Common snipe (Gallinago gallinago)

4.2.2. European Protected Areas (Natura 2000)

Exactly 13 years after the Birds Directive the Directive 92/43/EEC of the European Council from 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Natura 2000) was adopted. It is known as the Fauna-Flora-Habitat Directive or Habitats Directive. Its goal is to "safeguard biodiversity by conserving natural habitats and wildlife." The member states nominate significant "Sites of Community Interest" and are obliged to maintain or restore a favourable conservation status. Together with the protected areas under the Birds Directive, they form the Natura 2000 network (see Figure 17). The GIS dataset visualised in the map is available as open source at www.data.gv.at.

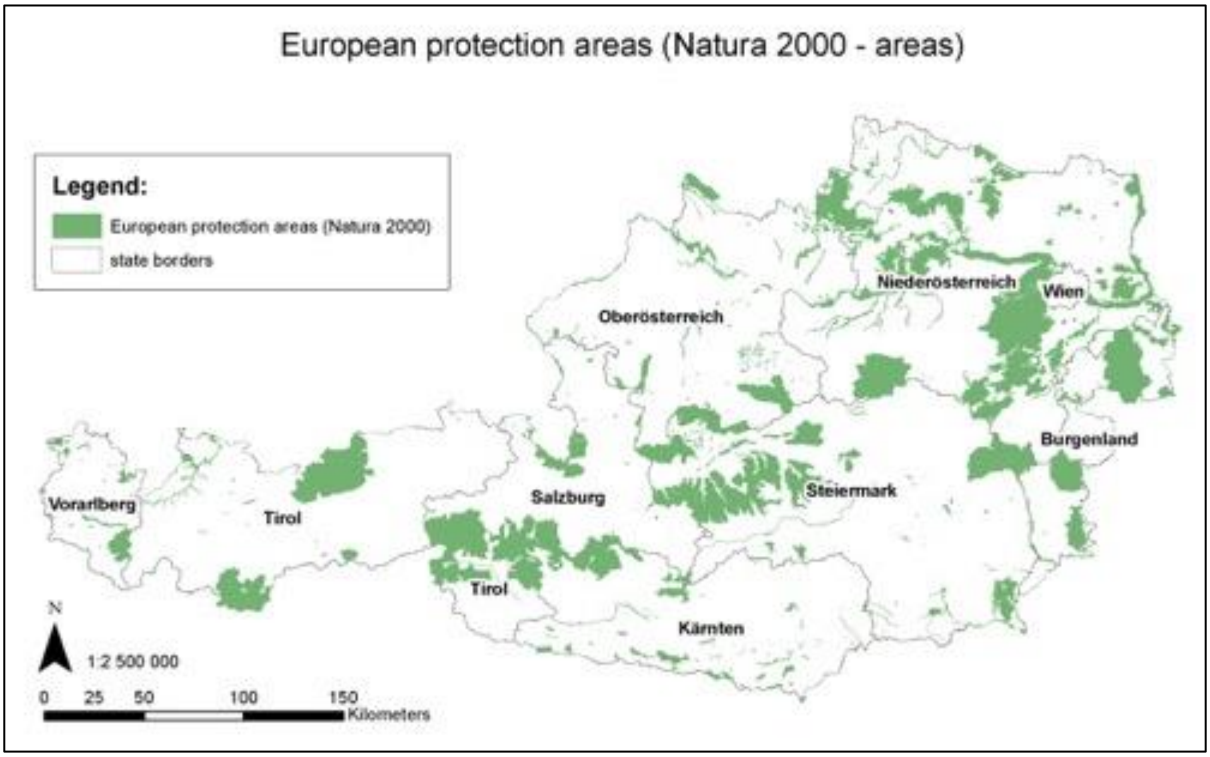

Figure 17: European protection areas (Natura 2000 areas)

In Austria there are 352 areas, which are declared European protected areas by the provincial governments through ordinances and which begin with the code designation AT. A further 106 areas border on Austrian territory or lie partly within the boarders and were designated with the country codes of the neighbouring states. Every project that is to be realized in European protected areas requires a permit from the provincial government. It is checked whether the project does not conflict with the protection purposes of the Natura 2000 Directive. The permit can be granted only in case of overriding public interests. In many cases, compensation measures are prescribed. The compensatory measures must cancel out negative impacts in that way that the ecological function of the Europe-wide Natura 2000 network of protected areas is maintained (Land Salzburg 2021).

4.2.3. Groundwater protection areas

Zones may be established by ordinance to protect water supply facilities against contamination or against impairment of their yield (EU Groundwater Directive, GWD[7]). It contains prohibitions or regulations on the management or other use of land and water in these areas. Thus, the construction of certain facilities can be prohibited or the operation of existing facilities and undertakings can be restricted to the extent necessary.

In Austria about 5.734 squarekilometres of groundwater protection area are designated. The GIS dataset visualised in the map (see Figure 18) is available as open source at www.data.gv.at.

[7] Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration

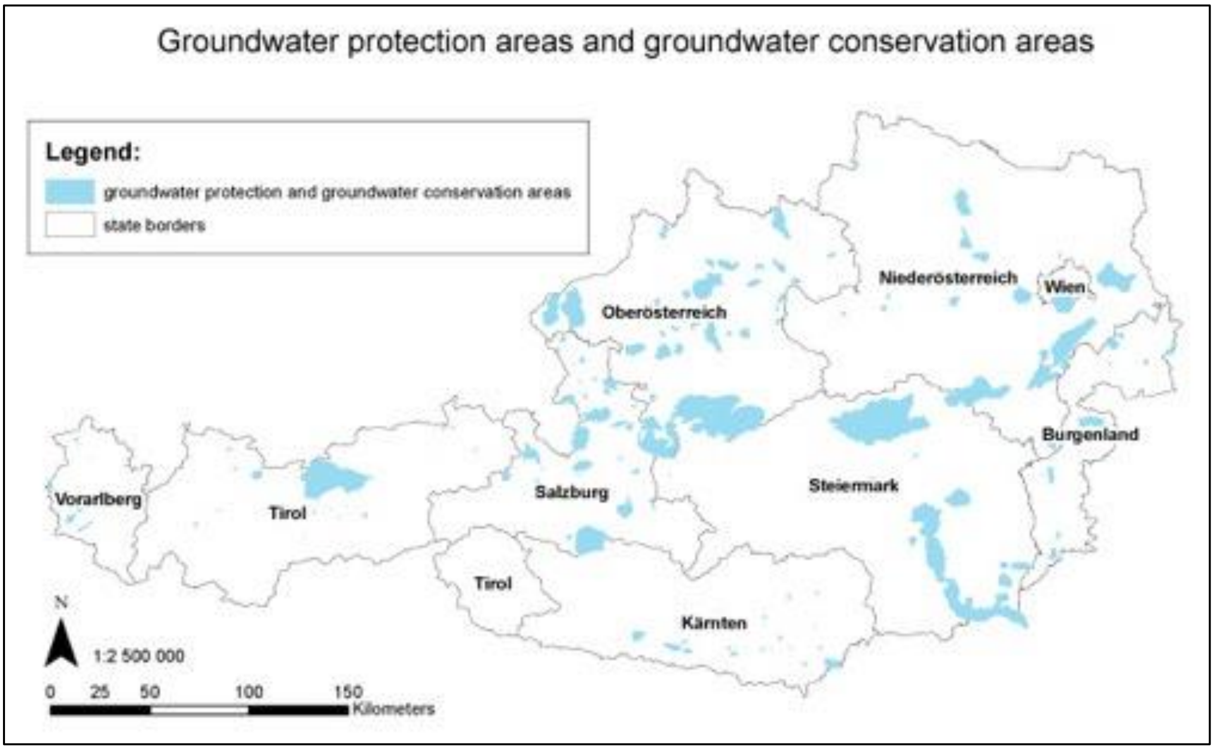

Figure 18: Groundwater protection areas and groundwater conservation areas

4.2.4. Aquatic ecosystems

Peatlands

Austria is covered by approx. 21,000 ha (up to 30,000 ha) of peatland, but particular in the Alpine region there are significant gaps in the data collection (Umweltbundesamt 2021, see Figure 19). The peatland strategy of Austria (BMLRT 2021) highlights the importance of peatlands as an important semi-terrestrial ecosystem: peatlands obtain their water requirements from precipitation and soak up rainwater like a big sponge. They store water and release it with a delay. Peatlands have also the ability to store carbon. This storage capacity has a balancing effect on the local climate and play an essential role for the climate and water balance. The diversity of peatland types thus implies a corresponding diversity of typical fauna and flora where rare animal and plant species find their habitat. The peatland strategy of Austria points out that peatlands are also extremely sensitive ecosystems. What has been lost or destroyed is difficult or impossible to restore on a human time scale. It is therefore all the more important and urgent to preserve and conserve the remaining remnants and to rehabilitate already damaged areas as far as possible.

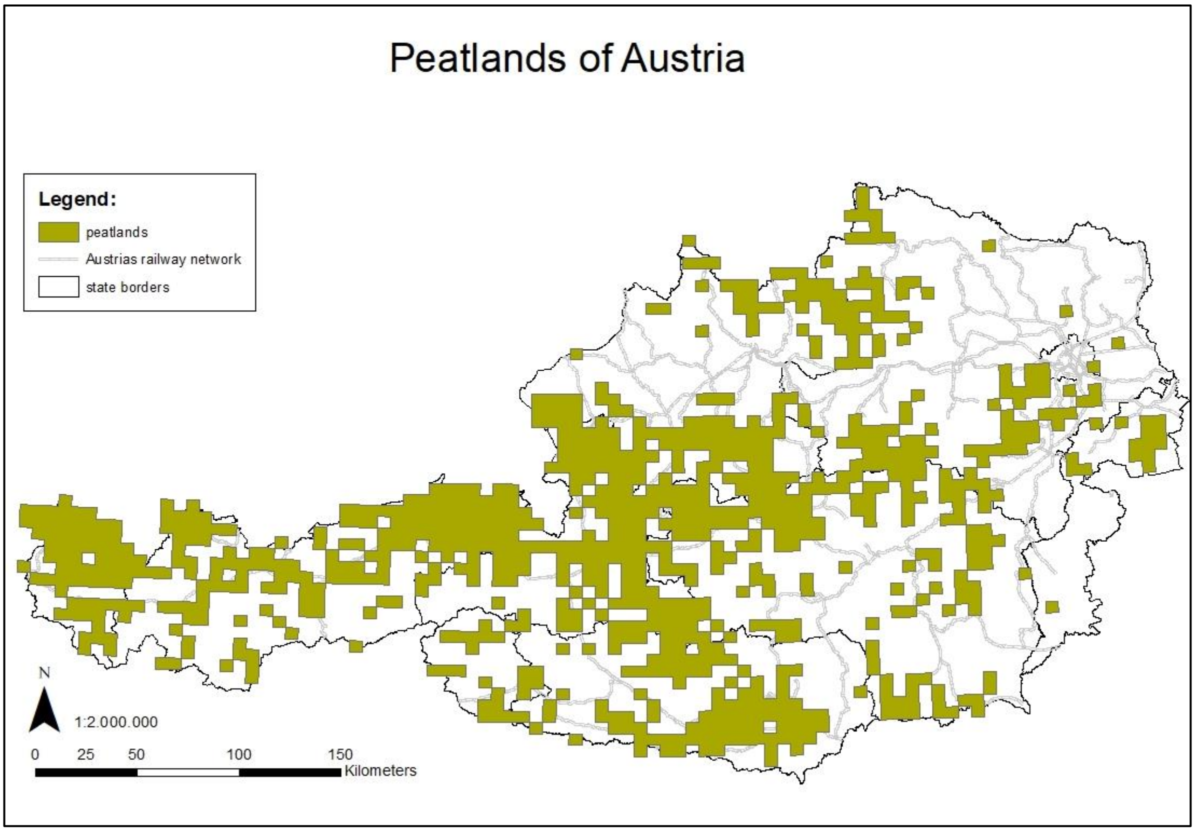

Figure 19: Map of peatlands of Austria (Umweltbundesamt 2015)

Floodplain forests

Floodplain forests fulfil numerous functions. They have an extraordinarily high biodiversity and fulfil many ecosystem services. For example, they can hold back floods and bedload, store nutrients and CO_2, promote groundwater recharge and serve the production of wood and other goods. They also form important recreational and nature experience areas (BMLFUW 2015). The Austrian Floodplain Forests Strategy 2020+[8] pursues the goal of conserving these ecosystems and restoring degraded ecosystems. The cartographic basis data is the floodplain forest inventory[9] and is produced by the Naturschutzbund and displayed in Figure 20.

[8] German: Auenstrategie 2020+ (Source: https://info.bmlrt.gv.at/service/publikationen/wasser/Auenstrategie-fuer-Oesterreich.html)

[9] German: Aueninventar

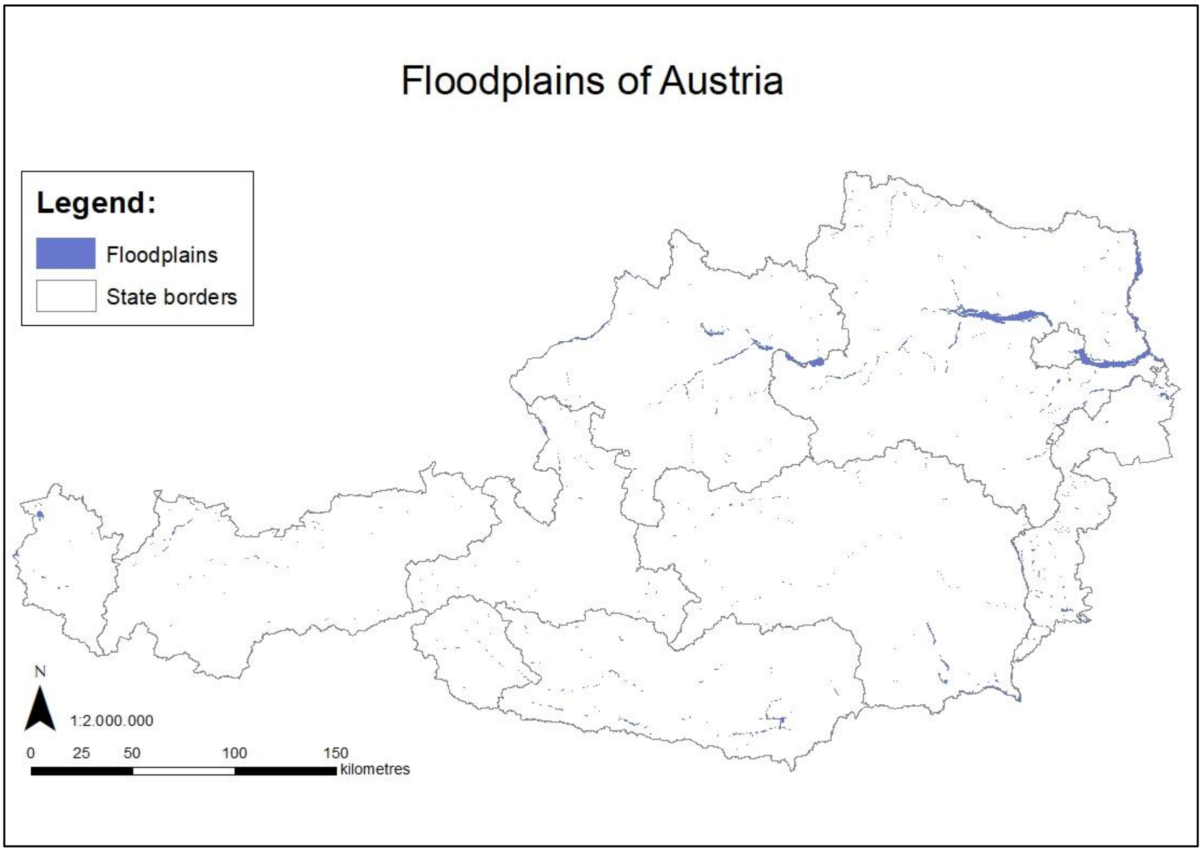

Figure 20: Floodplain forests of Austria (according to Floodplain inventory 2011)

Wetlands

Wetlands are areas in the transition zone from dry to permanently wet ecosystems. The Ramsar-Convention[10] defines the term "wetland" comprehensively: these are, among others, marshes, bogs, wet floodplain forests, shallow water areas up to a depth of eight metres, rivers and their estuaries. The Ramsar Convention is an international agreement "for the protection and wise use of wetlands". Since its foundation in the Iranian city of Ramsar on the Caspian Sea in 1971, 160 states have signed this convention (BMLRT 2021). The Wetland inventory[11] by the Umweltbundesamt (2012) includes the Ramsar sites of Austria as well as over 800 peatlands, lakes, river sections, riparian forests, etc. Figure 21 shows all of them in a map.

[10] Ramsar Convention on Wetlands, www.ramsar.org

[11] German: Feuchtgebietsinventar

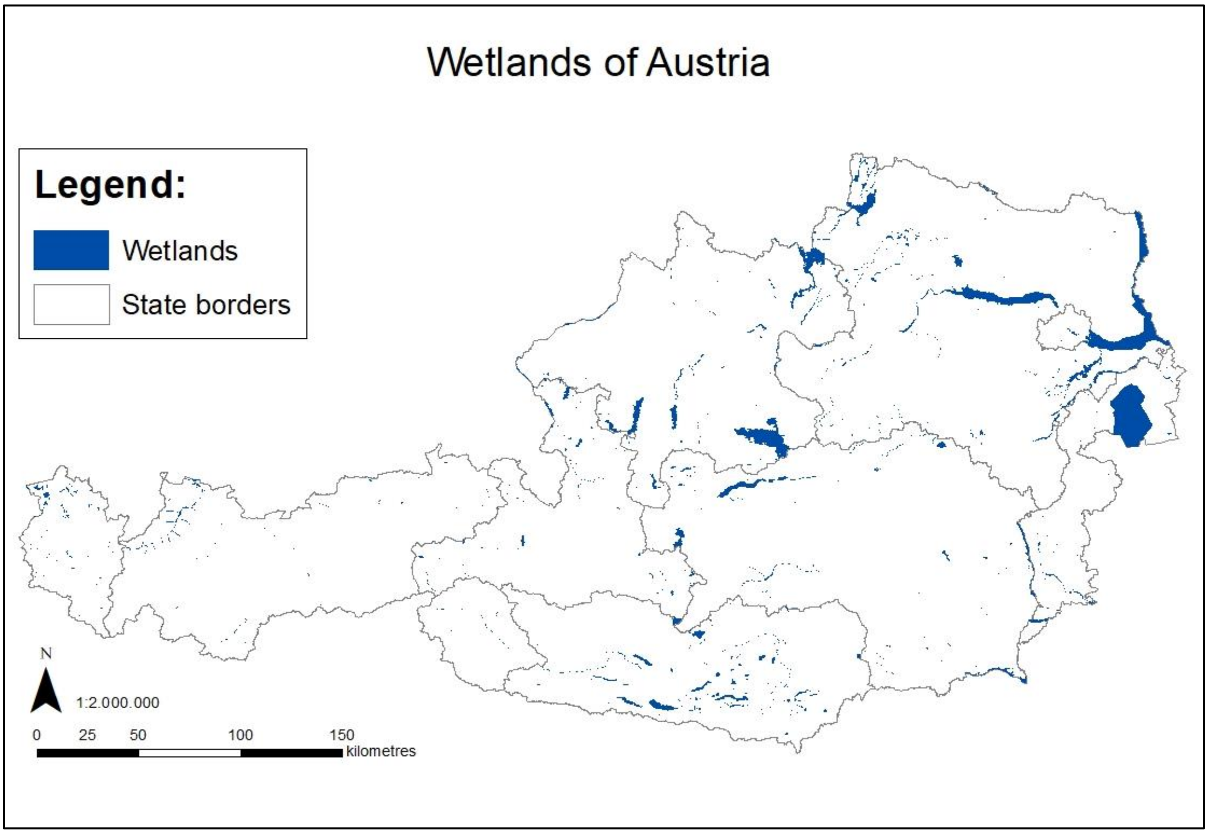

Figure 21: Wetlands of Austria (according to Wetland inventory 2012)

Riparian zones

Copernicus, the European´s Union´s Earth observation program [12], defines riparian zones as "*transitional areas occurring between land and freshwater ecosystems, characterised by distinctive hydrology, soil and biotic conditions and strongly influenced by the stream water. They provide a wide range of riparian functions (e.g. chemical filtration, flood control, bank stabilization, aquatic life and riparian wildlife support, etc.) and ecosystem services*." It makes the claim that the Riparian Zones products will support the objectives of several European legal acts and policy initiatives, such as the EU Biodiversity Strategy to 2030, the Habitats and Birds Directives and the Water Framework Directive. The data derives from The Land Cover/Land Use (LC/LU) classification which is extracted from VHR satellite data and other available data. It is a unique product with a high level of detail (Minimum Mapping Unit (MMU) is 0.5 ha).

For this master thesis the actual and the potential riparian zone was extracted for Austria and mapped in Figure 22. The observable riparian zone is an enveloping representation of these two and has not been presented.

[12] https://www.copernicus.eu/de

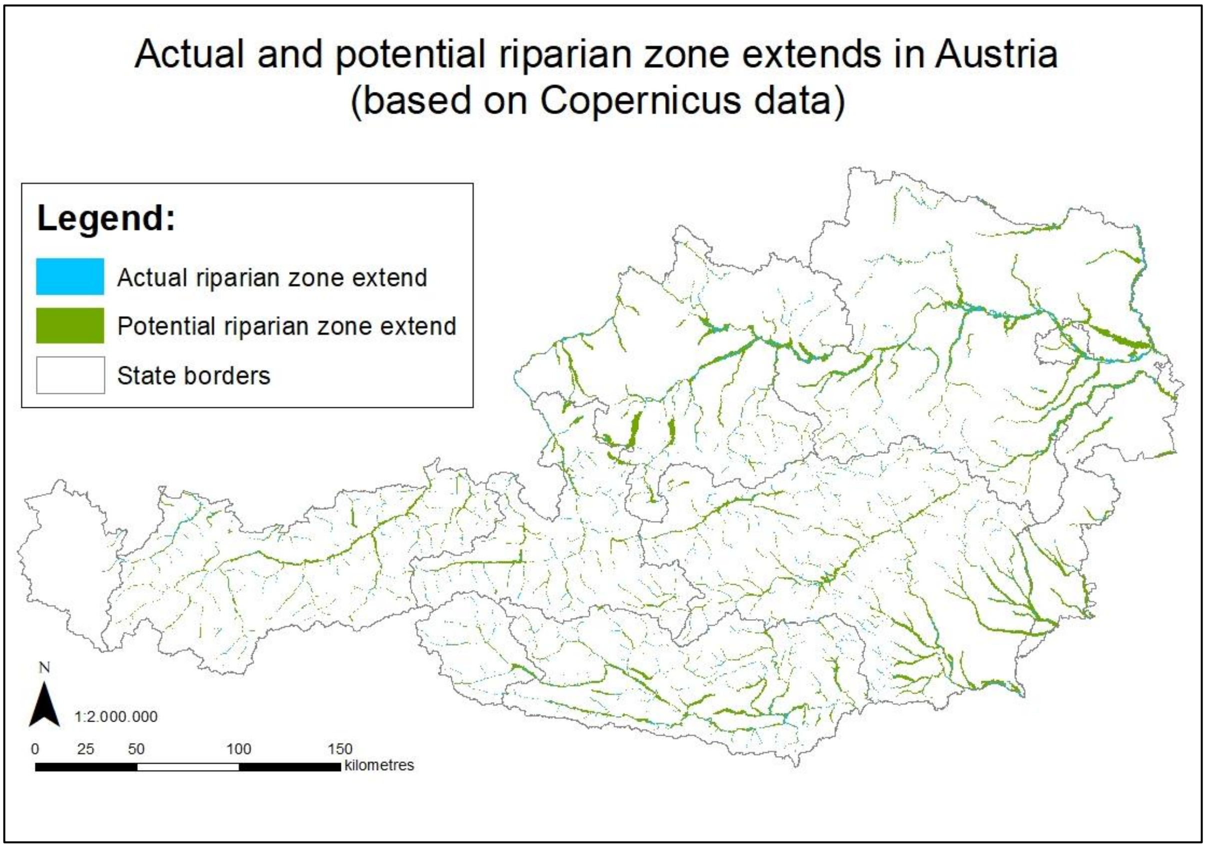

Figure 22: Actual and potential riparian zone extends in Austria

4.2.5. Flood risk areas

Floods occur at irregular intervals. Strong snowmelt due to sudden, rapid rise in temperature or long-lasting large-scale heavy rainfall can be reasons for that. The classification of floods is based on the so-called "annuality". The term describes the probability of the occurrence of a flood with the associated discharge volume. For example is a 30-year flood (HQ_{30}) statistically observed on average once in thirty years.

In Austria, the Flood Risk Management Plan (FRMP 2015[13]) is a management tool referring the EU Floods Directive to reduce flood risk. Flood areas should be kept free from intensive human activities in the future. While natural retention areas, such as floodplains, serve as passive flood protection settlement areas must be protected from floods. In the course of the detailed planning for flood protection all relevant spatial information (this also includes transportation plannings for railways) is collected and elaborated in consideration of the legal basis.

The FRMP 2015 states that for about 37,400 kilometres of surface water and lakes in Austria flood risk areas with annualities of HQ_{30}, HQ_{100} and HQ_{300} are available (BMLFUW 2015). These are mapped in Figure 23. The risk assessment has defined 5,5 % of river sections on very high or high flood risk, so called “Areas of potential significant flood risk (APSFR)”. The FRMP 2015 also states that 67 km railway

[13] FRMP2015: RMP_2015_barrierefrei_WISA.pdf (bml.gv.at)

infrastructures are in the 30-year flood risk, 143,3 km in the 100-year flood risk and 258,2 km in the 300-year flood risk area.

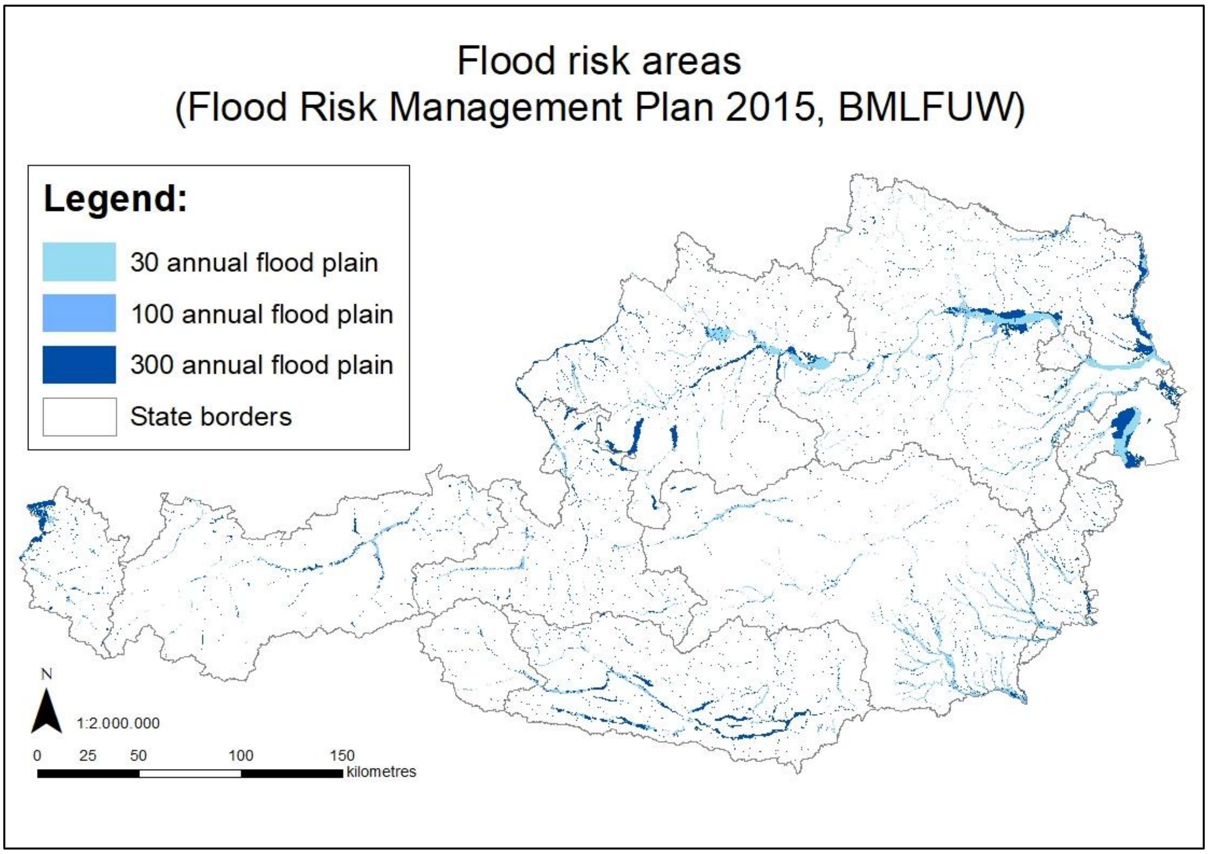

Figure 23: Flood risk areas of Austria

5. Railway data

The railway data is provided as open source by the Austrian Federal Railways[14]. Austria's railway network consists of 159 main routes. Together with 98 side routes (connecting tracks, supplementary railroads) the ÖBB network counts about 5.000 railroad kilometres. Most of them are located in Lower Austria (Niederösterreich). The fewest kilometres lead through Vorarlberg (see Figure 24 and Figure 25).

[14] German: Österreichische Bundesbahnen ÖBB

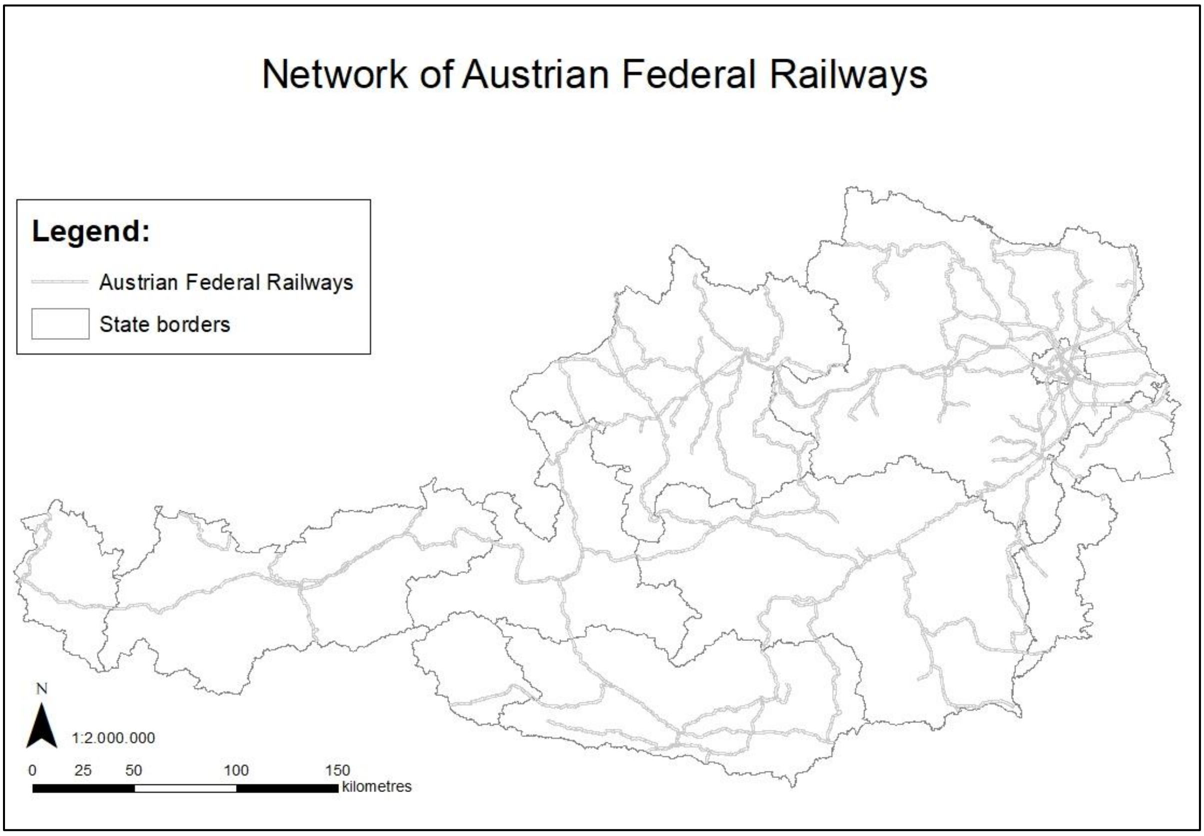

Figure 24: Map of network of the Austrian Federal Railways

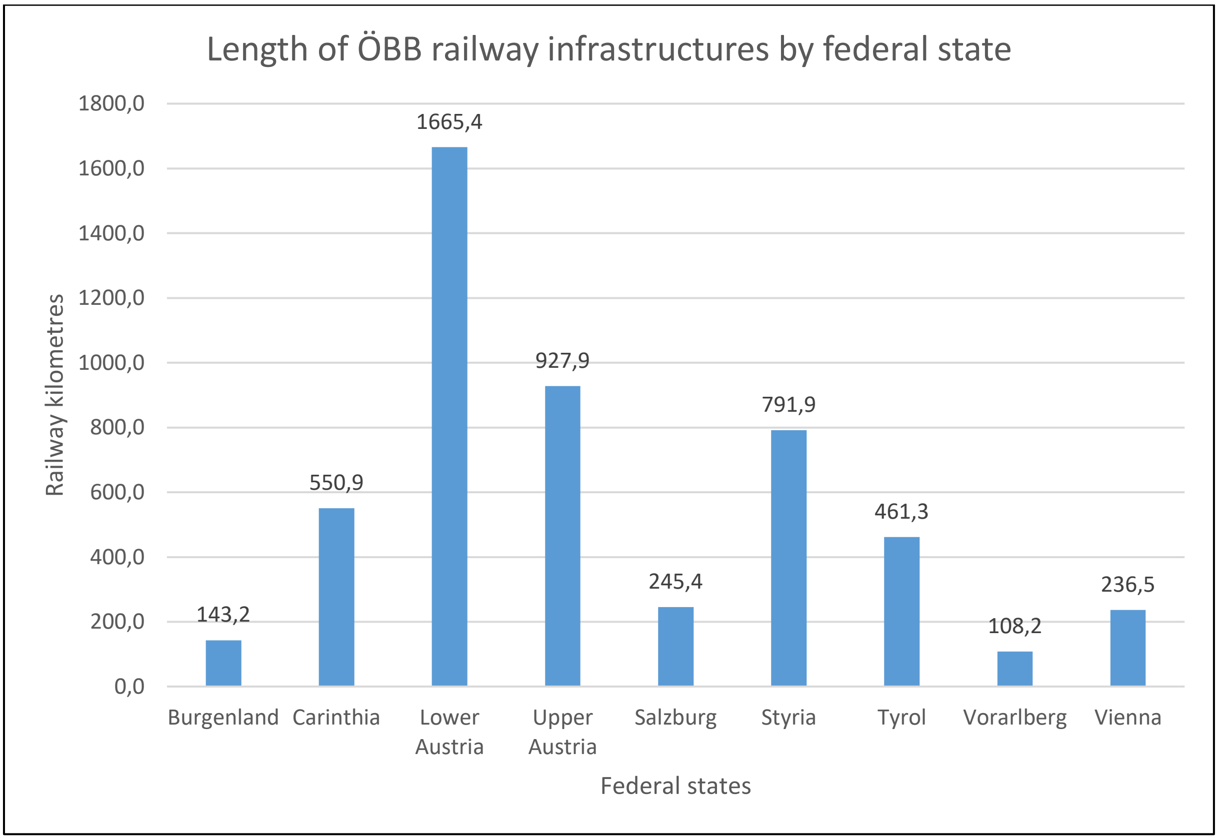

Figure 25: Length of ÖBB railway infrastructures by federal state

Some of the Austrian railway tracks are part of the European network of high prioritized main routes, a so called Trans-European Transport Network (TEN-T). It includes the most important railway routes, roads, waterways and airports. Roads and tracks are part of the "Core Network Corridors (CNC)", which are the most important long-distance traffic flows and serve the purpose of improving cross-border connections within the European Union. Under consideration of high prioritized main routes of Europe and traffic forecasts for Austria, a guideline for the development of a target railway network 2025+ was created (ÖBB Infrastruktur AG 2011). It describes the future development of Austrians railway network. It mentions that Austria´s current government programme in the rail sector aims to keep the share of passenger transport in total passenger transport stable at 15 %. For the transfer of freight traffic to rail a significant increase to 20 % of total traffic is targeted.

6. Definition of impacts

Researches show that not only hydropower production, river straightening for flood protection, and reclamation of land but also the existence and construction of railway infrastructure could have impacts on riverine habitats, on air, water, soil and animal assemblages. Schmutz et al. (2015) found out that hydrological and morphological alterations due to hydropeaking caused flow changes harm fish communities. According to Schinegger et al. (2018), especially hydromorphological and chemical-physical stressors are dominating in alpine river basins of Austria, which are often interacting. With reference to the morphological impairment of natural water courses Diebel et. al. (2014) found road crossing and culverts as elements for changing the stream channel and structure indicators. Nilson et al. (2005) summed up that the construction of artificial barrier, such as dams, weirs, culverts and other stream-road crossings has significantly reduced the connectivity of river systems worldwide. About it Lucas et al. (2017) described disturbances due to railway noise and vibrations and pollution of air, water and soil. Another example is a study about long-distance effects of a high-speed railway line on the distribution of the European tree frog in Eastern France (Clauzel et al. 2013), a case study of impacts of a new railway on shorebirds (Múrias et al. 2017) and observed bird exclusion effects in a wetland crossed by a railway (Godinho et al. 2017).

To keep all potential types of impacts clear, a simple and comprehensible identification and categorization of impacts is done. All potential impacts can be separated by three main characteristics. The description explains the effects of railway infrastructures on the sensitive habitats in more detail. For completeness, this master thesis briefly describes all relevant impacts, however, the focus of the analyses is on the morphological impacts.

6.1. Morphological impacts

Depending on how and in which distance the railway runs in relation to the watercourse, railway infrastructures can have different impacts on the river morphology and hydrology. On the one hand, railway construction running parallel to the river can result in hydrological disconnections (see Figure 26). They exert longitudinal pressure on the hydromorphological development of the river and its surrounding area. Railway-related embankments of rivers can have hydromorphological impacts: It affects foreland drainage and cut off foreland water flow paths, as they may also retend floods and cuts off landscapes like riparian zones and flood plain forests. Above all this longitudinal disturbance can dry the soils and increase surface runoff and degrade habitats (Beechie et al. 2010).

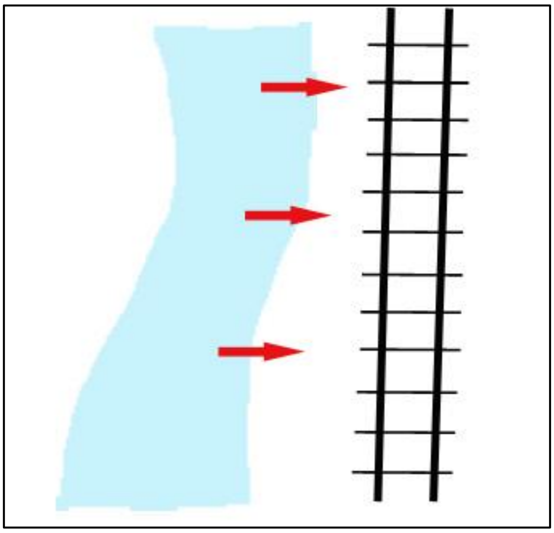

Figure 26: Longitudinal pressure on hydromorphological development

On the other hand, railway bridges and culverts are lateral disturbances on hydromorphological development and mostly run perpendicular to the direction of flow (see Figure 27). Near bridges, railway infrastructure has effects especially on river beds and river banks (Nilson et al. 2005). River channels are forced into the form of a corset, for which a consensus-based status has to be maintained and no morphological development will be permitted. Often, instream and not fishpassable instream technical constructions near or under bridges reduce the fish passability of a river in this punctual area. They are barriers and cause fish habitat loss (BMLFUW 2006), see example in Figure 28.

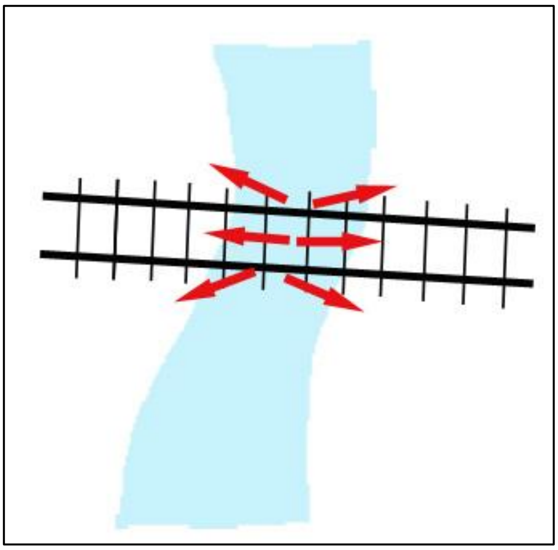

Figure 27: Lateral pressure on hydromorphological development

Figure 28: Example of a not fishpassable transverse element downstream a bridge (source: Office of the Salzburg Provincial Government, Water Protection Department)

6.2. Physical impacts – noise and vibrations

Impacts on aquatic ecosystems and species due to noise and shock waves caused by vibrations generated from the wheel and transmitted by the rail are little noticed so far. Lucas et al. (2017) proved "that there is a strong evidence that noise, light, and vibrations that can reach from 85.5 to 97 dB(A), can affect insects, amphibians and birds" (see Figure 29). Pletterbauer and Unfer (2015) have published a literature study, analyzing the disturbances of vibration on fish. The amplitude of the disturbance, the duration and the frequency of noise seem to be the most important variables for how fish react: cutting off migration routes, a decrease of biomass development of long-distance migratory species (decreasing reproduction rate) and a change of focal habitat types are potential consequences of riverside railways are effects of physical impacts.

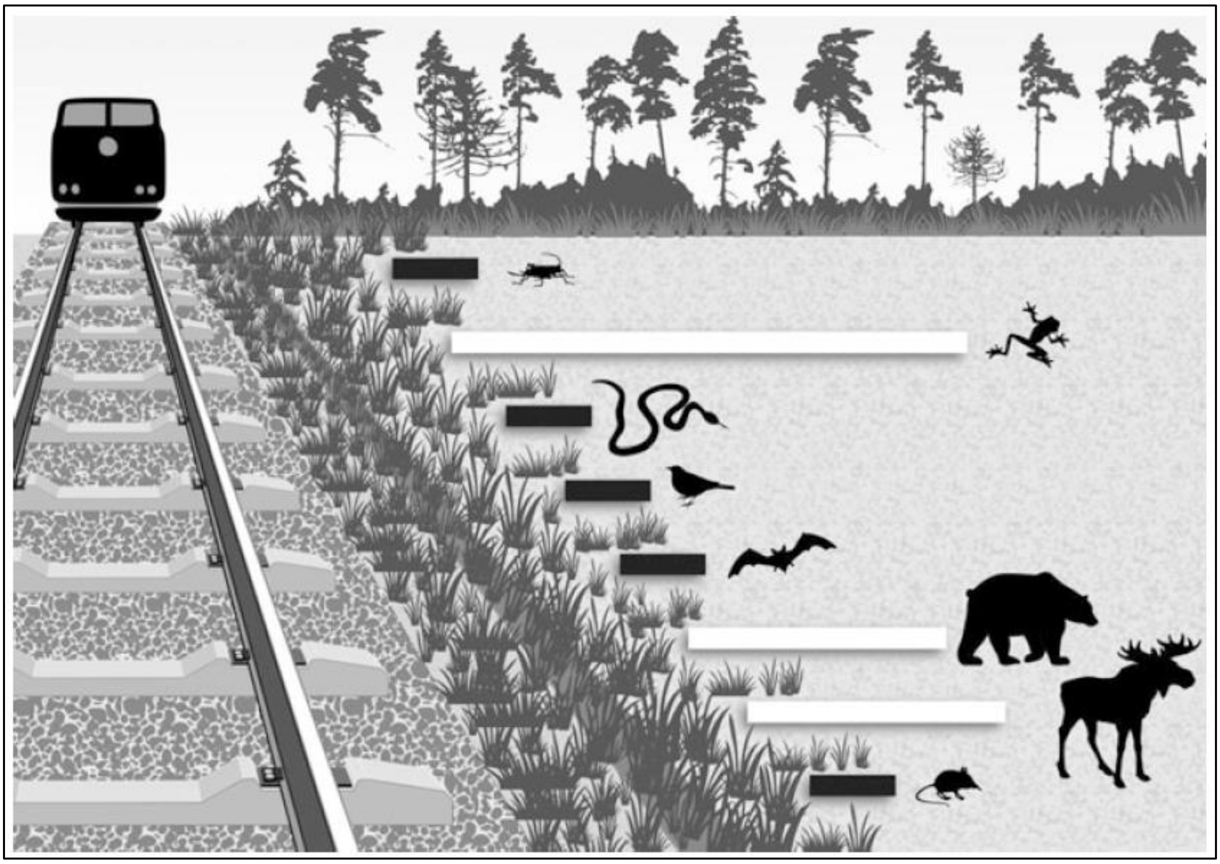

Figure 29: Spatial responses of wildlife to railway disturbances: the length of the white bars are proportional to the distance up to which the railway has an effect on a given taxon, while short and black bars correspond to species´ occurrence in the railway verges (Lucas et. al. 2017)

6.3. Chemical impacts

Chemical substances like oils, greases, metals, de-icing materials and herbicides are harmful substances which have measurable effects on physical-chemical quality components according to GZÜV. Lorenzen et al. (2020) proved that they impact water and soil quality, groundwater bodies and organisms. Here, especially old tar-oil treated railway sleepers contain carcinogenic PAH (polycyclic aromatic hydrocarbons) which endanger the environment.

Using herbicides can result in an accumulation in soil or dissolved in water (BAFU 2008). Up to now, ÖBB has used the standard mixture of two herbicides (Glyphosate and Flazasulfuro) to maintain the rails for safety reasons (BMK 2016). The chemicals were applied continuously along the entire route. With new technology, sensors and a camera system, it is possible to spray the vegetation in a targeted manner. Figure 30 demonstrates how chemicals are spreaded with new technology.In this way, the amount of chemicals used can be reduced. There are already isolated railway lines in Austria where the use of the herbicide glyphosate is completely dispensed with (ORF Kärnten 2022).

Apart from this, erosion of rail embankments can result in a washing out of sediments and, thus, pollute water (Lucas et al. 2017) and further degrade vegetation and soil.

Figure 30: Surveillance camera photos of the use of weedkillers along the ÖBB rail network (Source: ÖBB, Editorial office ORF Carinthia)

Effects of railroad infrastructure are suspected, especially in morphological and chemical terms, but also with regard to physical parameters. In the end, it is a cumulative impact on (riverine) ecosystems in the vicinity of railway infrastructures.

7. Results – Crossing points and intersections

7.1. Crossing points and transverse structures

If the railway network and the river network are intersected, they overlap at many points. With this approach a total of 1,035 crossing points could be generated. It is mainly embankments and rip-raps for railway stabilization or bridges, culverts or underpasses like the Figure 31 and Figure 32 should demonstrate.

Figure 31: Hametbach bridge 1838 (Source: R. Deopito)

Figure 32: Brunnbach culvert (Imsterberg) (Source: Ing. Berger & Brunner GmbH.)

These crossings were analyzed in terms of the aquatic ecological status of the crossed surface waterbodies. The Figure 33 shows that around 14 % of these are in good or very good (a total sum of 150 points), around 64 % are in a moderate or worse ecological status (a total sum of 659). When looking at the distribution of ecological status in waterbodies with railroad crossings, the majority of intersections is accounted for by single-track railroad lines. The waterbodies are predominantly in a moderate or poor ecological status. The distribution in Austria is shown in Figure 34.

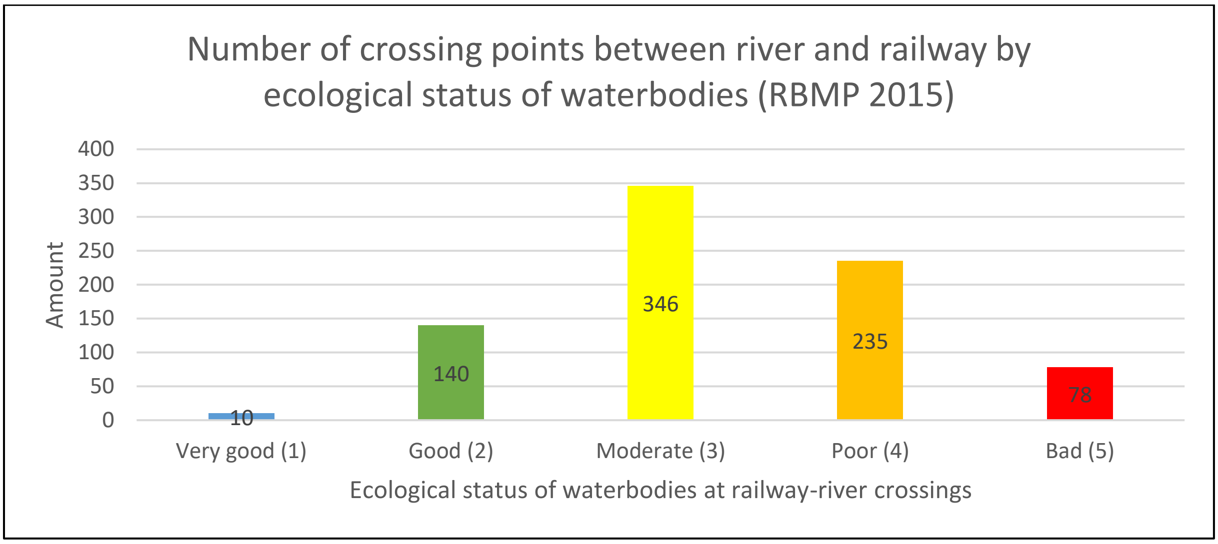

Figure 33: Number of crossing points between river and railway by ecological status of waterbodies (RBMP 2015)

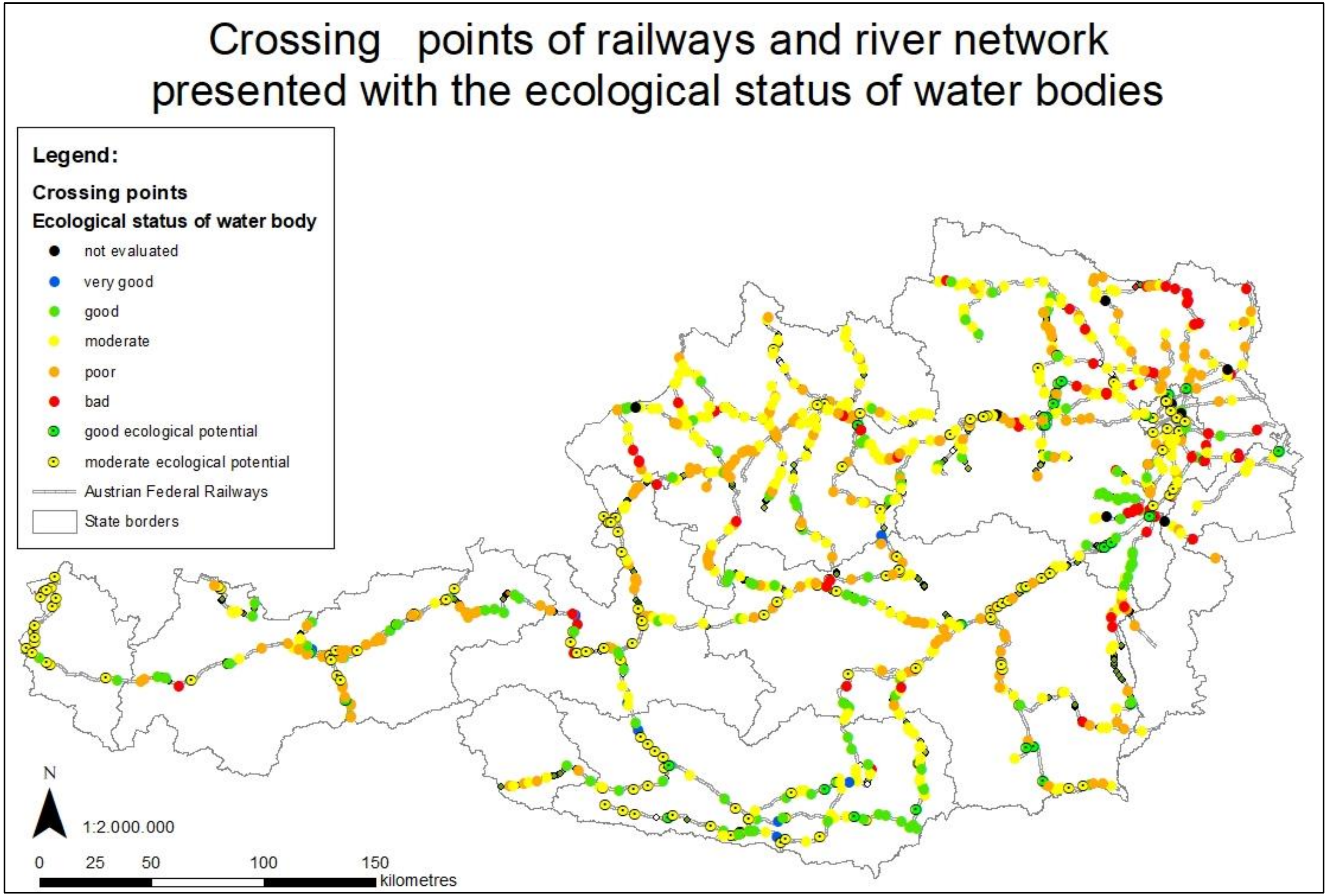

Figure 34: Map of crossing points between railway and river network in Austria presented with the ecological status of waterbodies

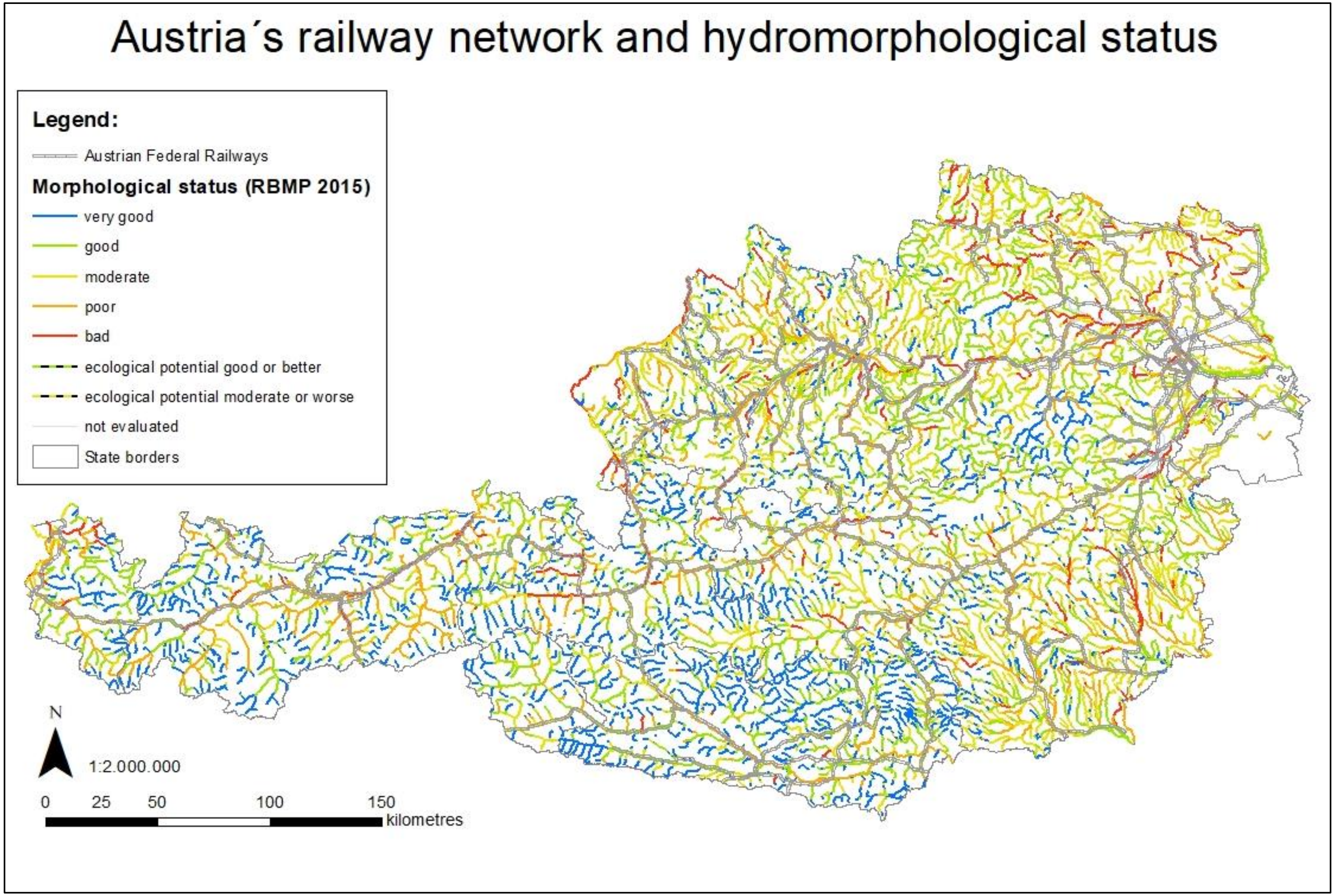

Figure 35: Austria Federal Railways and the hydromorphological status of waterbodies

As shown in Chapter 6 railway infrastructure can impact the hydromorphological condition of waterbodies. An overview of the hydromorphological status of Austria´s rivers in relation to the railway network is pictured in Figure 35. Similar to Figure 33 river crossings show mainly a moderate or worse hydromorphological status.

Priority action areas according to RBMP 2015 are rivers with hydromorphological deficits. The priority action area includes a significant proportion of waterbodies with a catchment size > 100 km², for which the residual flow and the fish passability at hydropower plants and other barriers has to be adjust. As the Figure 36 shows, a little more than 50 % of the waterbodies with a bad hydromorphological status near crossings are part of the priority action areas in the RBMP 2015. Another 40 % were rated in class 4 and just 30 % in class 3. This means that there is still a great need but also a large potential for the hydromorphological restoration of waterbodies and catchments for large size catchment areas.

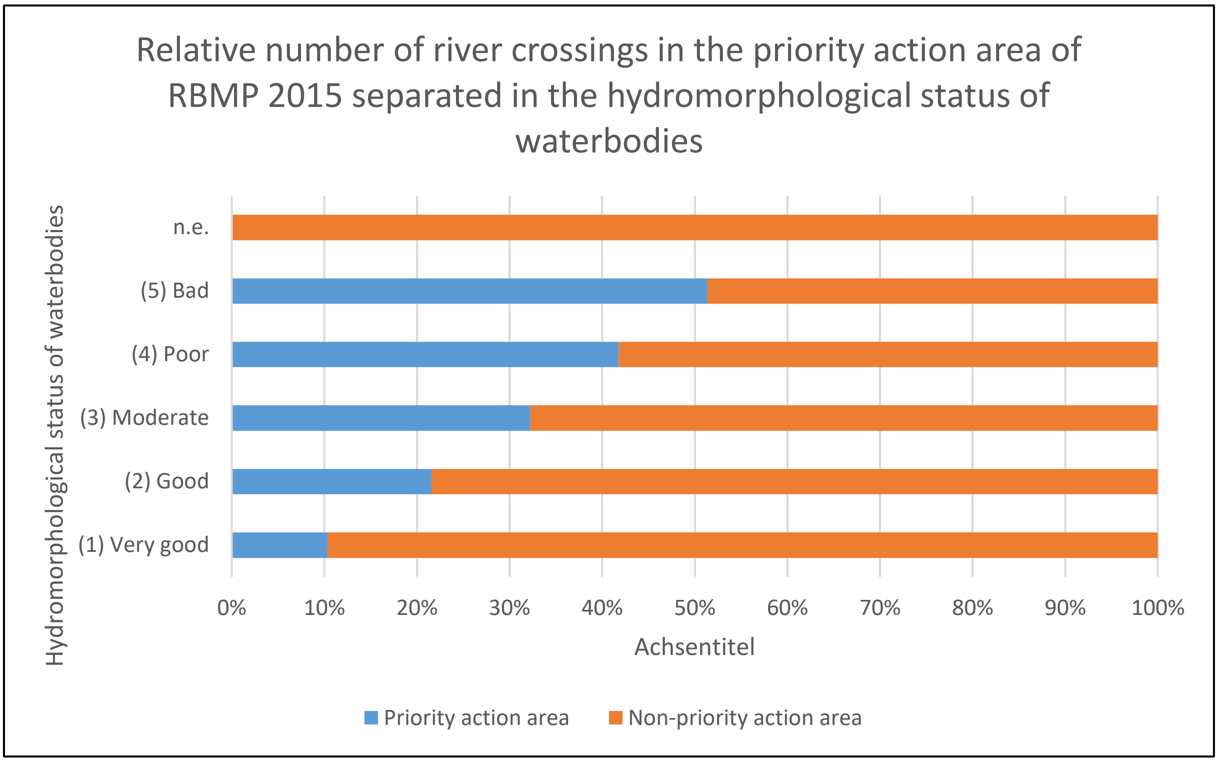

Figure 36: Relative number or river crossings in the priority action area according to RBMP 2015 separated in the hydromorphological status of waterbodies

7.1.1. Transverse structures – Instream barriers near river crossings

In addition to simple crossing points that result from the overlap of the two networks, other elements down- and upstream of crossing points that may affect the hydromorphology of waterbodies are also analysed. For this purpose, barrier data according to the EU WFD was used. Transverse structures/barriers are evaluated as a significant impact in the national WFD inventory analysis ("screening" method). These were surveyed to assess the connectivity of stream segments into stream systems (stream continuum). The construction of barriers usually occurred in the course of watercourse regulation, but may have other causers as hydropower electric plants or construction for torrent control.

The Austrian WFD mapping therefore distinguishes between the following barrier types:

- Type 1 - Barrier
- Type 2 - Other barrier
- Type 3 - Natural falls
- Type 4 - Chain of falls
- Type 5 - Unknown

Every barrier was built for a specific reason. A causer was defined for every element in the course of the surveys for the RBMP 2015 as following:

- Hydroelectric power station
- Flood protection
- Industry and commerce
- Settlement area and infrastructure
- Agriculture and forestry
- Leisure and tourism, snowmaking
- Leisure and tourism, other
- Water supply
- Fishery
- Shipping
- other
- unknown

Barriers are usually erected to keep the riverbed stable. Barriers, usually designed as ramps, prevent engineering structures such as bridges or transport infrastructures from being undermined or washed around. However, the waterbody can no longer develop naturally, resulting in alteration of the natural hydromorphological characteristics. Therefore, for the following consideration of hydromorphological pressures, those barriers were selected that were located near crossings which we have identified in 7.1. When having a detailed look on barriers located near crossings, the impact on the rivers morphological status of crossings in general can be derived. Barriers are usually erected in the immediate vicinity of railway infrastructures. For this purpose, all types of barriers within a 30, a 50 and a 100 metres distance from railway-river crossings were first detected. Figure 37 shows that classical barriers are the main type that is found downstream and upstream from railway-river crossings. From the 1,038 crossing points, 188 barriers lie within a 30 metre radius.

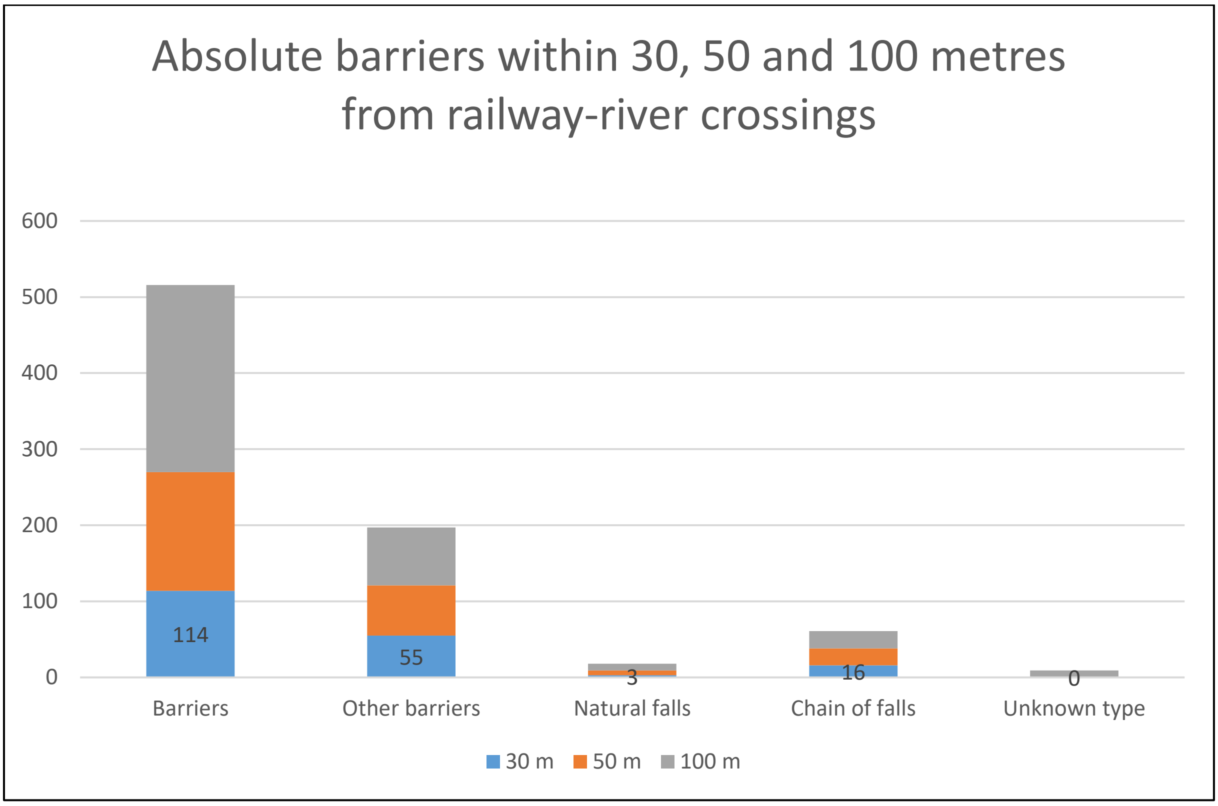

Figure 37: Amount of barrier types according to RBMP 2015 within 30, 50 and 100 metres from railway-river crossings

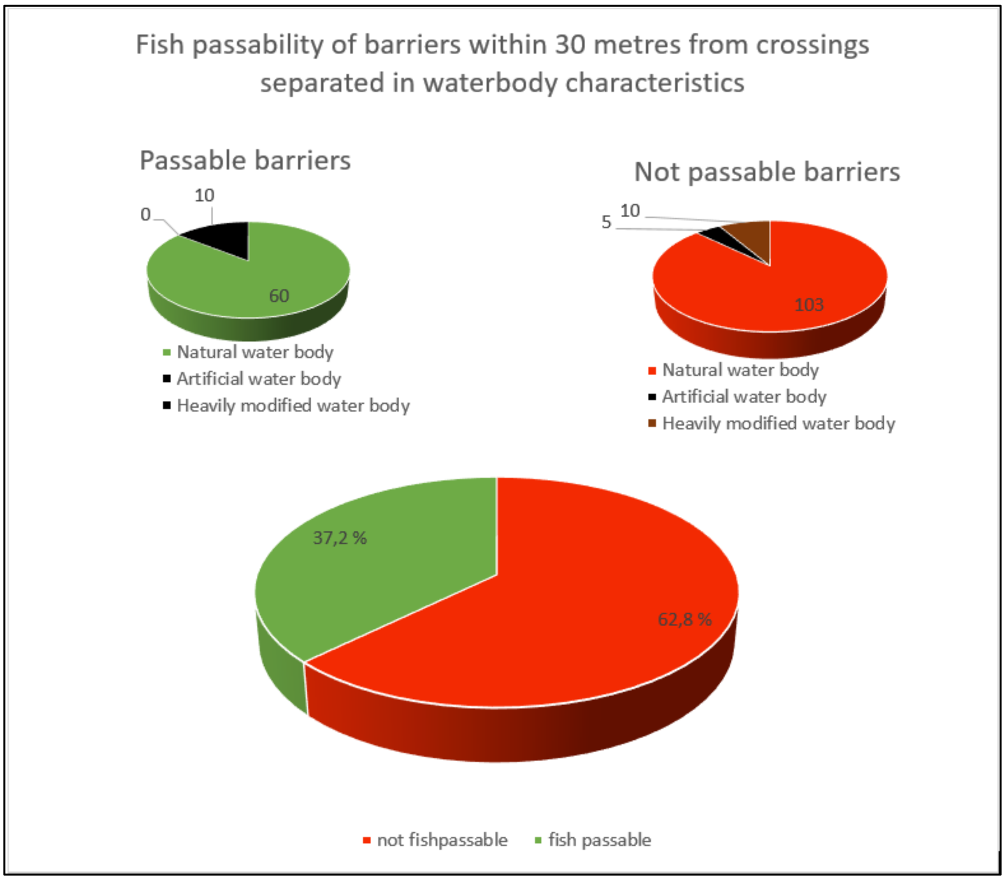

Figure 38: Fish passability of barriers within 30 metres from crossings separated in waterbody characteristics

It can be observed that the majority (around 63 %) of barriers is not fish passable protection (see Figure 38). These are predominantly natural waterbodies, which were regulated mainly due to flood.

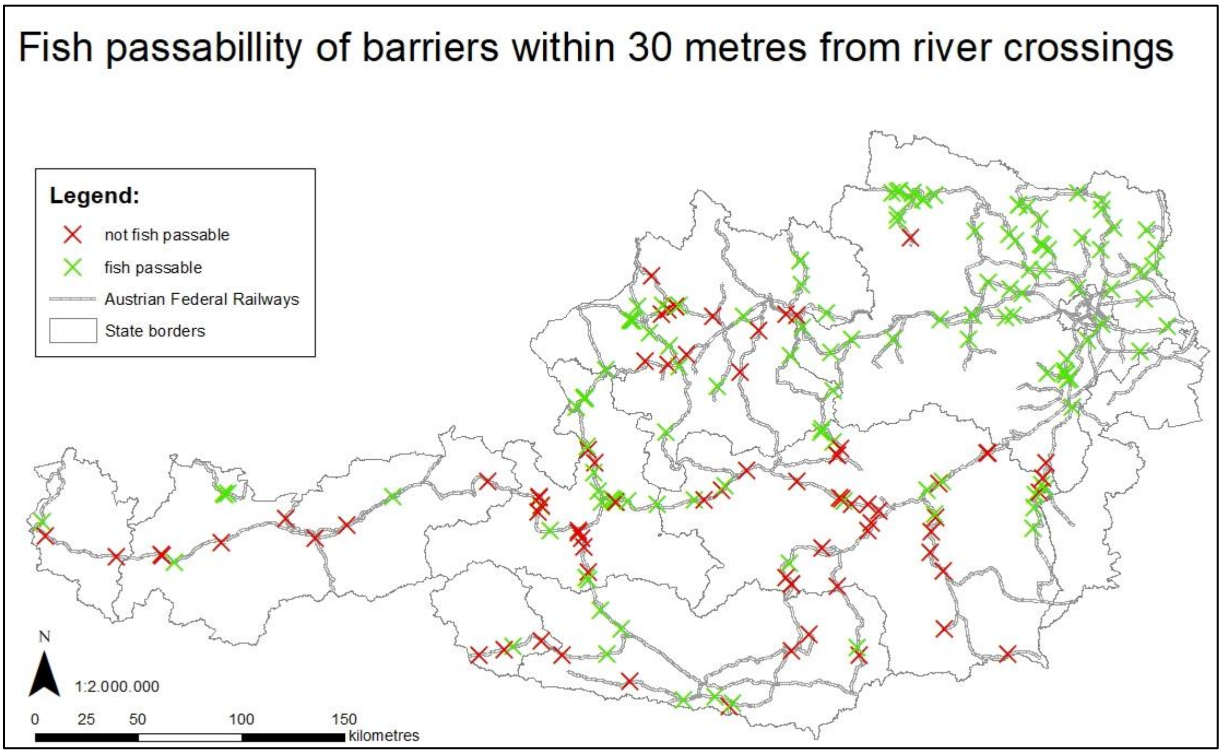

Figure 39: Map of fish passability of barriers within 30 metres from river crossings

In Figure 39 a map was created which shows the fish passability of barriers within 30 metres from river crossings. The fish passability of a crossing point was derived from the fish passability of the nearest barrier. If a non-fish-passable crossing element was located within a 30-metre radius upstream or downstream of a crossing point, the crossing (bridge or culvert) was automatically classified as not fish-passable.

In Figure 40 the amount of barriers within 30, 50 and 100 metres from crossings are displayed as a diagram. It shows that the main purpose for their building were "*Flood protection*", "*Unknown*", "*Hydroelectric power stations*" and "*Settlement areas and infrastructure*". These four main causers are singled out in Figure 41 and divided according to their transverse structure type. The majority of all transverse structures in the vicinity of railway infrastructures are barriers followed by chain falls which were built for the purpose of flood protection. Hydroelectric power plants have a high proportion of barriers, too. The fourth most frequent reason for barriers are settlements and infrastructures. This tendency does not change with the distance to crossing points.

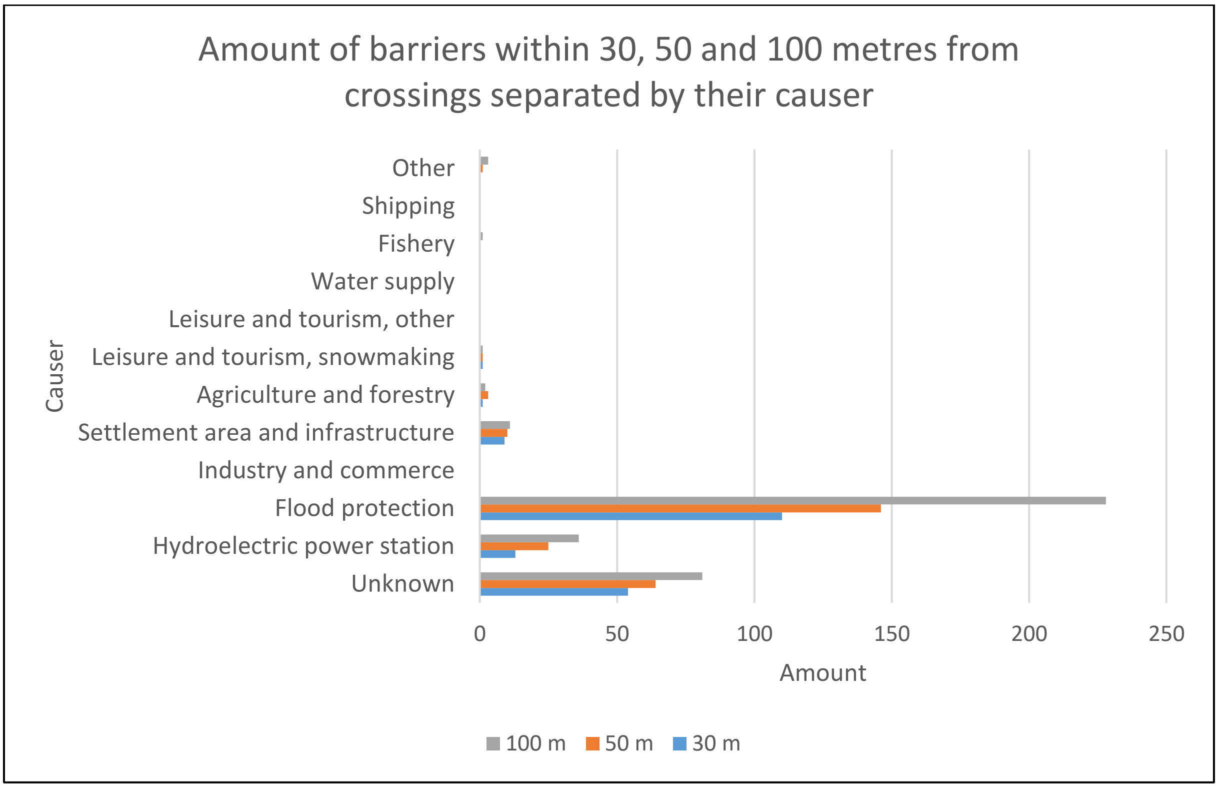

Figure 40: Causer of barriers within 30, 50 and 100 metres from crossings separated by their causer

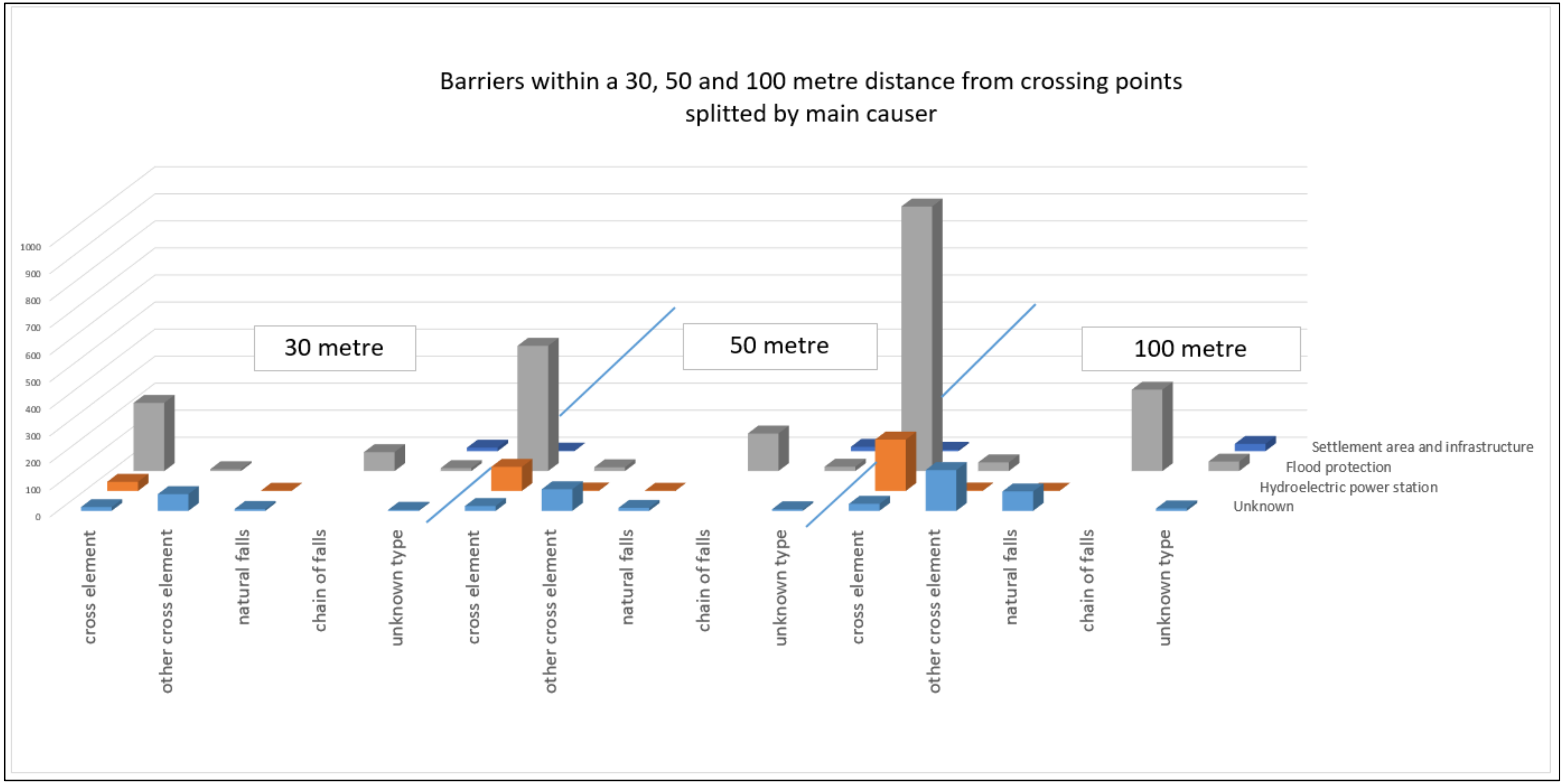

Figure 41: Barrier types within a 30, 50 and 100 meter distance from crossing points splitted by causer

7.1.2. Transverse structures - Instream barriers near railway infrastructures

To assess any potential impacts of railway infrastructure to the hydromorphological status of waterbodies, the consideration of crossing points of railway- and river networks is not sufficient. Rivers are linear structures in the landscape and therefore a multiple of barriers should be taken into account. Figure 42 displays all river sections near railway infrastructures. In contrast to chapter 6.1.1, the distance buffers for this analysis were chosen more broadly.

Spatial proximity was defined by two distance buffers (50 and 100 metres):

- The buffer radius of 50 metres was derived from a study investigating the effectiveness of riparian strips for the protection of surface waters. In this study, a 50 m riparian strip was recommended to reduce nutrient inputs into waterbodies (WPA 2009).
- The distance of 100 metres was chosen because in Switzerland, for example, there are distance regulations for the application of plant protection products. Depending on the product and its ingredients, mandatory distances to the nearest surface water must be observed (BLW 2020).

Of the entire ÖBB rail network, around 610 kilometres run within a distance buffer of 100 metres from rivers. The maximum track length is about 8 km, the average track length 160 metres. Only about 40 kilometers less (574 kilometers) extend within a 50-meter distance buffer. The longest section of railroad is 11 kilometers and the average length is 200 meters (Overlapping sections were deleted in favor of the smaller distance buffer to avoid double counting.).

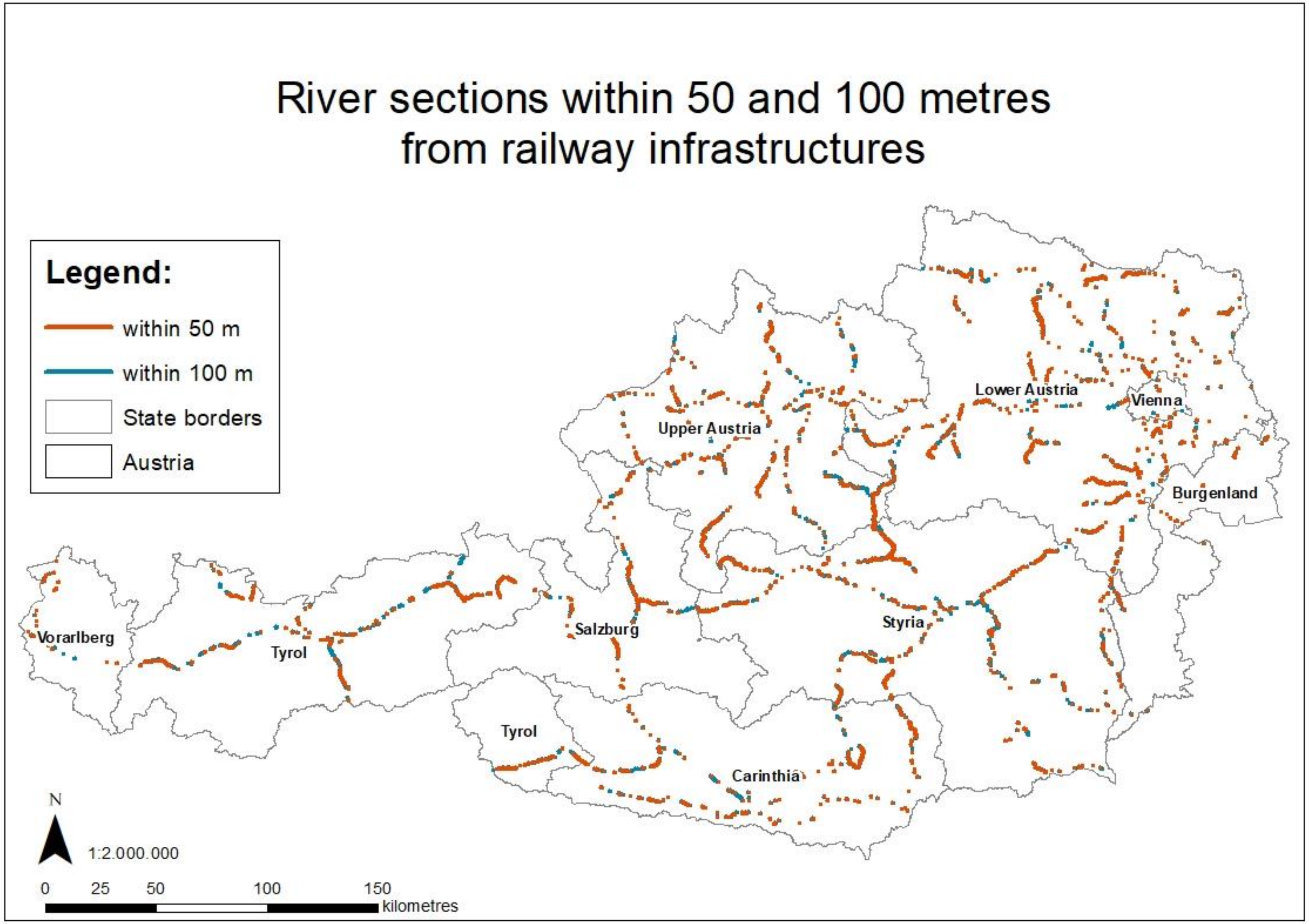

Figure 42: River sections within 50 and 100 metres from railway infrastructures

Of particular interest, however, are barriers in those sections that are located in the vicinity of railroad infrastructures. Due to the higher selected distance buffers the barriers sample is larger. This allows a more reliable statement on whether railways are hydromorphological stressors. Within 100 metre of railways a total of 1,884 barriers could be identified. Out of that 978 barriers are not fish passable (see Figure 44). For the 50 metre buffer, about half the amounts were determined (459 out of 894 within a 50 metre distance). An example of a near chain falls is demonstrated in Figure 45.

The evaluations (see Figure 43) show that the highest amount (about 1,600) of barriers is recorded for flood protection and hydroelectric power plants. A not inconsiderable number (about 200) also falls to unknown causers. The main type of barriers are typical barriers but also chain falls. These results are similar to those from the previous study in Chapter 7.1.1 which focused on barriers upstream and downstream from crossing points.

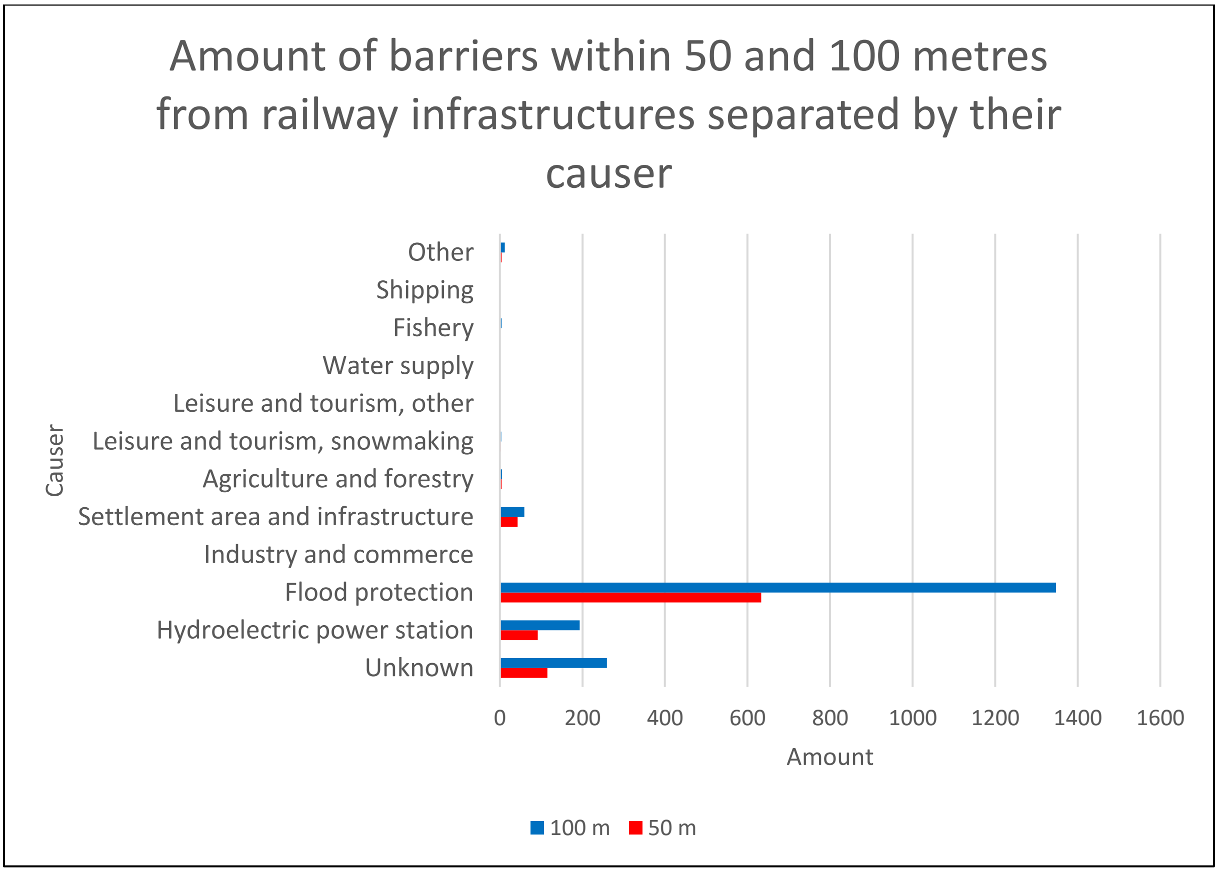

Figure 43: Amount of barriers within 50 and 100 metres from railway infrastructure separated by their causer

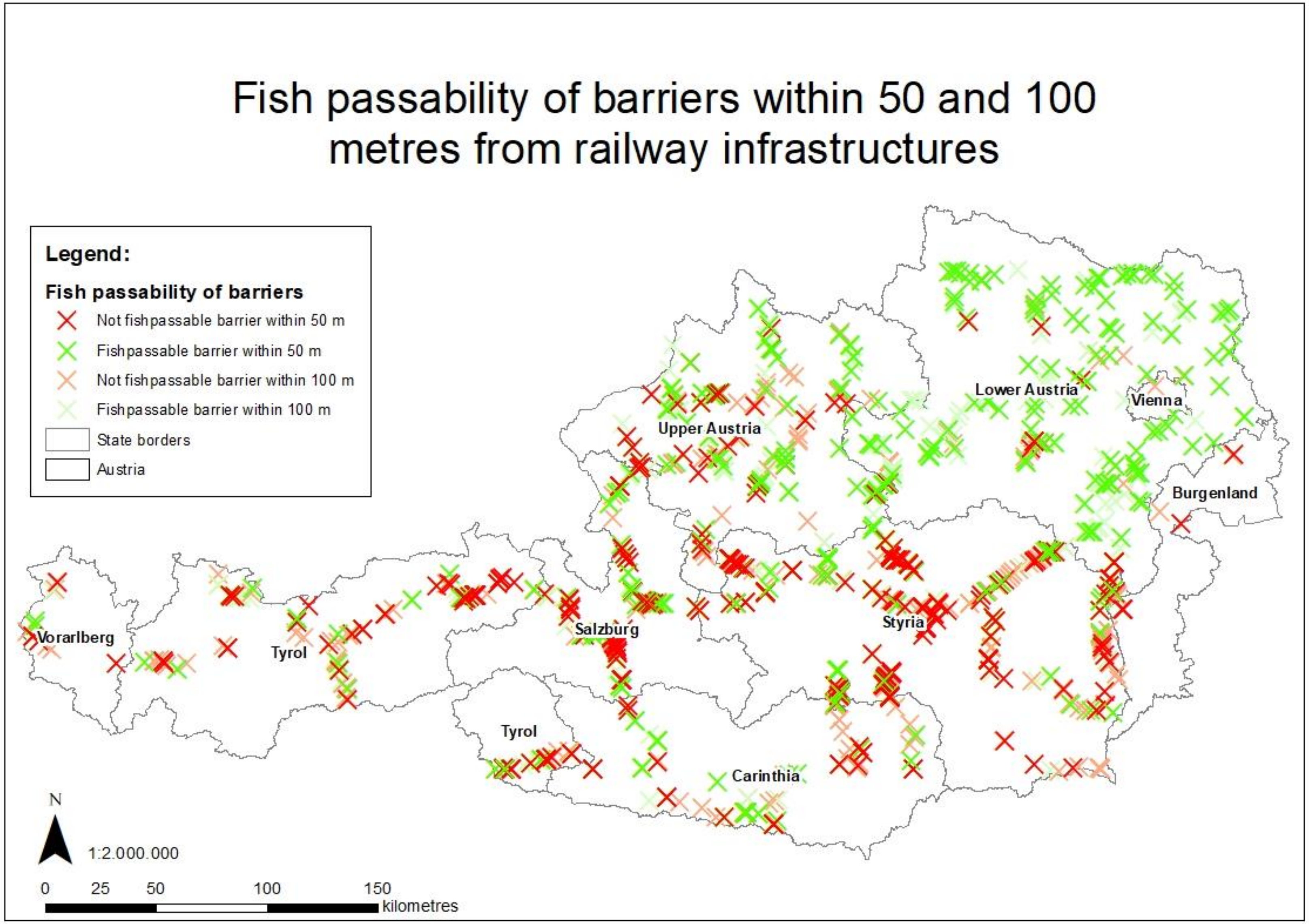

Figure 44: Fish passability of barriers within 50 and 100 metres from railway infrastructure

Figure 45: Not fishpassable instream barriers within 50 metres from railway infrastructures

Since the quantity and quality of the barriers have an impact on the assessment of the ecological status of waterbodies, the hydromorphological conditions are examined in more detail. For this purpose, waterbodies that are located within 100 metres of railway infrastructures (see Figure 46) are investigated. The biggest amount of waterbodies is in a moderate hydromorphological condition.

In addition, a percentage evaluation was made of the increase in river stretch lengths in the respective hydromorphological status classes. This evaluation was supplemented by another distance class (percentage increase between 100 and 200 m) to obtain comparable results. What is striking, however, is the respective percentage increase from one distance class to the next (see Table 2). While the percentage increase between 50 m and 100 m distance is highest for hydromorphologically poor and bad designated waterbodies, the increase between 100 m and 200 m distance classes is highest for the very good and bad sections.

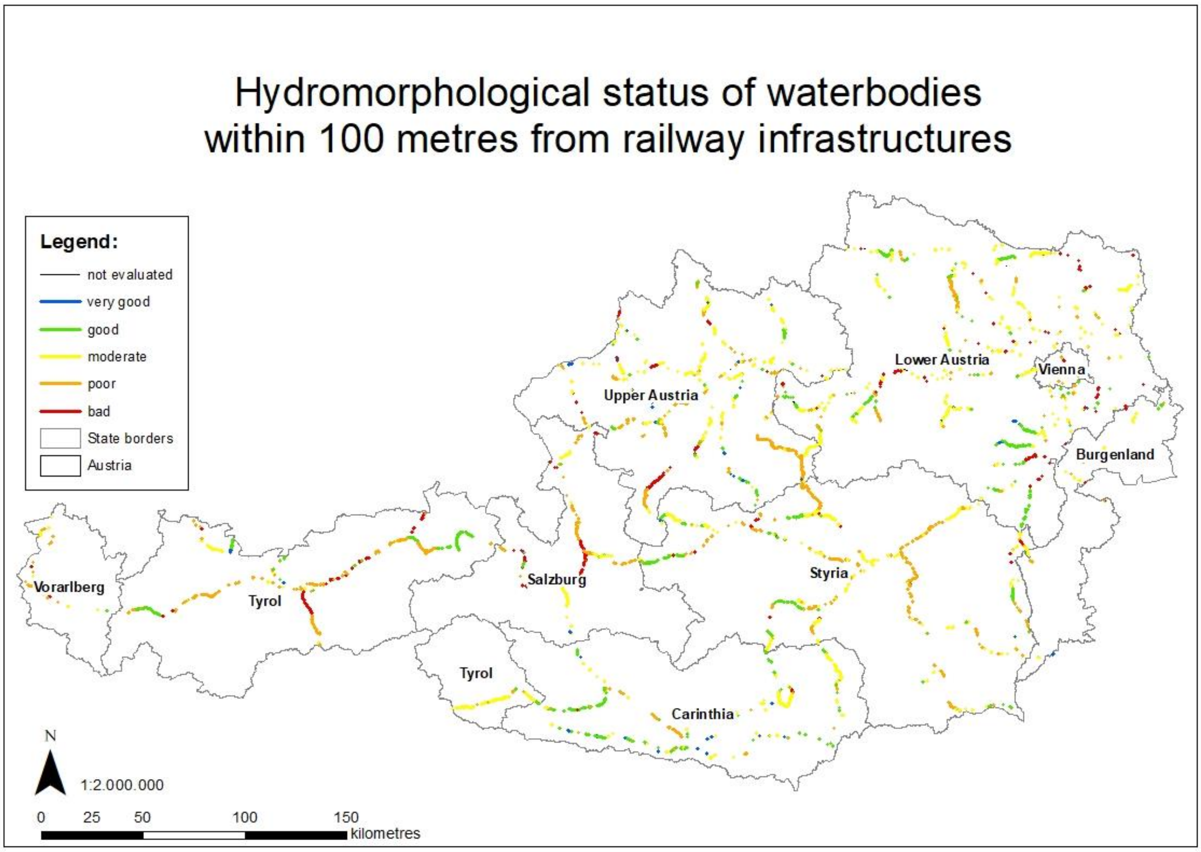

Figure 46: Hydromorphological status of waterbodies within 100 m from railway infrastructures

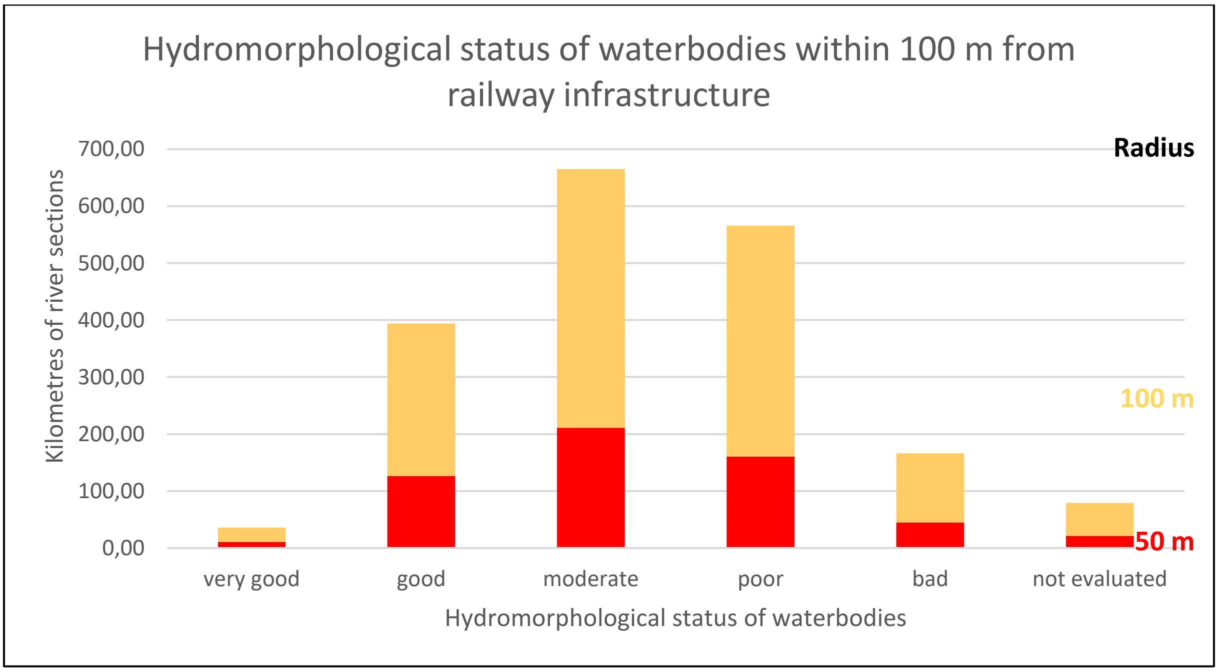

Figure 47: Diagram of the hydromorphological status of waterbodies within 100 metres from railway infrastructures

Table 2: River section length within 50, 100 and 200 metres from railway infrastructure and the percentage of increase from 50 to 100 and 100 to 200 metres separated in their hydromorphological status

	50 m	100 m	200 m	Percentage of increase 50 - 100 m	Percentage of increase 100 - 200 m
River section length [km]	574,53	1317,51	2732,60	129,32 %	107,41 %
Hydromorphological status					
Very good	10,39	25,73	66,11	147,80 %	156,92 %
Good	126,17	267,64	520,69	112,13 %	94,55 %
Moderate	210,87	454,27	913,25	115,42 %	101,04 %
Poor	160,77	404,75	831,39	151,77 %	105,41 %
Bad	45,16	121,19	296,49	168,36 %	144,65 %
Not evaluated	21,18	57,94	104,67	173,52 %	80,65 %

With regard to the hydromorphological condition of waterbodies, free flowing sections without flow continuum interruptions are of particular importance in this context. In a study by the Institute of Hydrobiology and Aquatic Ecosystem Management at the University of Natural Resources and Life Sciences Vienna, commissioned by WWF (Scheikl, et al. 2020), the free flowing sections were defined as freely passable sections of water that have neither not passable barriers nor residual flowing sections or impoundments. As a minimum criteria, they must have lengths of ≥ 50 km (Potamal), ≥ 25 km (Hyporhithral) or ≥ 5 km (Epi-/Metarhithral). According to this study, only 17 % of the river network fulfill these criteria.

Consequently, it is unlikely that there are many crossing points between railway infrastructures and free flowing river sections in Austria. Of the 1035 crossing points 117 concern free flowing sections, which amounts to 8 % (see Figure 48). From an ecological perspective, these neuralgic points are particularly worthy of protection. Figure 49 maps the distribution of intersections between railways and free flowing section in Austria.

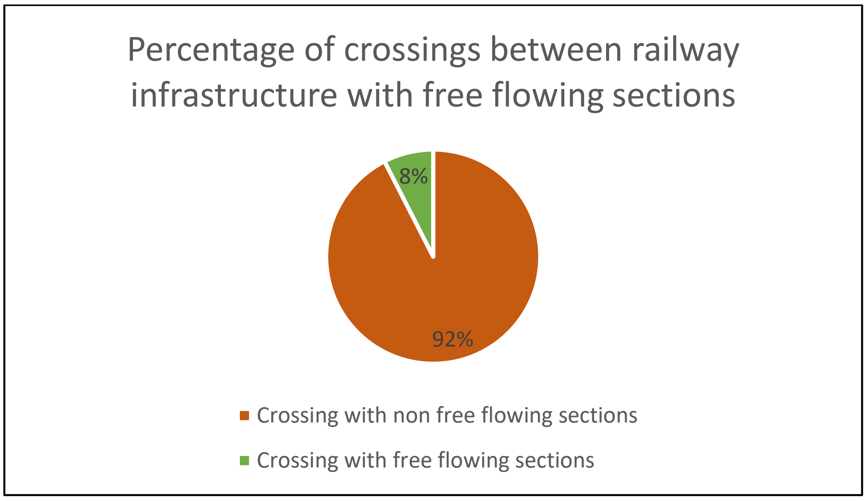

Figure 48: Percentage of crossings between railway infrastructures with free flowing sections

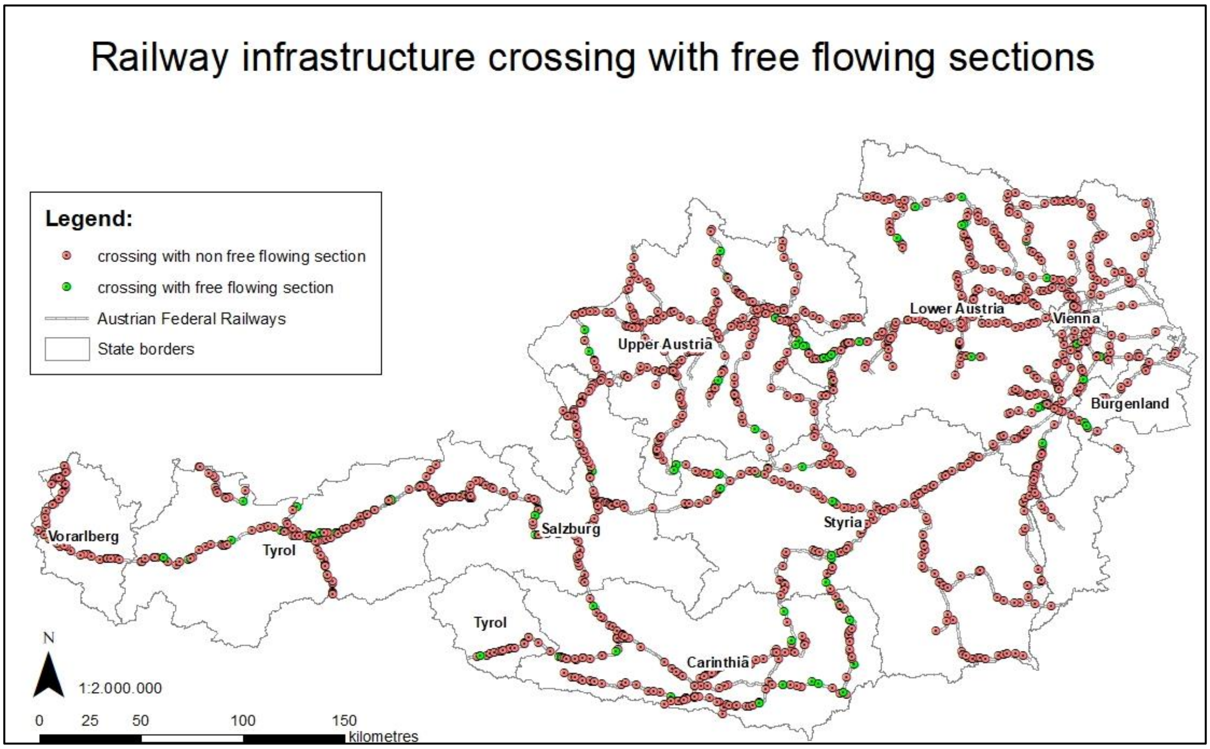

Figure 49: Crossings of railway infrastructure with free flowing sections

7.2. Intersection of railway network with selected endangered species datasets

As shown in Chapter 2, selected species with high demands on the aquatic habitat are chosen to demonstrate that the railway network also crosses sensitive fish habitats. The following paragraphs explain the intersection of the Austrian railway network with the distribution zones of Danube salmon, European grayling and River pearl mussel.

Danube salmon

In order to identify the points of contact between railway infrastructures and the distribution zones of Danube salmon, the data collection of Hofpointner (2013) as well as the modifications and the update of IHG (2019) were used.

Hofpointner assessed the Danube salmon populations documented in Austria and their conservation statuses C2 to A, where C2 is used to designate sections where Danube salmon occurs only in very low densities, and A where the conservation status of the populations can be described as excellent. In addition, the IHG (2019) has transferred Hofpointner's classification to the 500 m waterbodies according to the RBMP 2015. The classification was also supplemented by a further category with where "*high species development potential*" can be identified. Based on this categorisation the data set was blended with the railway network. A total of 57 points of contact could be identified between railways and the distribution area of Danube salmon. Areas with conservation status A can be found in the provinces Styria and Carinthia (see Figure 50). There are sections of the Danube with high development potential in Lower Austria, where the fish population can spread again under certain conditions. These include river sections that either have a conservation status of class C or where the fish species could no longer be detected (see Figure 51).

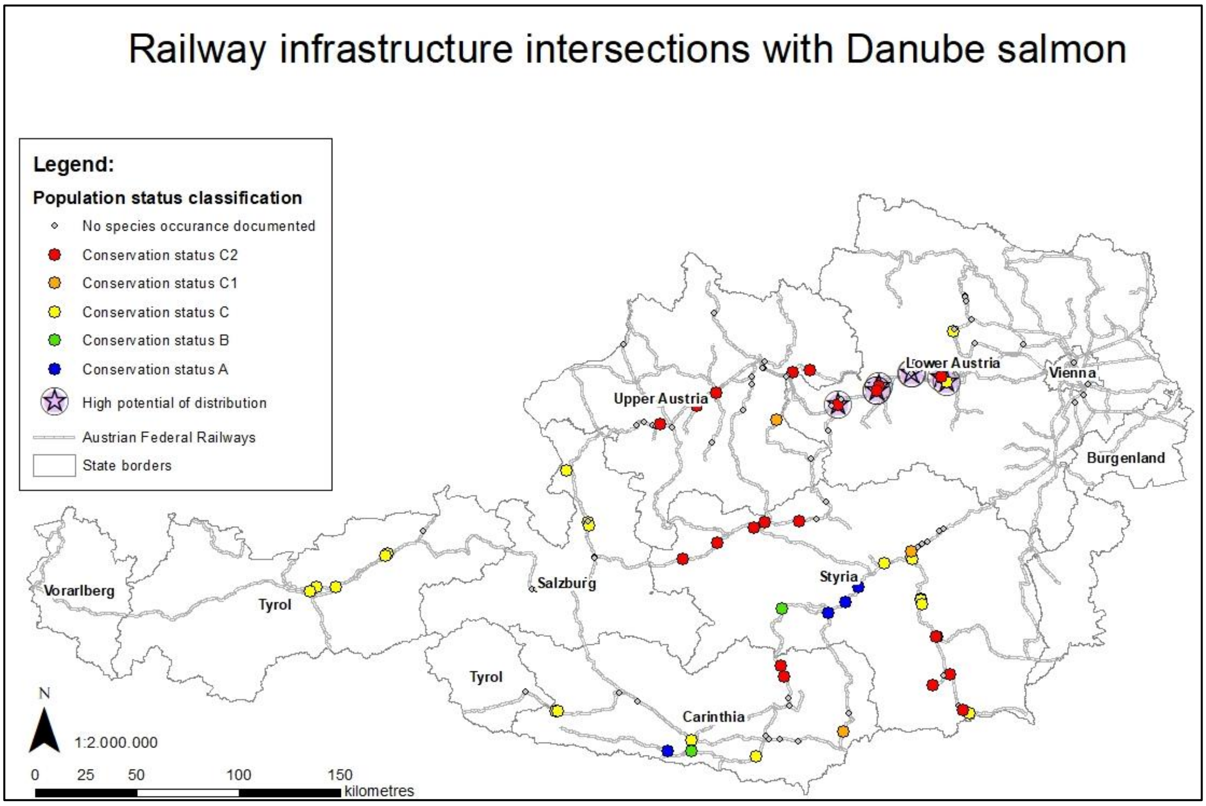

Figure 50: Railway intersection with Danube salmon river sections (from C2… very low densities to A…. excellent)

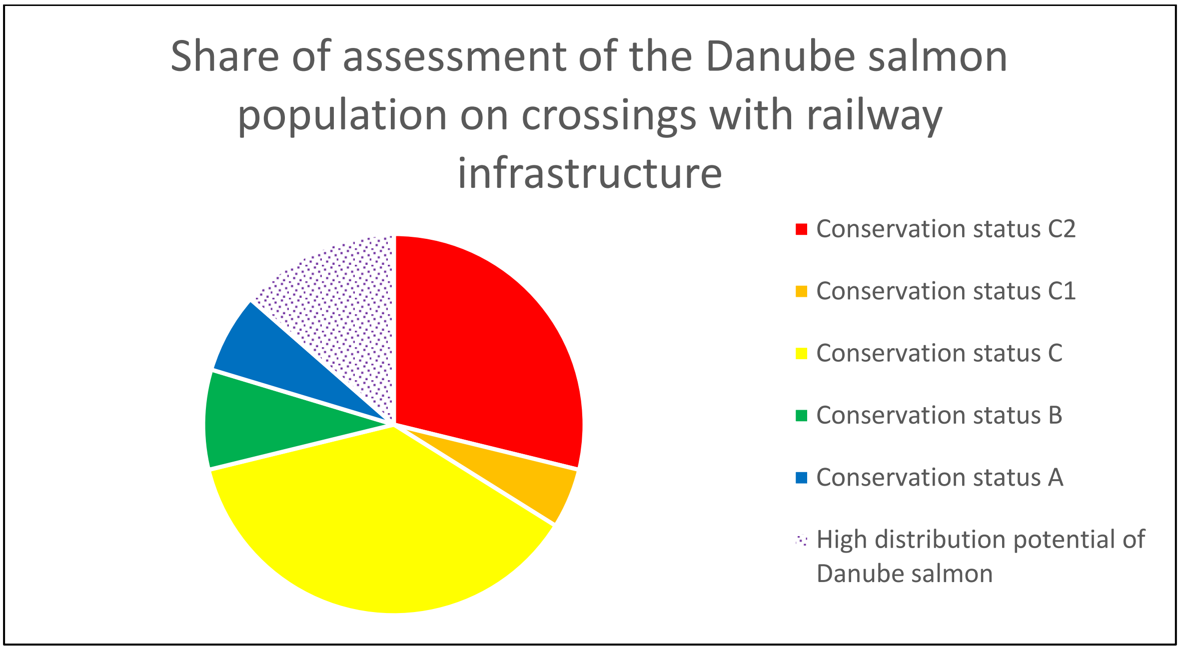

Figure 51: Share of Danube salmon population of railway intersections (from C2… very low densities to A…. excellent)

European grayling

The European grayling is wide spread in Austria. Overall, 531 points of contact with the railway network were identified, which is highlighted in Figure 52.

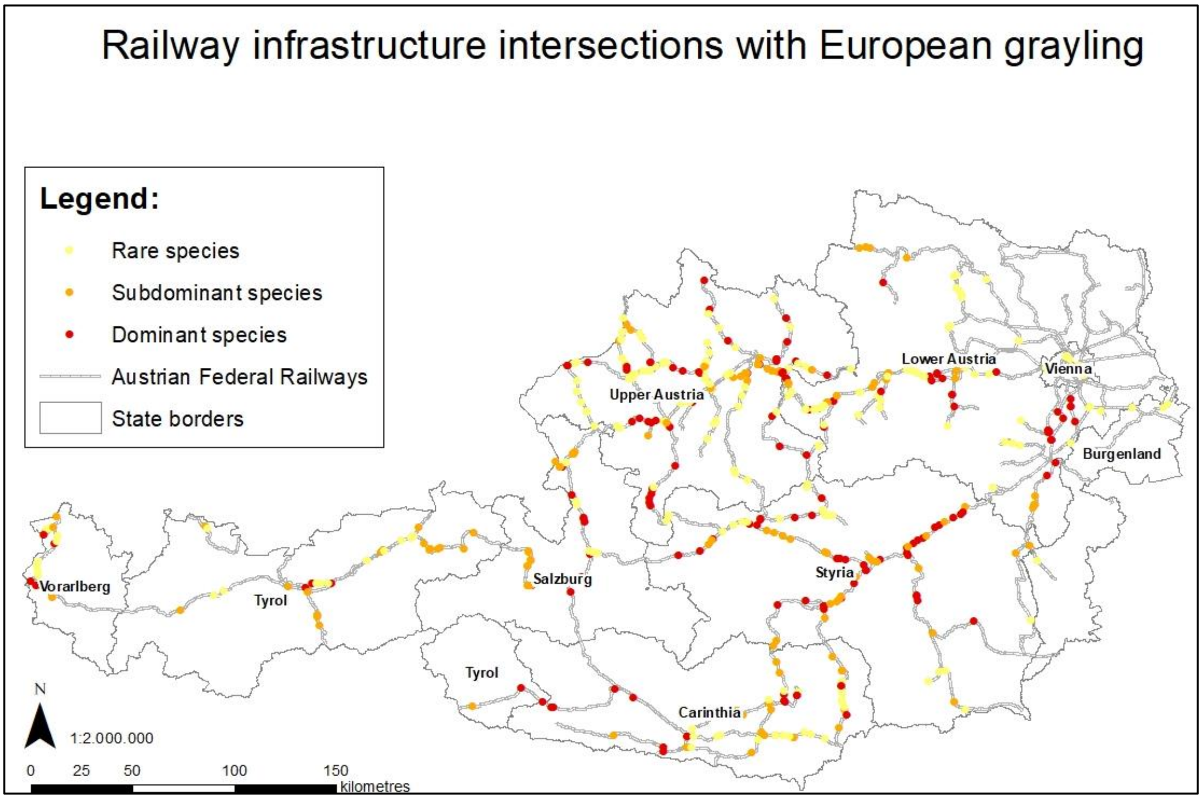

Figure 52: Railway intersection with European grayling river sections

The grayling mostly occurs either as a rare species or as a dominant species according to the Fish Index Austria (FIA) (see Figure 53).

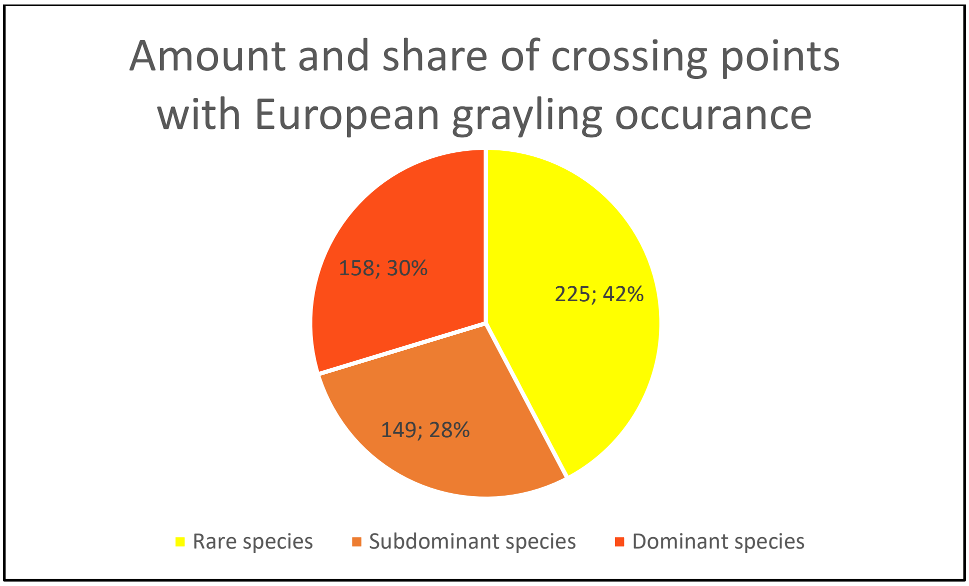

Figure 53: Amount and share of crossing points with European grayling occurrence

Critically endangered, endangered and vulnerable fish species

Railway infrastructures cross waterbodies with potential occurrence of critically endangered, endangered or vulnerable fish species. Figure 54 sums up railways crossings with these three categories. In addition to this it is considered whether the species were dominant, subdominant or rare. The most affected are vulnerable fish species, because they are the most widespread. None of the critically endangered and dominant species is to be found at railway crossing points. In the group of rare species, all three risk classes are equally affected by railway infrastructure.

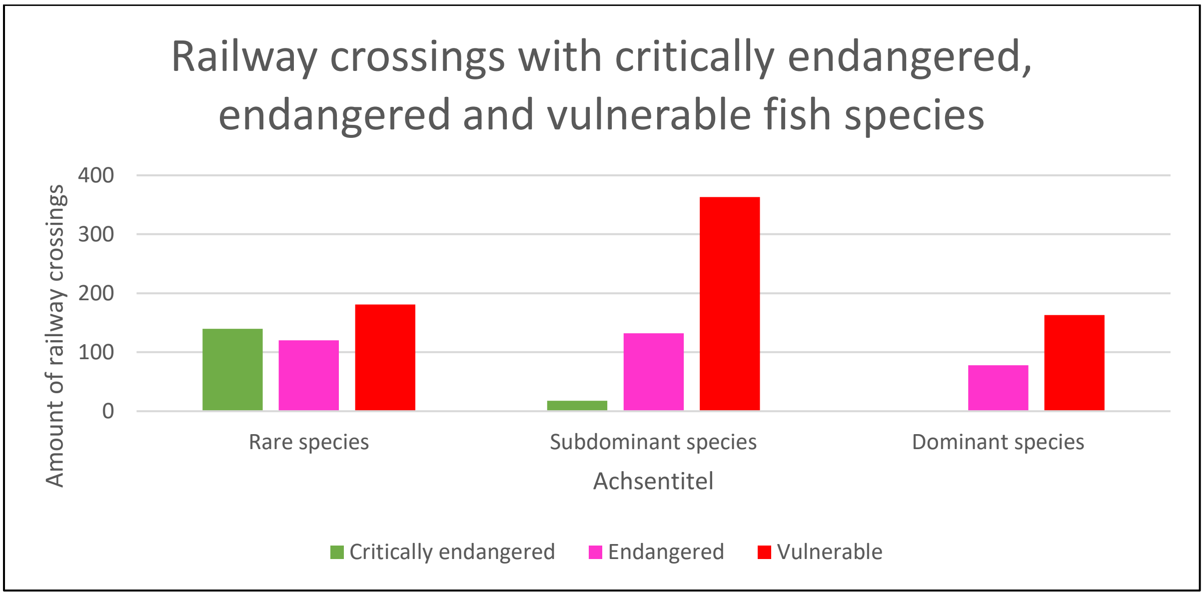

Figure 54: Railway crossings with critically endangered, endangered and vulnerable fish species according to the water catalogue (BAW, 2017)

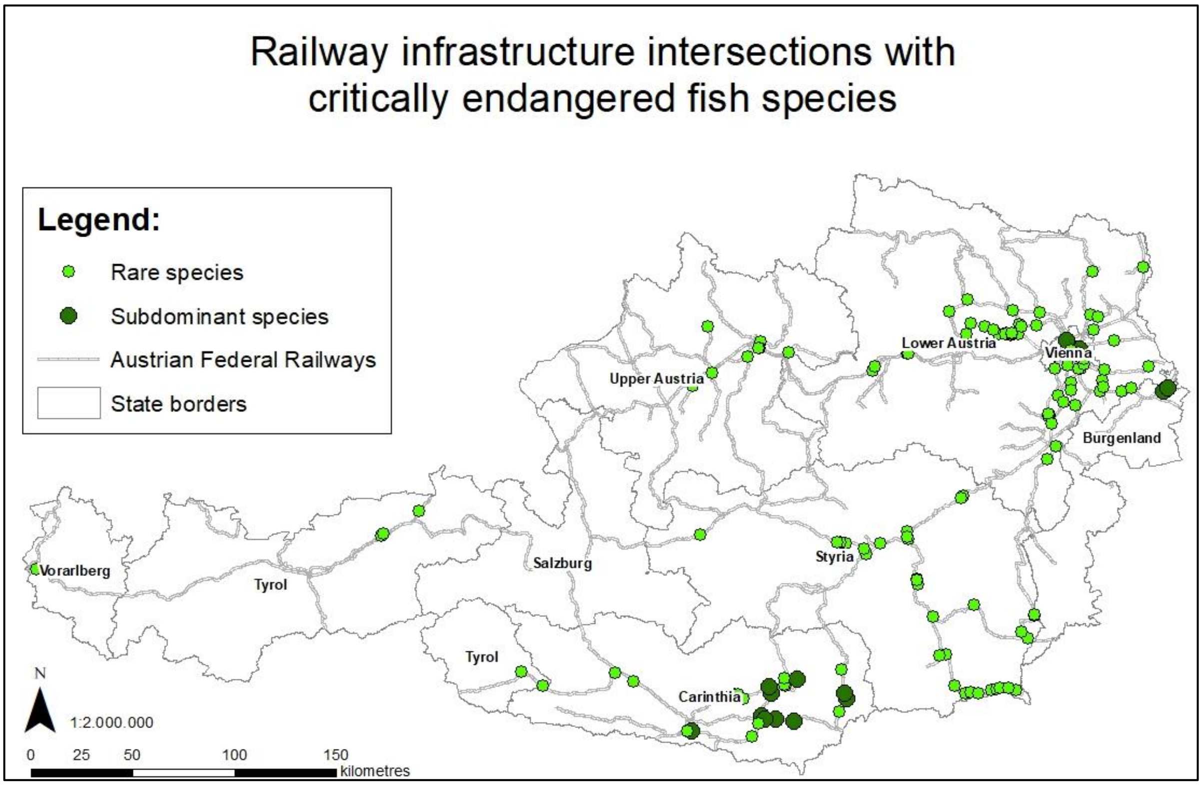

Figure 55: Railway infrastructure intersection with potential river sections with critically endangered fish species

Railway intersections with waterbodies where critically endangered fish species occur are mapped in Figure 55. Critically endangered species occur either as a rare (light green dots) or as a subdominant species (dark green dots). Subdominant critically endangered fish species can be found in Carinthia and in the North Eastern of Austria, where rare species are often found, too.

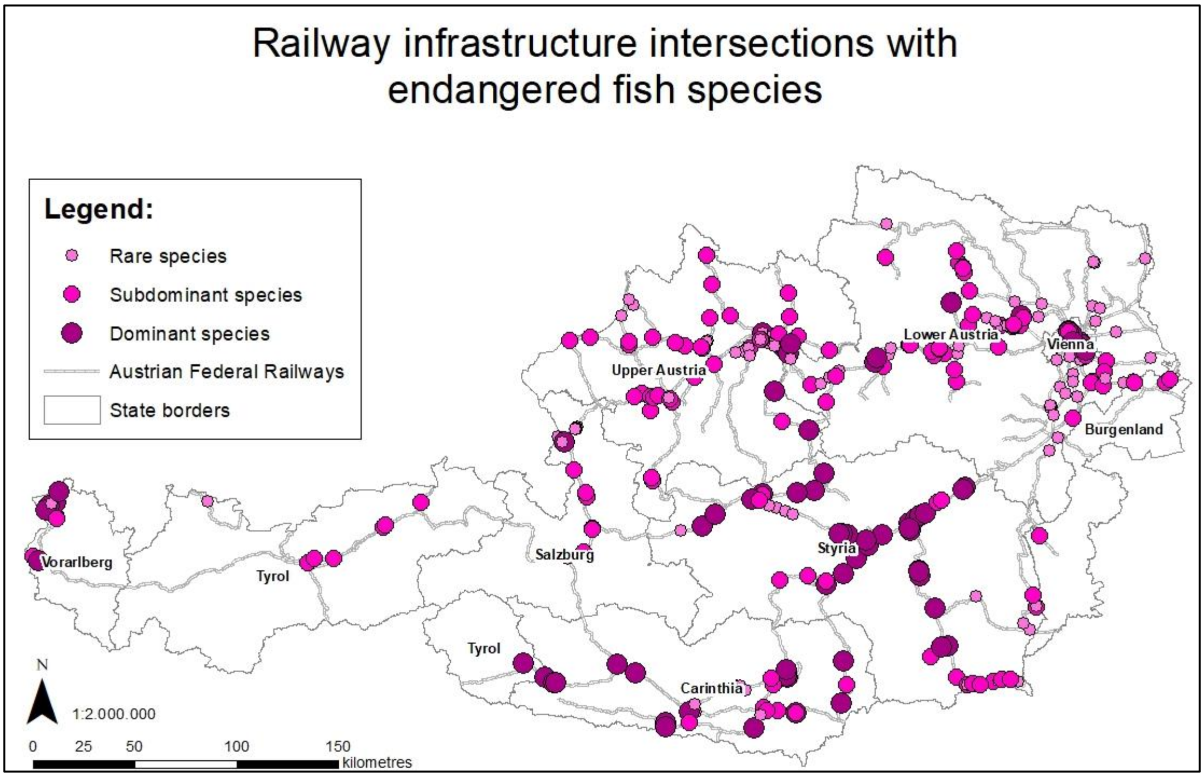

Figure 56: Railway intersections with potential river sections with endangered fish species

Railway intersections with waterbodies where endangered fish species occur are mapped in Figure 56. In the case of endangered fish species, there are even intersections where dominant species occur if the aquatic ecological conditions are suitable for their distribution (dark purple dots). Endangered fish species are represented as dominant species along railways in every federal state of Austria except Tyrol and Burgenland, but mostly in Styria and Carinthia.

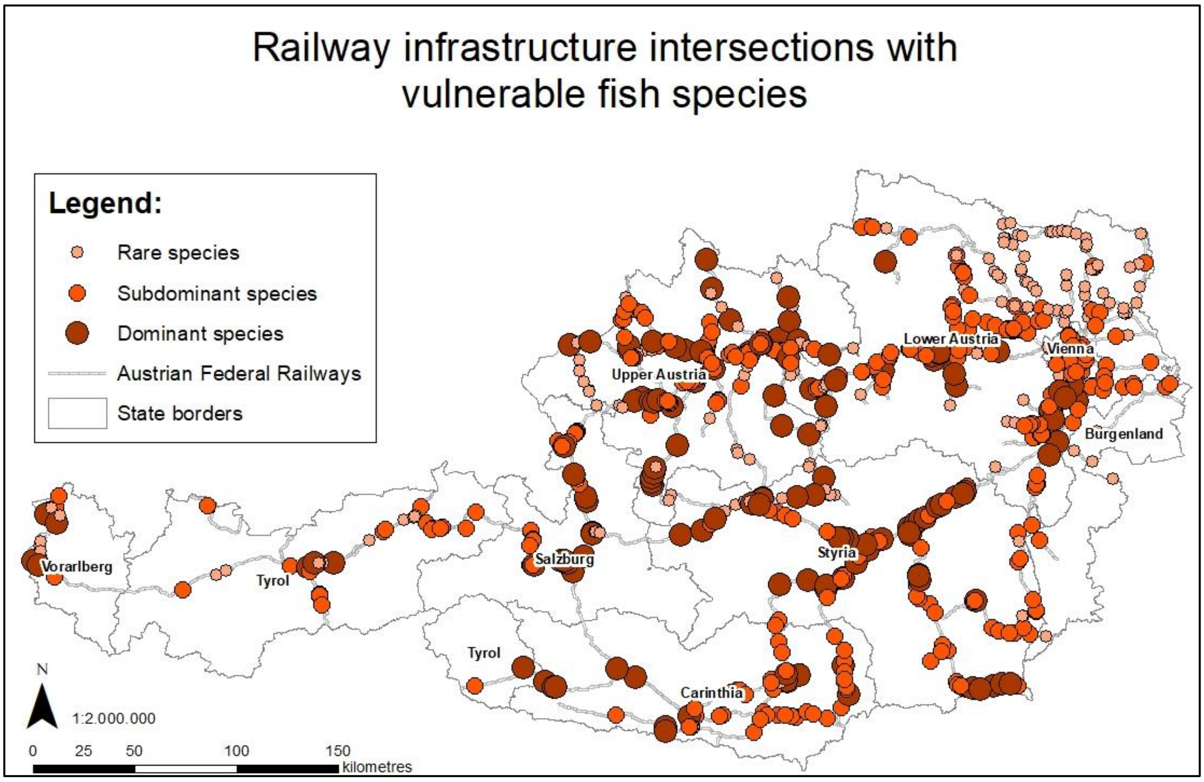

Figure 57: Railway intersections with potential river sections with vulnerable fish species

The group of vulnerable fish species is the one that is most widespread in Austria. Therefore, there are numerous waterbodies distributed over all federal states (except Burgenland and Vienna), which are crossed by the railways (Figure 57).

River pearl mussel

There are also some interaction points between the River pearl mussel and the railway network. At 12 crossing points there could be potential impacts on the distribution of the highly endangered mussel (see Figure 58). A more detailed description of the location cannot be given here, in order to protect this species from further negative influences according to data owners.

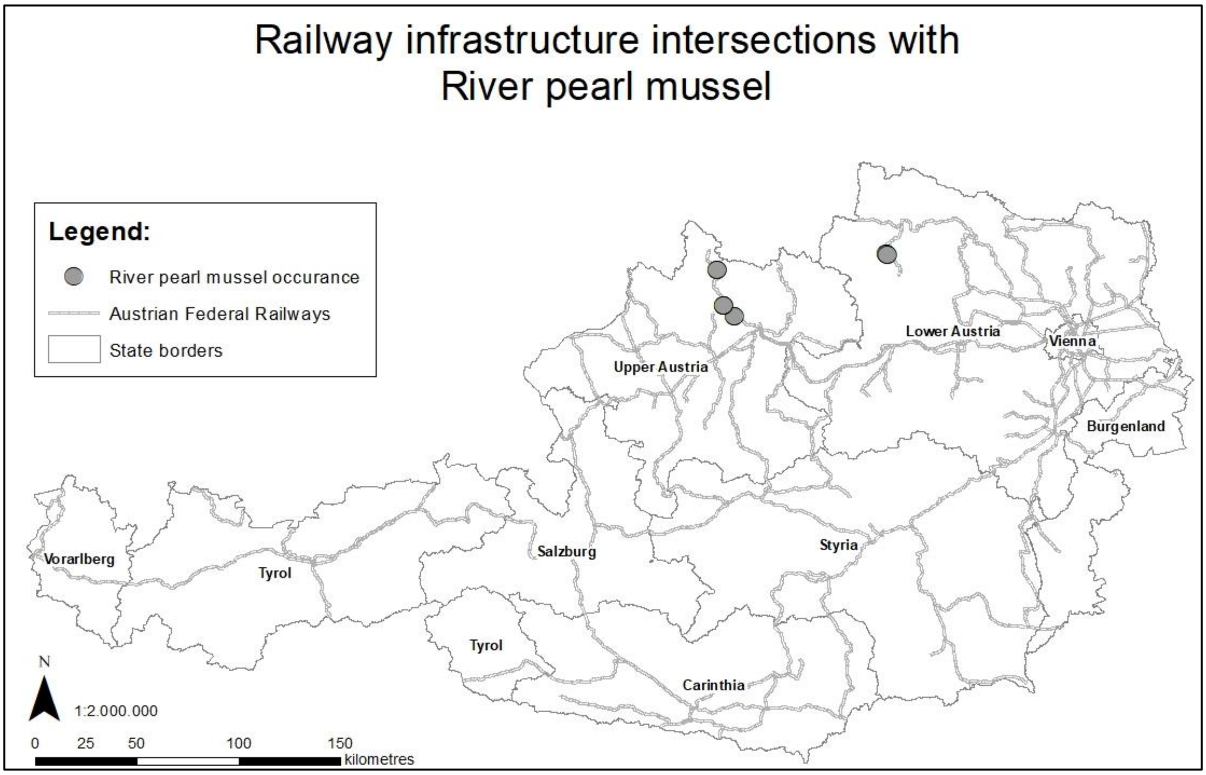

Figure 58: Railway infrastructure intersections with River pearl mussel

7.3. Intersection of railway network with Important bird areas (IBA)

Besides the intersections with aquatic biota, birds react to railway infrastructures. Lucas et. al. (2017) He was able to prove that accompanying vegetation strips along railway tracks are bird habitats. Different species´ occur in the railway verges. Figure 59 shows the intersections with Important Birds Areas. The Figure 60 provides an overview of the railways running through the distribution range of the three selected bird species. Most railway miles run through the range of the Common sandpiper, the fewest through the territory of the Common snipe (see Figure 61).

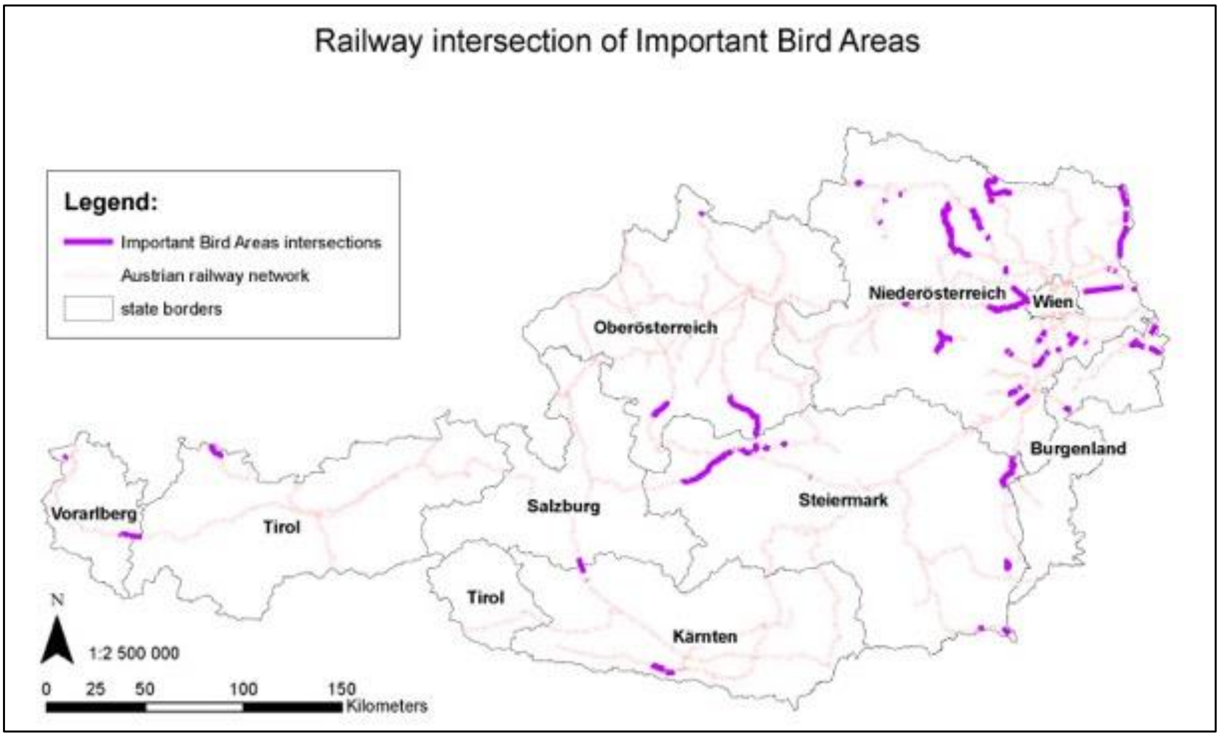

Figure 59: Intersections of railway network with Important Bird Areas

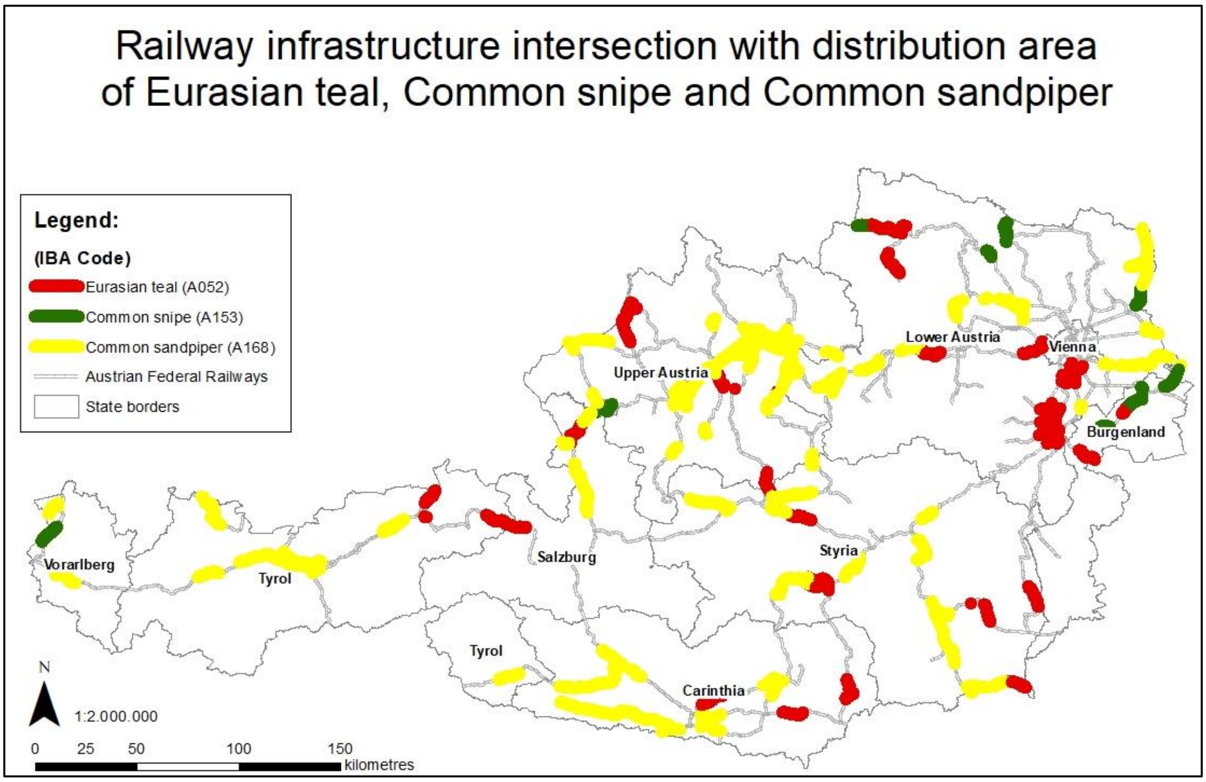

Figure 60: Intersection of railway network with distribution areas of European teal, Common snipe and Common sandpiper

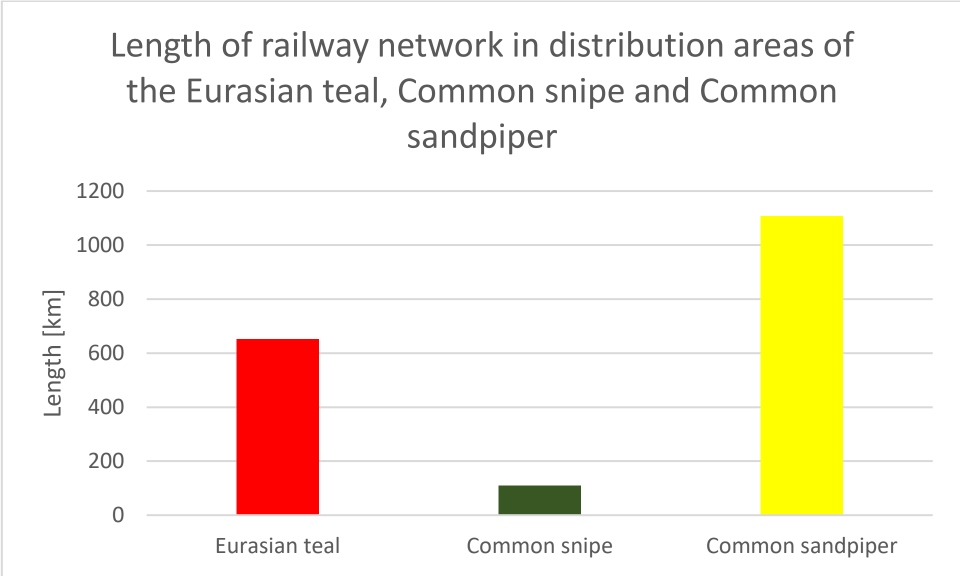

Figure 61: Amount of intersections of Austrian railway network with distribution areas of Eurasian teal, Common snipe and Common sandpiper

7.4. Intersection of railway network with European Protected Areas (Natura 2000)

In addition to the IBAs, the protected areas and nature reserves are also crossed by railway infrastructures (see Figure 62). A total of 437 km of railway network runs through protected areas. The longest continuous stretch is about 10 kilometres. The median is 200 metres. Lower Austria and Styria are the provinces with the highest amount of railway network in protected areas.

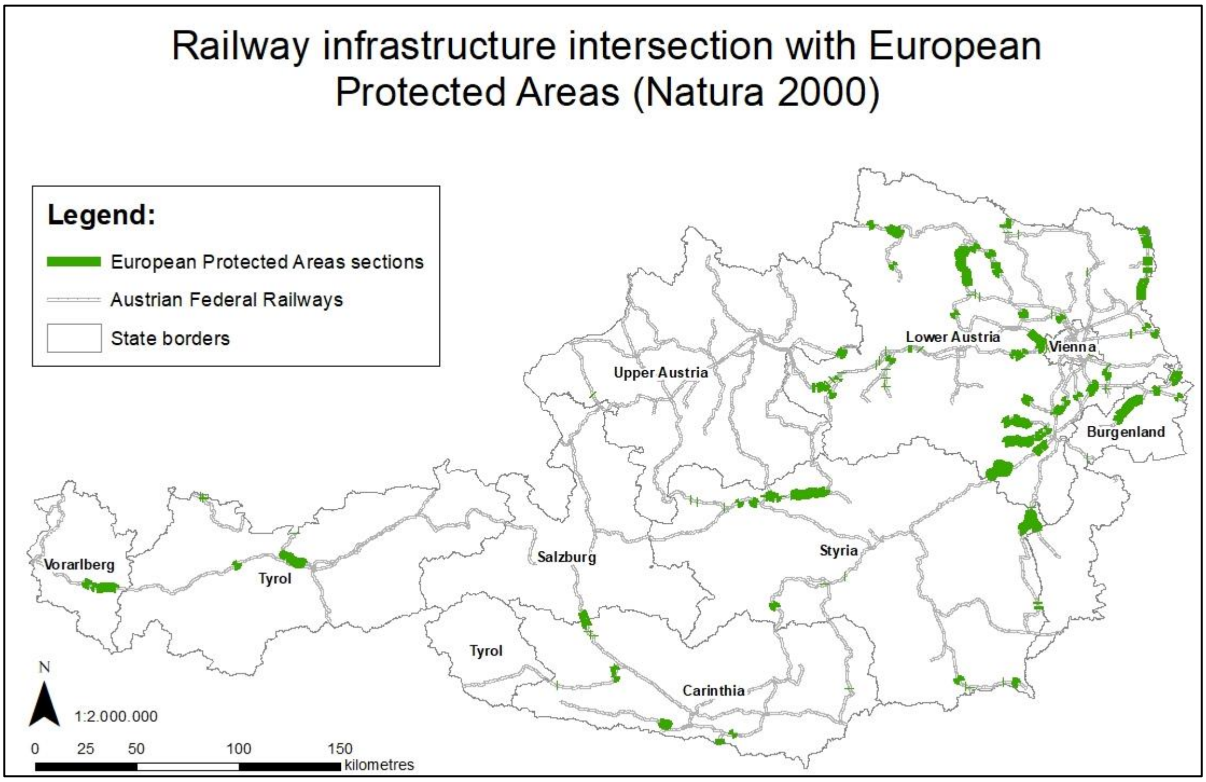

Figure 62: Railway network intersection with European Protection Areas (Natura 2000)

7.5. Intersection of railway network with Groundwater protection areas

Overall, 471 kilometres of railway network runs through groundwater protection areas (see Figure 63). A distinction must be made between single tracks, double tracks and railways station areas. Depending on these categories, it can be assumed that the amount of chemical substances introduced into the soil is different: While a single amount is expected on single tracks, double the amount is applied on double tracks. At this point, we will therefore take a closer look at the different railway categories. . Of these 471 kilometres, more than half are single tracks and one third are double tracks (see Figure 64).

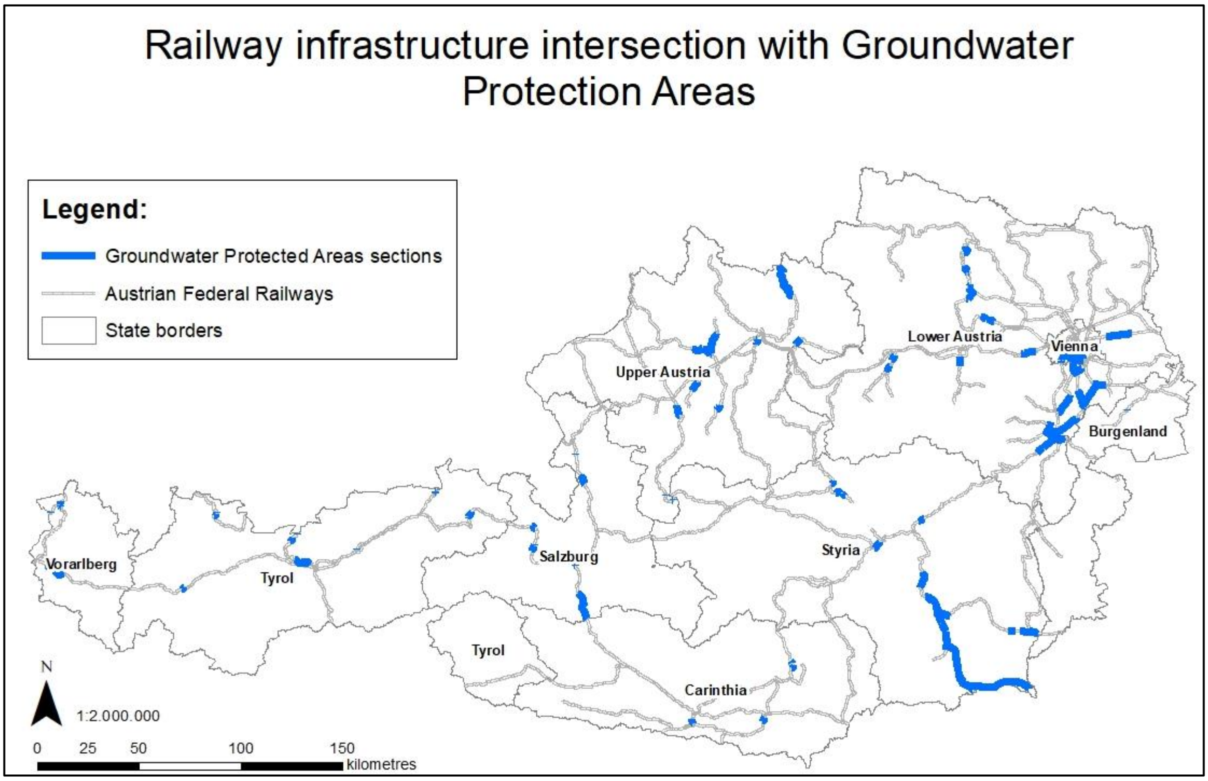

Figure 63: Intersection of railway network with Groundwater Protection Areas

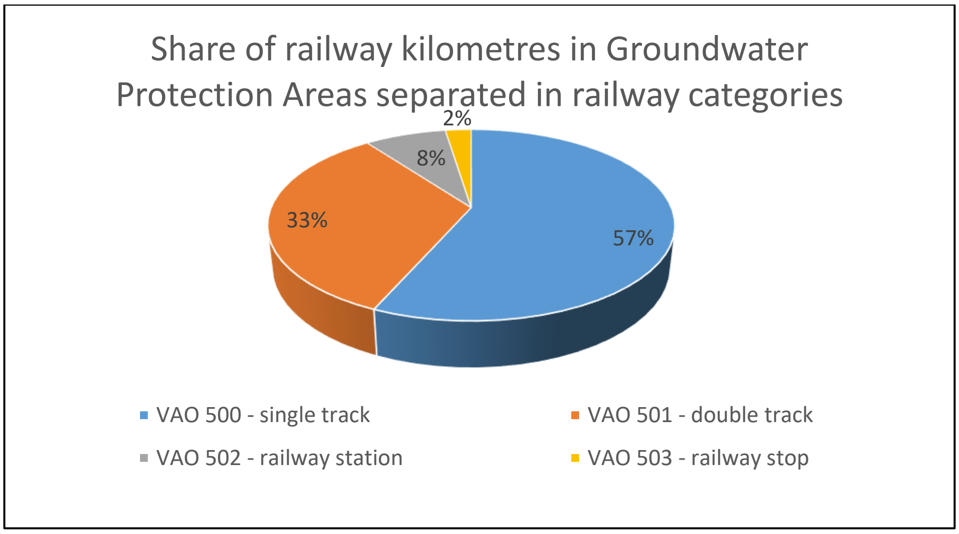

Figure 64: Share of railway kilometres in Groundwater Protection Areas separated in railway categories

7.6. Intersection of railway network with riverine and riparian habitats

As expected, numerous kilometres of railway network run through riverine and riparian habitats (see Table 8). The longest stretch identified is of about 31 kilometres and located within the potential riparian zone. None of the sections exceeds one kilometer in median length. For each of these ecosystems, it can be assumed that all three types of impacts can be expected from railway infrastructures, as shown in Chapter 6 described.

Table 3: Length of intersections of railway network with riverine and riparian habitats

Aquatic ecosystem	**Length of railway network sections [km]**	**Max. length of railway network sections [km]**	**Median**
Peatlands	1.431	8,5	0,32
floodplain forests	97	4,0	0,23
Wetlands	180	7,8	0,28
Riparian zones			
- **Actual**	185	2,2	0,59
- **Potential**	1.628	31,2	0,33

The following three maps (see Figure 65, Figure 66 and Figure 67) show the geographical distribution of the intersections between riverine and riparian habitats.

Peatlands

The longest peatland crossing routes are in the west and south of Austria (see Figure 65).

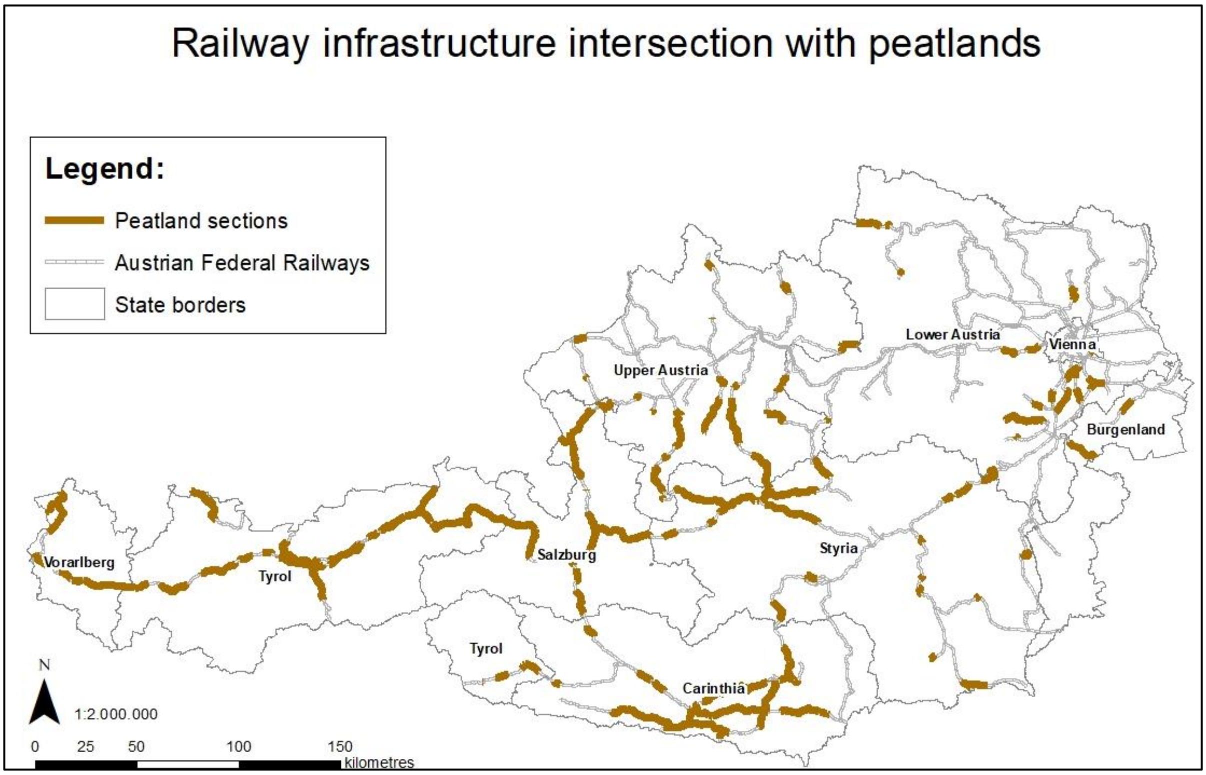

Figure 65: Intersection of railway network with peatlands (UBA, 2015)

Floodplain forests

The highest density of floodplain forests is found in the south and east of Austria (see Figure 66).

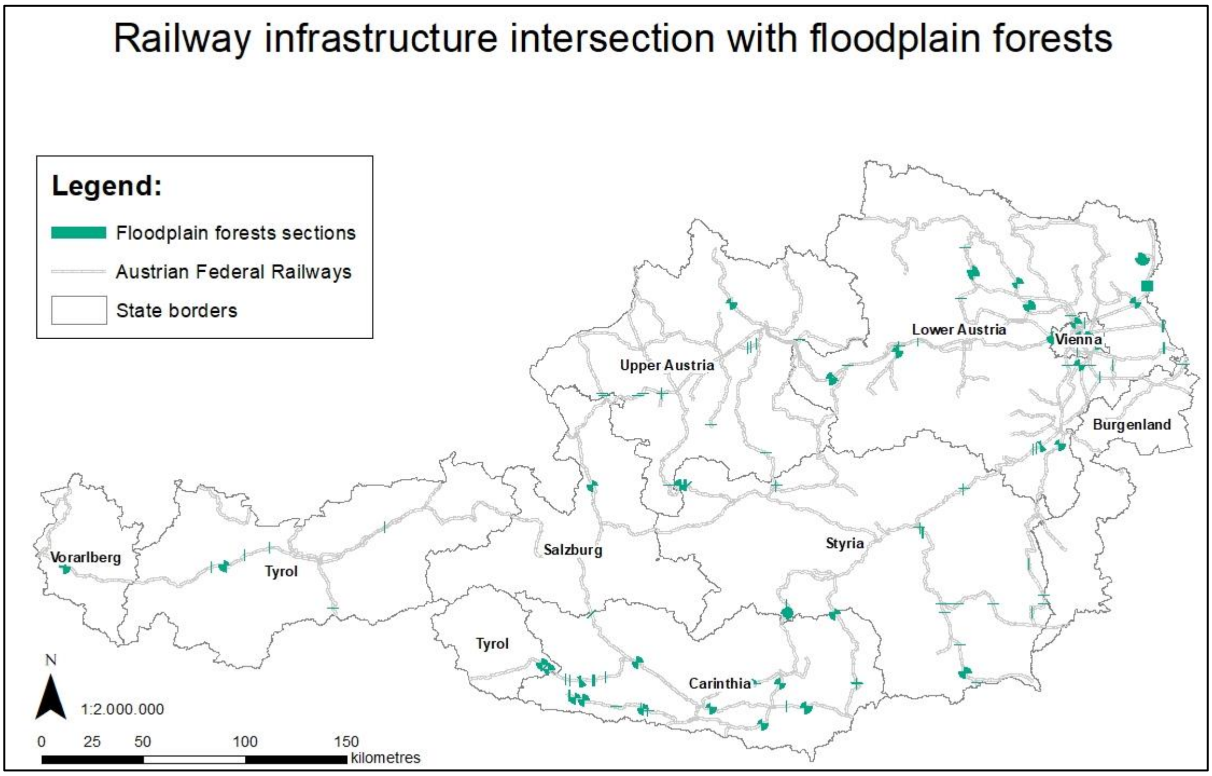

Figure 66: Intersection of railway network with floodplain forests

Wetlands

The longest railway sections within wetlands are found in central and eastern Austria (see Figure 67).

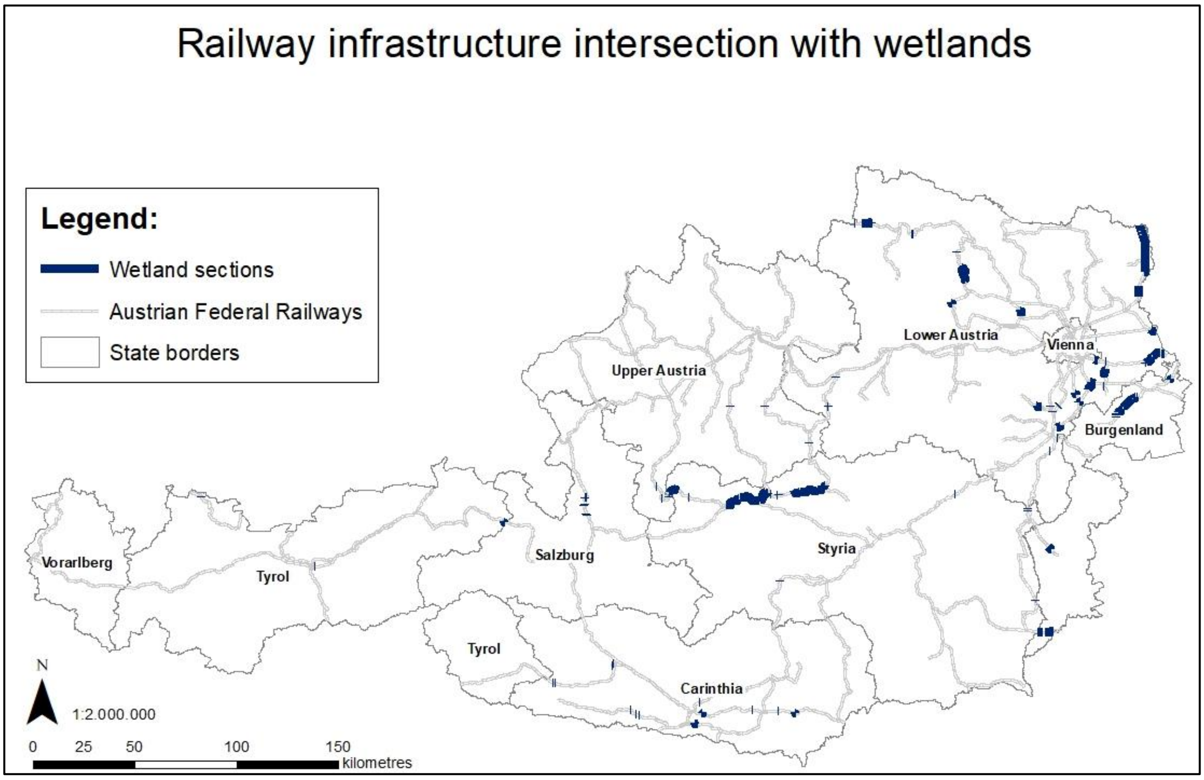

Figure 67: Intersection of railway network with wetlands

Copernicus riparian zones

As stated in Chapter 4.2.4, riparian zones have the widest extent of habitats mentioned here. Therefore, they also have the longest stretches of crossings with railway infrastructures. The longest routes are found in Styria and Lower Austria (see Figure 68).

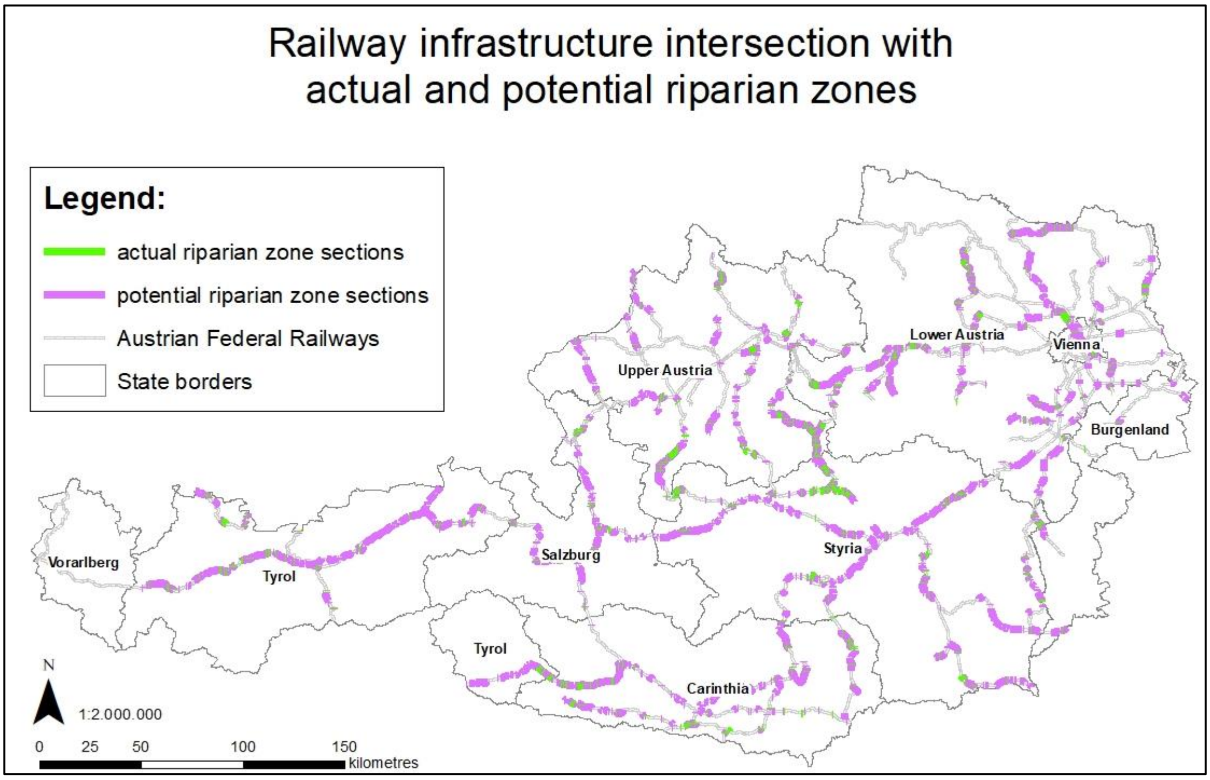

Figure 68: Intersection of railway network with actual and potential riparian zones

7.7. Intersection of railway network with flood risk areas

Almost every ÖBB railway line passes through one of the three flood risk areas (HQ30, HQ100 or HQ300) according to Chapter 4.2.5 (see Figure 69 and Figure 70). Although flood protection measures have been implemented in numerous valley areas in Austria, 10 % are still at risk at least from a 300-year flood event (HQ300), as large parts of flood protection measures were established in the 20th century and only have a maximum consensus for a 100-year flood event (HQ100). Many of them are even only dimensioned up to a 30-year event (HQ30). Railway embankments often cut off floodplains, as they usually have embankment crest heights that are above the calculated flood stop line. More and more often, culverts are built in the embankment so that the natural retention area is still preserved.

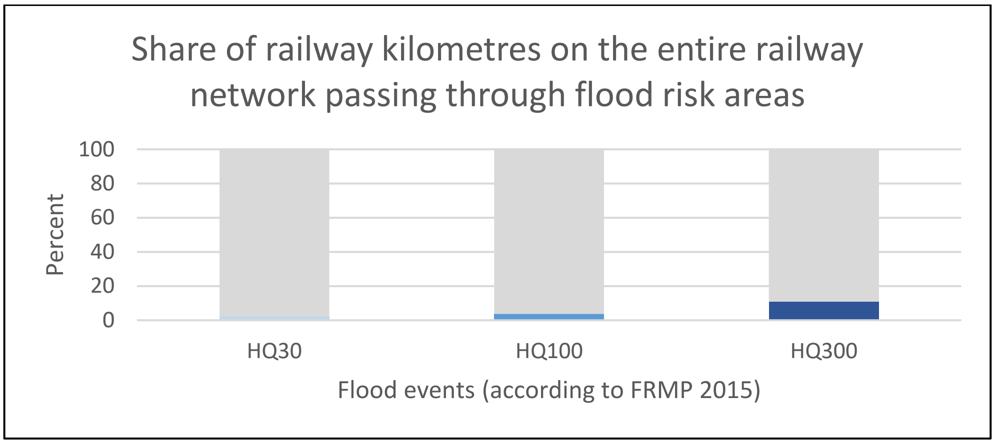

Figure 69: Share of railway kilometres passing through flood risk areas

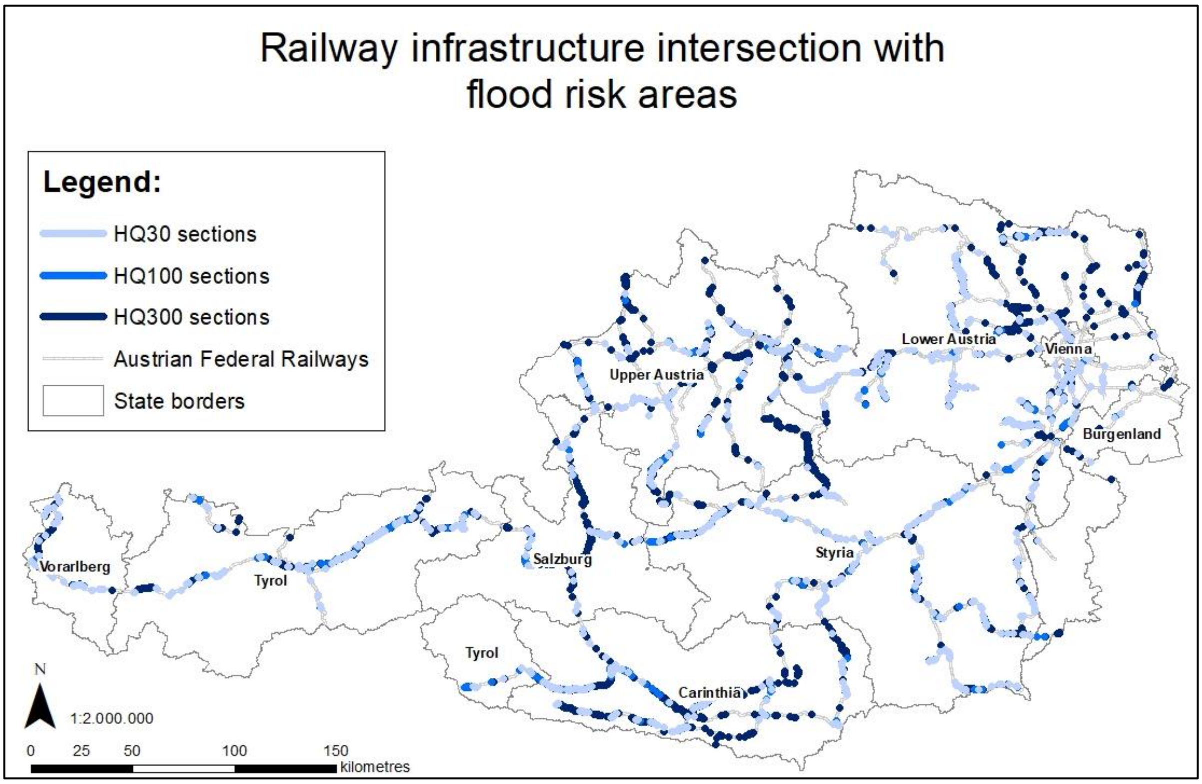

Figure 70: Intersection of railway network with flood risk areas

8. Results - Identification of sensitive river sections along the railway network

8.1. River sections along railway infrastructure with a preserving and protection need

The amount of valuable ecological habitats ("*Amount of overlapping polygons*") is assessed in four ways and named E1 to E4.

- E1: Areas, where river sections are rated with a very good or a good ecological status or are designated with a good potential, but are not linked with any riverine habitat ("*Amount of* *overlapping polygons*" is zero), have to be preserved. No additional measures need to be taken to improve the river condition or achieve the target. In any case, deterioration of the status is not permissible. Any structural interventions that could worsen the ecological status are to be avoided.

- E2: Areas, where river sections are rated with a very good or a good ecological status or are designated with a good potential, and have 1 to 2 counts for the "*Amount of overlapping polygons*". These areas are to be preserved, too. In any case, these river sections are worthy of preservation and protection and have a high need for preservation. They are to be impaired in their character.
- E3: Areas, where river sections are rated with a very good or a good ecological status or are designated with a good potential, and have 3 to 6 counts for the "*Amount of overlapping polygons*". This group with overall 780 polygons is worthy of special protection and have a high protection need at certain points. This applies above all to areas where endangered fish or bird species, habitat structures worthy of protection (e.g. floodplain forests, wetlands) or free flowing sections occur. The individual polygons are to be assessed in detail if necessary.
- E4: Areas, where river sections are rated with a very good or a good ecological status or are designated with a good potential, and have more than 7 counts for the "*Amount of overlapping polygons*", These areas are worthy of special protection and are to be protected at maximum rank. The simultaneous presence of endangered fish or bird species, habitat structures worthy of protection (e.g. peatlands, wetlands), groundwater protection areas, free-flowing sections and others is a special need for protection factor.

The frequency distributions of these four classes in Annex 5 show that most overlapping polygon areas are a few hundred hectares in size. In group E1, however, there are also river sections that have very large areas up to 480 hectares. Group E4 contains some areas of 2 to 7 hectares that are significantly above-average plot sizes (0,6 hectares) and can be found in Carinthia and Lower Austria (see Figure 71).

Table 4: Definition of "River sections along railway infrastructure with a preserving and protection need"

	Criteria "*Status*"	Amount of overlapping polygons	Area [hectares]	Mean value [hectares]
E1 - River sections with a minimum of preservation need (without valuable ecological habitats)	1, 2 or 22	none	598,8 (maximum: 488,2)	26,0
E2 – River sections with a high protection need (with designated ecotype counts)		1 or 2	26.578,2 (maximum: 3.556,3)	67,5
E3 – River sections with a very high protection need		3 to 6	9.100,3 (maximum: 438,4)	4,4
E4 – River sections along railways worthy with a maximum of protection need		At least 7 and up to 14	290,0 (maximum: 25,3)	0,6

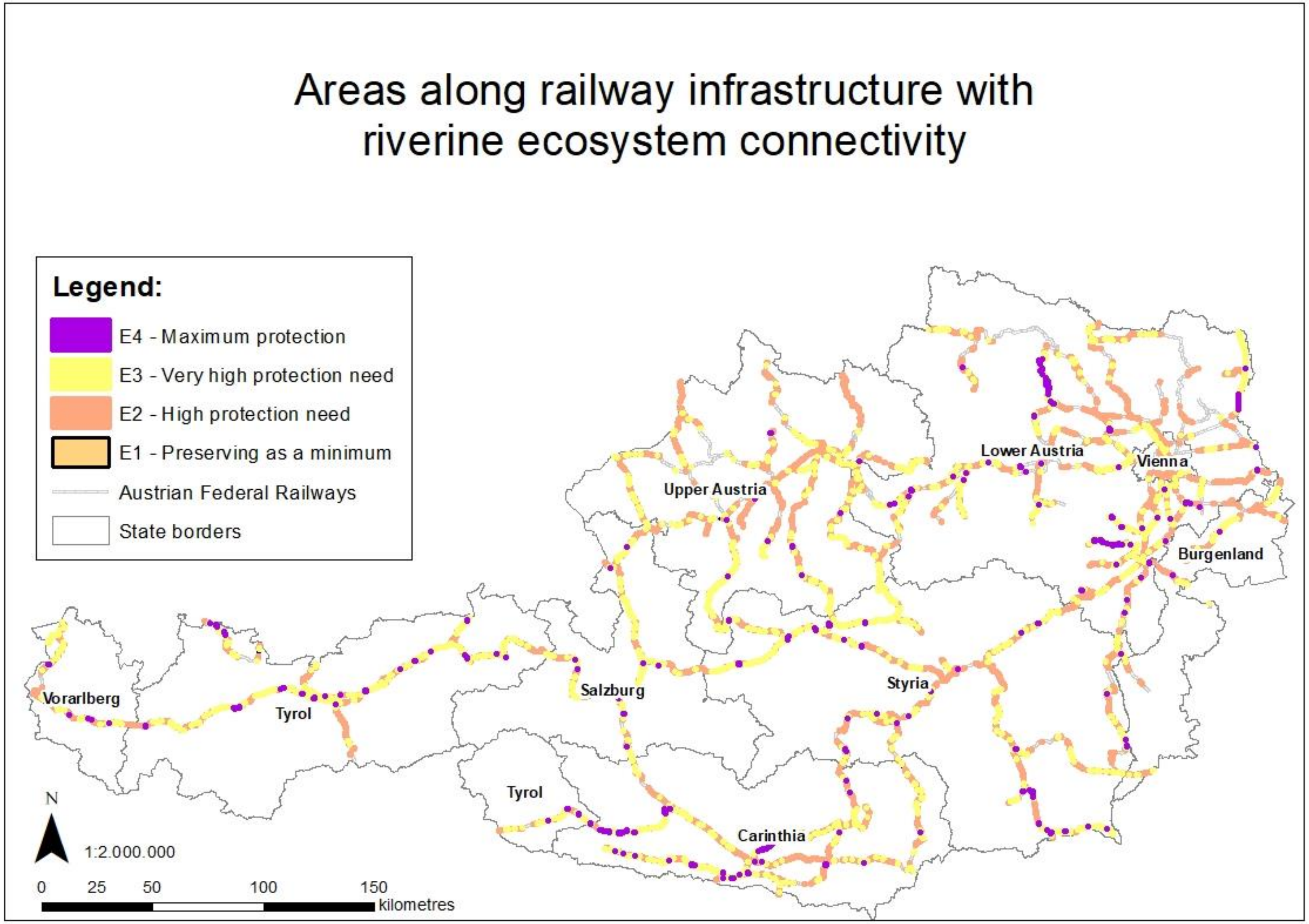

Figure 71: Areas along railways worth preserving and protecting

8.2. River sections with potential for riverine ecosystem connectivity

Similar to the definition of river sections along railway infrastructures with a preserving and protection need, an analysis was also made of river sections that have potential for improvement of the ecological status through ecological connectivity. Here, "*River sections with potential for riverine ecosystem connectivity"* are defined as sites where not only the status of a waterbody including the embankment areas can be improved but also ecosystems that can establish lateral connectivity with the waterbody are considered. This is, for example, the connection of floodplains, the reactivation of peatlands or areas where protected fish and bird species live. When considering the potential, other ecosystems outside the actual watercourse are also included.

Table 5: Definition of "River sections with potential for riverine ecosystem connectivity"

	Criteria "*ecological status or ecological potential*"	**Amount of overlapping polygons**	**Area [hectares]**	**Mean value [hectares]**
V1 – River sections improvement obligation and low riverine ecosystem connectivity	3, 33, 4 or 5	none	2.233,5 (maximum: 951,5)	54,5
V2 – River sections improvement obligation and very high riverine ecosystem connectivity	3 or 33	at least 3	1.063,0 (maximum: 41,5)	0,6
V3 – River sections improvement obligation and high riverine ecosystem connectivity	4 or 5	at least 3	613,0 (maximum: 37,8)	0,5

For group V1, the ecological status of waterbodies has to be improved first and foremost. However, these sections are river-only sections and located in areas outside of other overlapping ecosystems. In these three classes the majority of the overlapping polygons have very small areal extents. In the frequency distribution of group V1, however, there are also areas that are several hundred hectares in size. The longest sections can be found in Tyrol, Upper Austria and Lower Austria (see Figure 72).

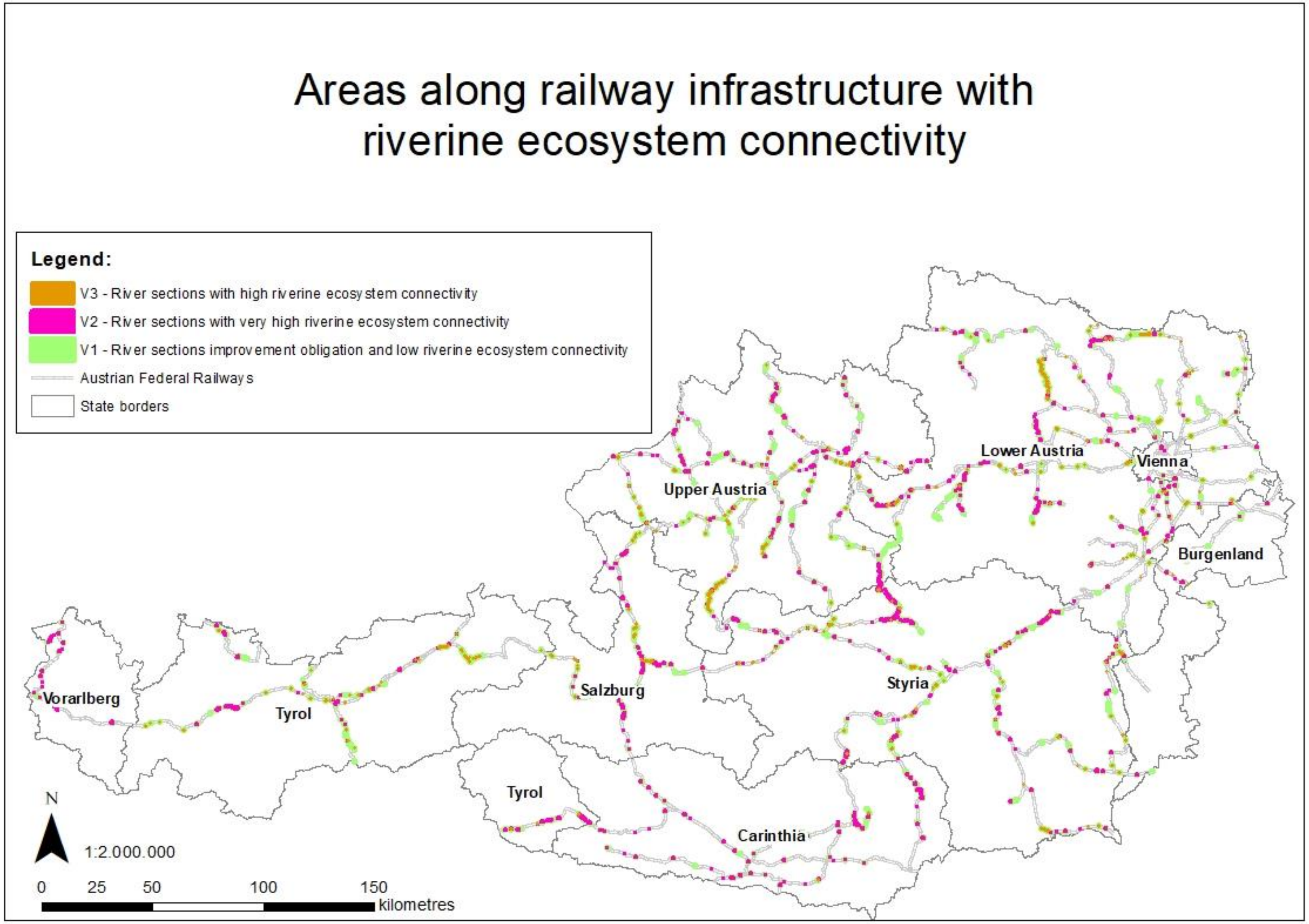

Figure 72: Areas along railways with potential for ecosystem improvement

9. Results - Hot spot analysis

To highlight the special area characteristics, the databases were grouped thematically and examined separately with regard to hot spots along the railway network. The following thematic areas have been defined:

- Hot spots of riverine and riparian habitats
- Hot spots with water storage function
- Hot spots of hydromorphologically sensitive sections
- Hot spots with restoration potential for hydromorphological status
- Hot spots of fish population areas
- Hot spots of protected areas and nature reserves

The Tables 7 to 12 describe which criteria and related values are used for the numerical analysis in the geoinformation system. The entire model representing the procedure is attached in the Annex 3.

Hot spots of riverine and riparian habitats

Here the river network of Austria, floodplain forests, wetlands as well as actual & potential riparian zones along the railway network (with a buffer of 100 metres) were combined. Both the waterbodies and riparian zones were ranked with a value according to their need for protection (see Table 6: Criteria table).

Lower Austria as well as some areas in Styria and Upper Austria have been designated as areas with hot spots of riverine and riparian habitats. There, all criteria can be found in maximum value. In the rest of Austria, it is mainly Carinthia and Lower Austria where areas with dense preservation priority are located (see Figure 73).

Table 6: Criteria table "Hot spots of riverine and riparian habitats"

Data source	Indicators	Value (1-5)
Ecological status	Status class = 1, 2	5
	Status class = 3	4
	Status class = 4, 5	3
Floodplain forests	meadow area	5
Wetlands	wetland area	5
Riparian zones	only actual riparian zones or only potential riparian zones	4
	actual and potential riparian zone	5

Hot spots with water storage function

Here drinking water protected areas, peatlands and flood plains were combined. All these three ecological criteria are areas of great importance for water retention and water storage. The own model graphic for this subject area is available in the Annex. Due to the change in the method of analysis (see Chapter 2), Table 8 does not list any values. These are only part of the grid analysis. The result (map symbology of conservation priority) must therefore also be interpreted differently and is as follows:

Hot spot storage function:

- Very high: Combination of peatlands, drinking water protected area and flood plains HQ_{30}
- High: Combination of flood plains HQ_{30} and peatlands
- Mediate: Combination of drinking water protected area und flood plains HQ_{30}

Very high priority areas are found south of Vienna, but also in Salzburg, in southern Styria (Grenzmur) and sporadically in Tyrol and in Vorarlberg. The high priority areas are mainly found in western and central Austria (see Figure 74).

Table 7: Criteria table “Hot spots with water storage function”

Data source	**Indicators**	**Value (1-5)**
Drinking water protected area	Drinking water protected area	-
Peatlands	Peatlands	-
Flood plains	Flood plains HQ30	-

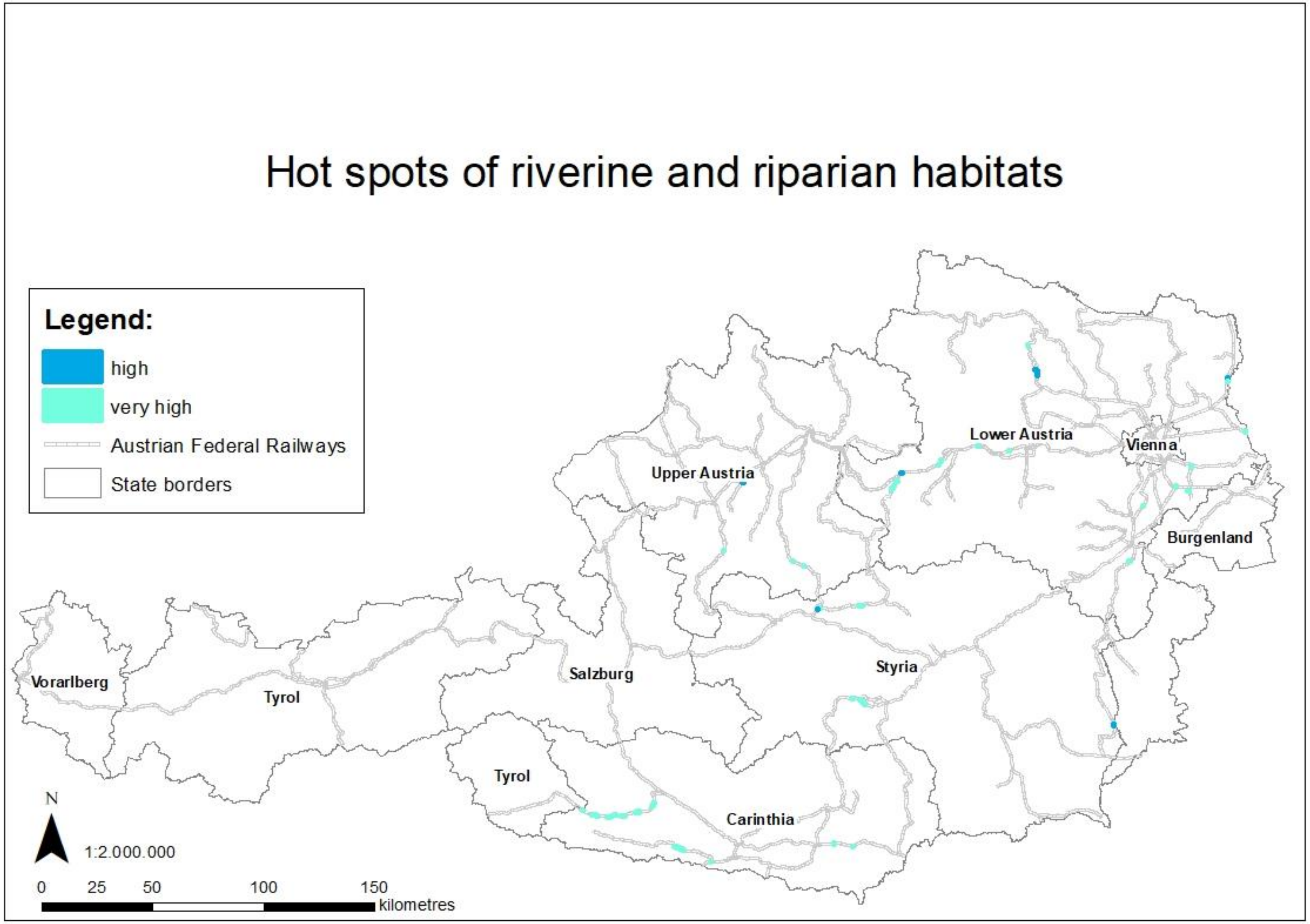

Figure 73: Hot spots of aquatic ecosystem areas

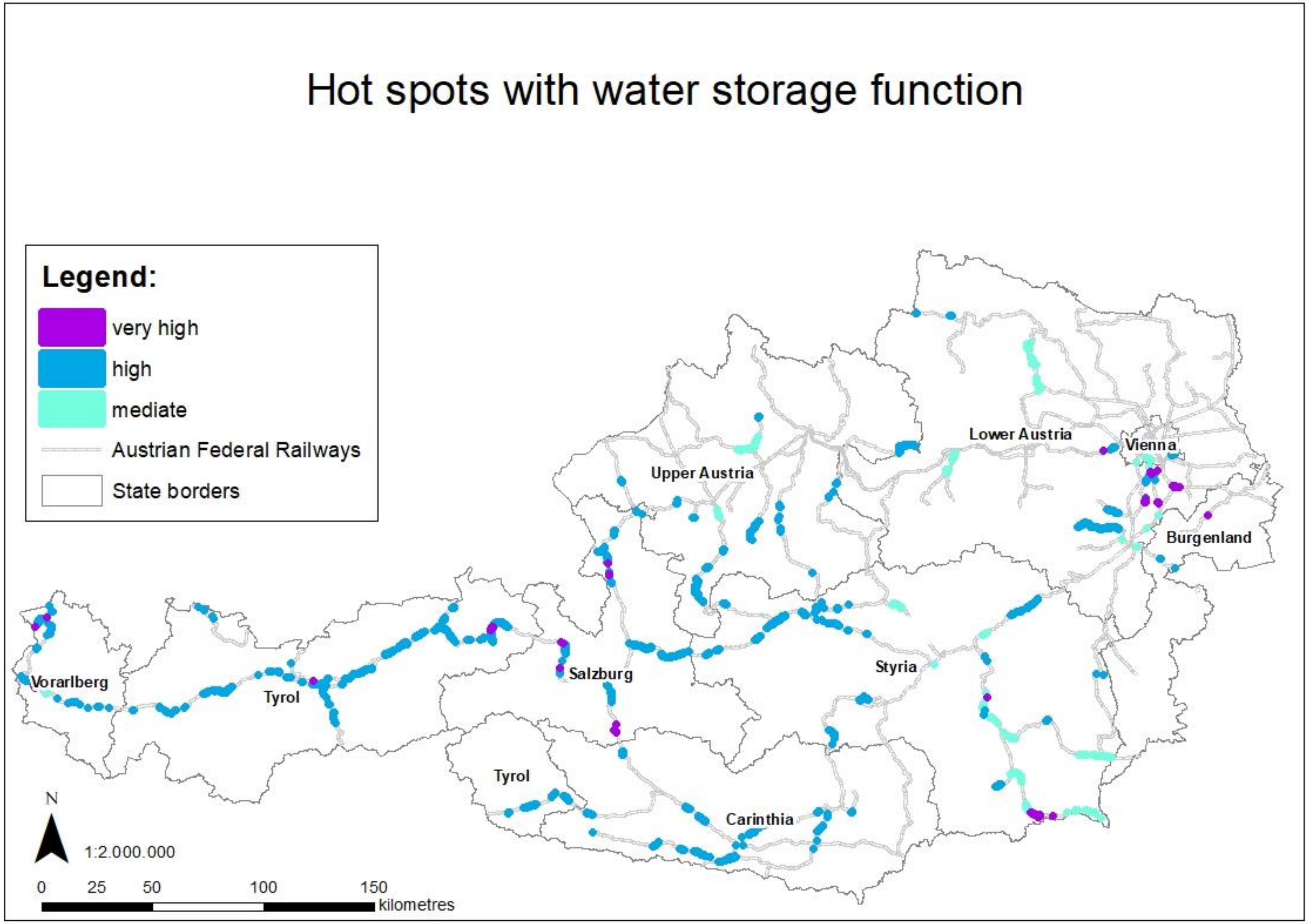

Figure 74: Hot spots with water storage function

Hot spots of hydromorphologically sensitive waterbodies

To obtain ecologically sensitive hot spots, especially with regard to the hydromorphology, waterbodies with a very good or a good morphological status and free flowing sections were combined. The hot spots with distinctive natural routes are distributed throughout Austria. If these valuable water bodies are located near railway infrastructures, it depends on the pressure of use to what extent these valuable river sections are or remain unaffected by external impacts. The superposition shows that there are three different classes of pressure of use (see Figure 75). The blue dots show morphologically intact river sections near stations or stops. The yellow and red dots show areas where the very good and good river morphology has to be maintained. However, ongoing railway traffic in both directions is to be expected while the ecological status of waterbodies has to be maintained.

Table 8: Criteria table "Hot spots of water morphology priority sections"

Data source	Indicators	Value (1-5)
River network	Morphological status of waterbodies 1, 2	 5
Free flowing sections	Free flowing sections	5

Hot spots of restoration potential for hydromorphological status

Waterbodies with a mediate, poor or bad morphological status and free flowing sections were combined with railways. The superposition shows that there are three different classes of pressure of use (see Figure 76). It is particularly river sections in Tyrol, Carinthia and sporadically in Lower Austria and Styria that have a very high pressure on hydromorphological status improvement near high-level railway infrastructures High pressure of use High pressure of use is recorded on the routes between Carinthia and Salzburg, Carinthia and Vienna, but also on the western railway lines.

Table 9: Criteria table "Hot spots of restoration potential for hydromorphological status"

Data source	Indicators	Value (1-5)
River network	Hydromorphological status of waterbodies 3 4 5	 5 4 3
Free flowing sections	Free flowing sections	5

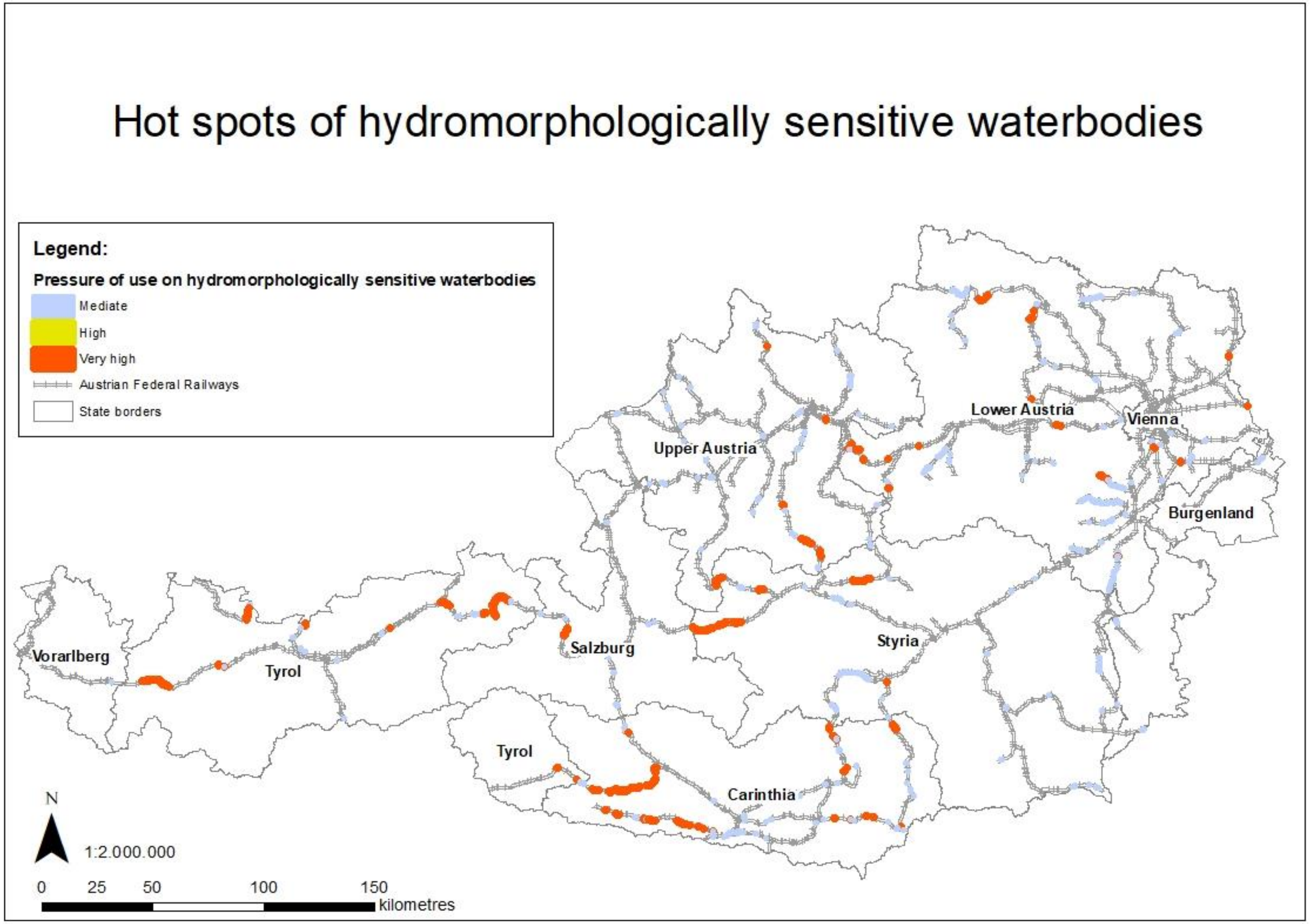

Figure 75: Hot spots of hydromorphologically sensitive waterbodies

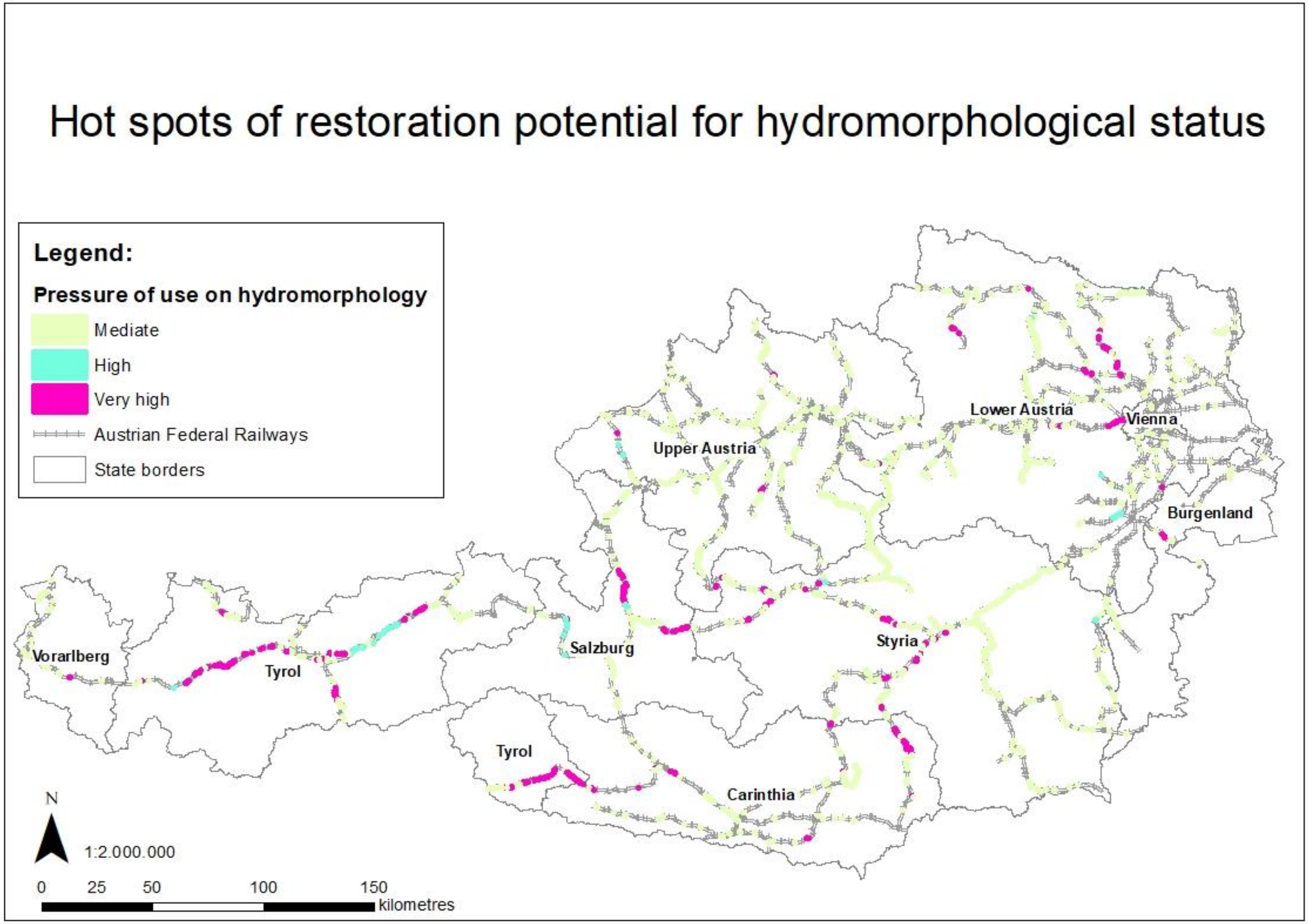

Figure 76: Hot spots of restoration potential for hydromorphological status

Hot spots of fish population areas

Analogous to the classification of the assessment of Danube salmon occurrence (see Chapter 7.2), values were assigned. River sections with a Conservation status C2 were rated with Value 1 and sections with high potential of Danube salmon occurrence were rated Value 6. In addition, the assessment of grayling occurrence was adopted by the IHG (2019). Waterbodies with grayling occurrence and a very good ecological status have been assessed with Value 2, those with a good status with Value 1 (see Table 11).

Table 10: Criteria table "Hot spots of fish population areas"

Data source	Indicators	Value (1-6)
Fish Database Austria (Scharfling 2015, Seliger 2019 and Scheikl et. al. 2020)	Waterbodies with endangered, critically endangered and vulnerable fish	1
Fish Database Austria (FDA, 2015), Hofpointner (2013), IHG (2019)	Waterbodies with Danube salmon population	
	1 – Conservation status C2	1
	2 – Conservation status C1	2
	3 – Conservation status C	3
	4 – Conservation status B	4
	5 – Conservation status A	5
	6 - Sections with high potential	6
Fish Database Austria (FDA 2015), IHG (2019)	Waterbodies with European grayling population	
	1 – Very good ecological status	2
	2 – Good ecological status	1

It is the River Mur where highly endangered fish species (first and foremost the Danube salmon) occur or could occur and which are considered to be very sensitive sections. But also on the River Inn, the River Drau, the River Enns and the River Danube there are river sections near railways that require special fish protection (see Figure 77).

A separate ranking for the River pearl mussel was dispensed with, as every intersection with the shell is worth protecting. The River pearl mussel is inherently extremely worthy of protection. At this point, reference should be made to the illustration in chapter 7.2.

Hot spots of protected areas and nature reserves

Data from BirdLife Austria and European Protected Areas were combined and selected within a railway infrastructure buffer of 100 metres (see Table 12). It is Lower Austria and northern Burgenland that have the highest density of protected areas and bird species along railways (see Figure 78).

Table 11: Criteria table "Hot spots of nature conservation areas"

Data source	Indicators	Value (1-5)
BirdLife Austria 2017	Areas with important bird species	5
European Protected Areas (Natura 2000)	Nature conservation areas	5
BirdLife Austria 2017	Combined distribution areas of European teal, Common sandpiper and Common snipe	5

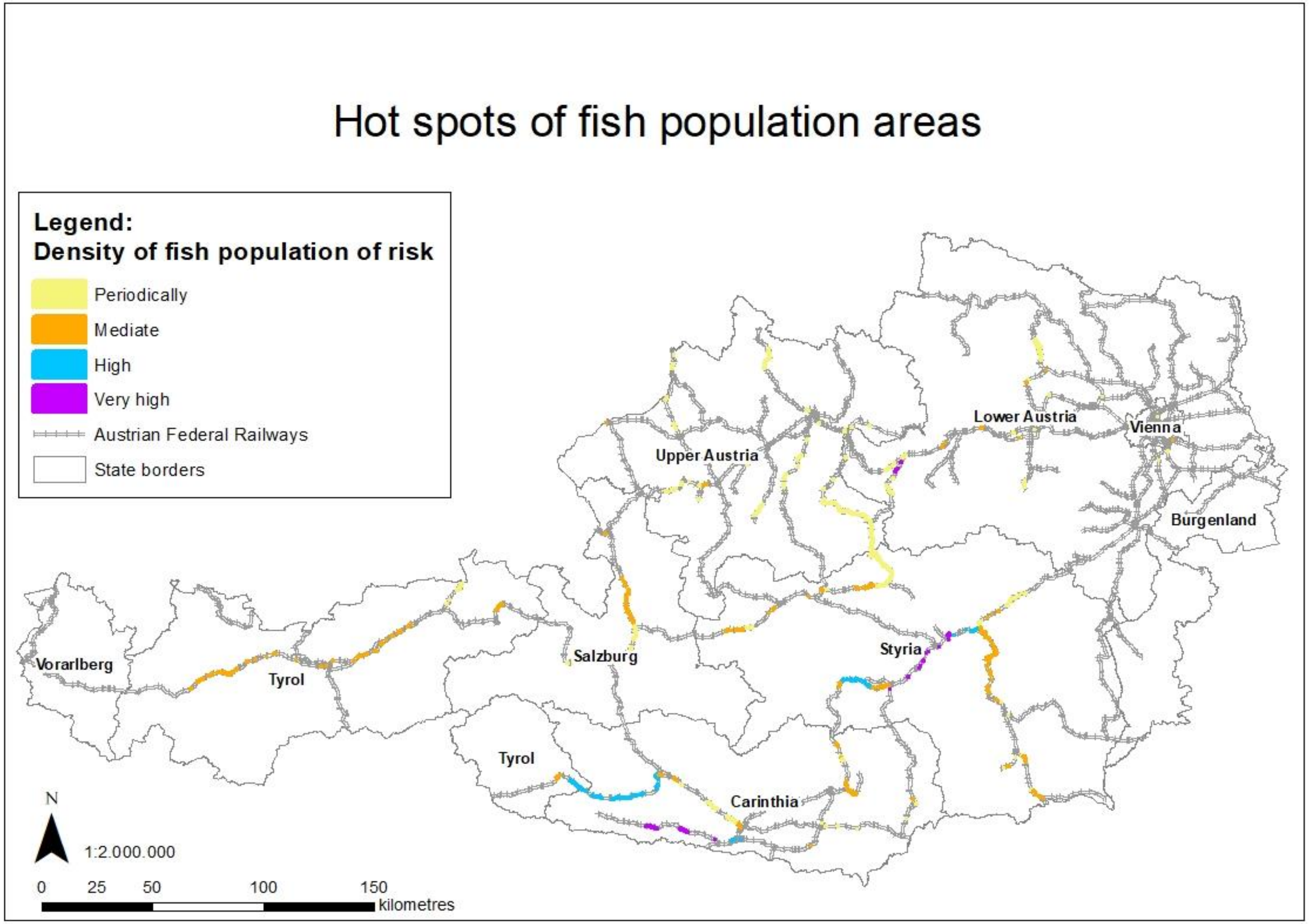

Figure 77: Hot spots of fish population areas

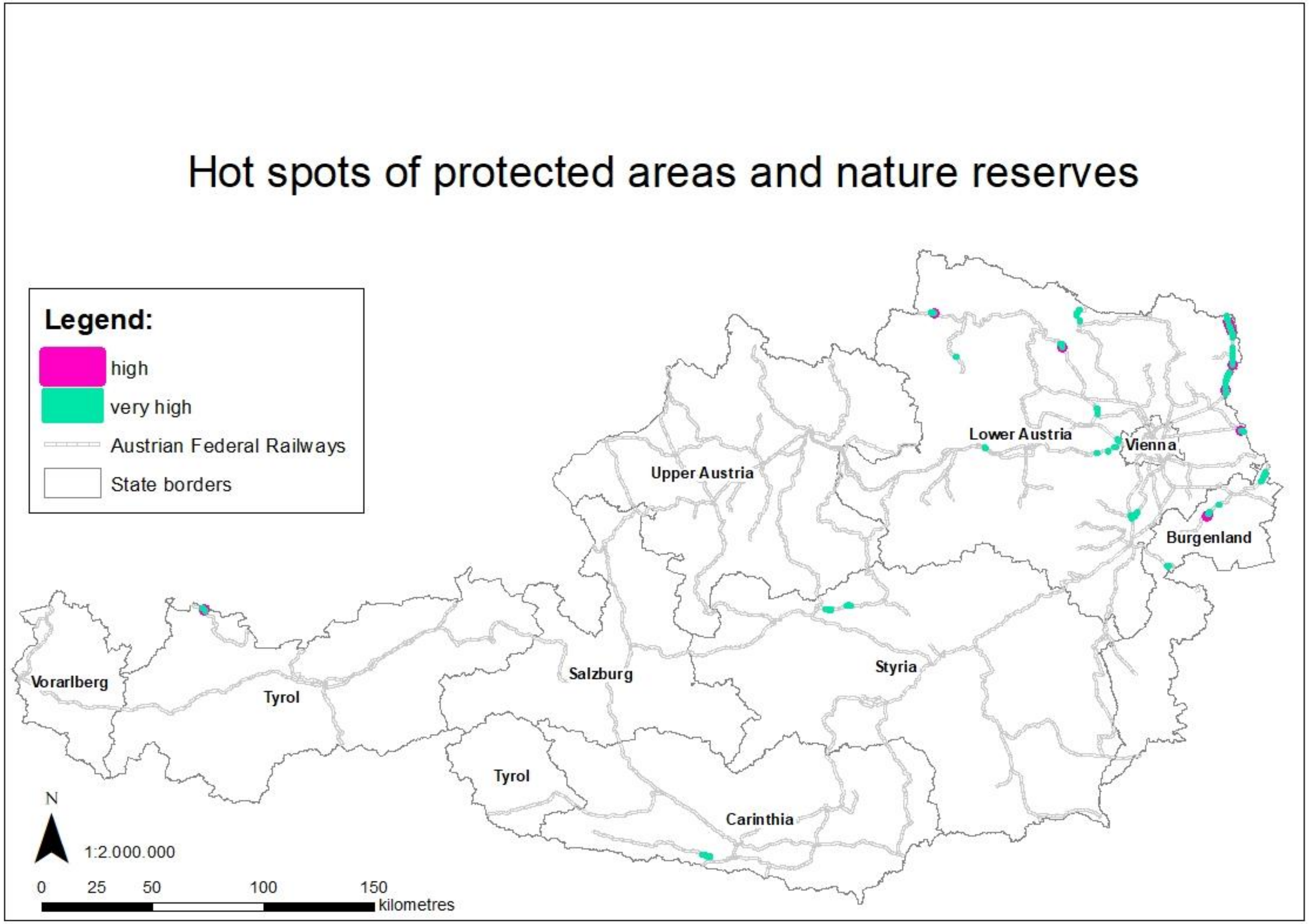

Figure 78: Hot spots of nature conservations areas

10.Discussion

There are waterbodies in Austria, where railway infrastructure exerts pressures on riverine ecosystems. These are mainly of hydromorphological character.

The first geospatial result shows that an intersection between the railway network and the river network produces numerous overlaps. A total of 1,035 spatial crossing points could be identified. The results are maps showing the sum of crossings and intersections between railway and rivers, which are mainly bridges and water culverts. The vast majority of waterbodies in the area of these crossing points are in moderate or worse ecological condition. Regarding the quality target of the WFD, which is, that all surface waterbodies have to reach the "good ecological status", most waterbodies with railway crossings are in need of ecological improvement.

With regard to the evaluation of the causer of barrier construction, it can be assumed that in the vicinity of human infrastructures, especially in the vicinity of transport infrastructures, interventions were made in the natural hydromorphological development of flowing waters. In the Danube Basin Management Plan human settlements are seen as a source of water pollution and as a driver that can influence pressures on the natural hydromorphological structures of surface waters. Railroad and road infrastructure are part of human settlements and can therefor alter the river´s hydromorphology.

Barriers were erected to stabilise the riverbed and to prevent lateral erosion and undercutting of transport routes of railways and roads. Roads were not considered in this Master thesis and therefore require separate or joint consideration. It is suspected that numerous barriers were built as part of the construction of road or railroad infrastructures in connection with flood protection. In the last century, numerous waterbodies were regulated in the course of infrastructure development regarding flood risk. Often, flood protection was realized not only for settlements, but mainly to protect roads and railroads as well as agricultural land from floods. It was customary that obligation of maintenance was transferred to the municipalities. During recent surveys conducted as part of the Styrian RBMP 2021 update, it was found that some barriers were not only specific due to "*flood protection*" measures for settlements, because there was no human settlement there at that time that had to be protected. At the same time a high ranking road was built. It can be assumed that the construction of barriers was part of road extension. It can also be assumed, that some of the "*unknown*"-assessed elements are constructed due to transport infrastructure establishment. They were built to create space for traffic routes and prevent lateral erosion and the undercutting of traffic routes.

Intersections can be barriers in many ways. On the one hand, rail crossings restrict the hydromorphological development of the waterbodies, on the other hand, railways cause noise emissions, ground vibrations and chemical impacts. The same applies to railway sections located close to the river or riverine habitats. Here, the impacts mentioned in Chapter 5 have an effect on longer stretches. In most cases, these impacts do not act as isolated but as cumulative effects, which have a greater impact than at individual points depending on the length. In addition, around 63 % of the 188 barriers within a 30 metres radius from railway crossings are not fish passable and thus represent an additional water morphological factor that can impedes the improvement of the condition of the waterbodies.

Waterbodies within 100 metres of railway infrastructures are mainly in a moderate hydromorphological condition. In addition a total of 1,884 barriers could be identified, half of which are classified as not fish-passable. About 89 % of them is recorded for flood protection and hydroelectric power plants. The main type of barriers are typical barriers but also chain falls.

The analyses show that there are definitely hydromorphological restrictions here, both at selective points and along flow corridors. The results suggest that less impact can be expected from direct crossings than from railway infrastructures that run parallel to the river for a longer distance. The highest proportion of contact points with railway infrastructures is found in small river valleys. In order to be able to assess the degree of morphological stress caused by these restrictions and how it affected the fish biocoenoses over the time, more datasets must be taken into account in an additional consideration. In connection with the fish regions, the associated natural river morphology (i.e. based on the Franziszeischer Kataster) and the historic development of railway lines, the influence of stress could be assessed more detailed.

Besides waterbodies, there are sensitive aquatic areas which are affected by railway infrastructures. Here, protected areas, key habitats for aquatic and semi-aquatic animals and endangered species play a major role.

In most cases constructional operations have effects on the natural environment. Thus, it is very likely that the increase of investment in infrastructure will intense pressure to resources like soil and water. The current railway network is located in narrow valleys and mountain regions and contains unavoidable encroachments, like bridges and railway stations. Some of them are located in very sensitive areas with high endangered fish species or birds. For every sensitive ecosystem and species data considered, contact points with railway infrastructures could be found. Sensitive areas should be protected against negative effects of intensively used and important traffic infrastructures. In this sense, all ÖBB planning projects must also take ecological concerns into account. This concerns both future projects and maintenance measures by taking proper and effective compensatory measures.

Vulnerable fish species occur at most contact points. These are most strongly represented by subdominant guilds. There are particularly many contact points with sensitive fish species along the Mur river in central Styria, along the Drava river in Carinthia and along the Danube river in Lower Austria.

Bird habitats are also affected by railway infrastructures. Literature shows that especially very fast and noisy trains are potential sources of danger for migratory birds, i.e. risk of collision. The analyses show that the Common sandpiper is more affected than the other two selected waterbirds, because its breeding habitats occur more frequently along main routes according to Chapter 4. The primary objective here is to maintain and improve the quality of stay in the summer quarters for migratory birds and wintering species. In coordination with the railway owner, it must be ensured that the place of residence or the time spent by humans in sensitive breeding zones is reduced so as not to endanger the breeding sites. In addition, tourist destinations are to be controlled by means of management measures coordinated with nature conservation.

In the groundwater protection areas of Austria, most of the railway sections are either single or double tracks and mostly located within the trans-European network. Due to the high maintenance effort and the intensive care of the railway lines by means of chemical substances (see Chapter 5.3), an increased pressure of use on the good quality of the groundwater is to be expected. These areas are mostly located in protected areas that are already heavily affected by agriculture (nitrates, phosphates) and suffer from an accumulation of chemical substances.

The analysis of the riverine and riparian habitats clearly shows that very many, but very short sections are affected by railway infrastructures. Thus, it becomes clear that there is a direct proximity of the railway network to that of the watercourses. This is particularly evident in the riparian zones, which include the direct riparian areas of the river network. The intersections with the potential riparian zones are more frequent, as these have the largest area. However, the analysis also shows that a large area of potential riparian zones would be available and is currently not actively ecologically connected to the river network.

The flood risk areas show a similar picture as the riparian zones in Chapter 6.5. Due to the numerous flood protection measures, many areas of HQ30 or HQ100 have been reduced and thus the areas of HQ300 would potentially be larger. Many railway infrastructures have been protected from floods.

Sensitive river sections titled E2 and E3 (Chapter 7) (very high and high protection need) can be found overall in Austria along railway infrastructures, whereby areas of high protection need cumulate in Upper and Eastern Lower Austria. Since all waterbodies have to reach the good ecological status for many waterbodies in Austria no addictive measures have to be taken anymore. However, the protection of these routes is all the more important. Any additional intervention in the ecosystem can provoke a deterioration of the condition. This can also affect riverine habitats that are in ecological balance with the watercourse (especially floodplains, riparian zones, wetlands). Intervention in these areas can mean indirect intervention in the riverine ecosystem. The more habitats are counted, the higher the need for protection of these areas.

In principle, areas along railway infrastructures with riverine ecosystem connectivity potential should be restored to the maximum of their original river type. However, it must be carefully examined whether large-scale renaturation is at all sensible or whether, for cost-efficient reasons, small-scale (so-called instream measures) with upstream and downstream dispersal effects are sufficient. The areas of groups V2 and V3 are fragmented (area size), but in any case have potential for the restoration of river habitat connectivity. In order to assess the potential more precisely, the two groups V2 and V3 were examined more closely. Group V2 comprises those sections in the vicinity of surface waterbodies with a moderate ecological status or potential, while group V3 comprises those with a bad or poor ecological status. Both were compared regarding the count of criteria. A closer look at these two groups reveals that the potential related to the ecosystems is partly more differentiated. There are sections of water near railway infrastructures which, despite their bad or poor ecological status (4 or 5), nevertheless have the potential to be ecologically improved. This is especially true for those sections out of the group V3 where more polygons with riverine ecosystems are than the group V2. Of particular note are those areas where more wetlands or IBAs are located (see Figure 79). Not to be neglected are also those areas where European Protected Areas have a similarly high presence as in the comparison group V2. These areas have the highest potential from group V3 to bring about an improvement in ecological status while establishing connectivity with the surrounding aquatic ecology.

Hot spots of riverine and riparian habitats and hot spots with water storage function are areas, where mainly chemical and physical impacts are to be expected. In the water-wetted habitats of the watercourse, fish react sensitively to noise and ground vibrations, and amphibians live in the peatlands, which have also been shown to be sensitive to chemical impacts. In the water storage areas there are cumulative effects of chemical substances from diffuse sources, which accumulate both in the water and especially in the soil. Riparian habitats are also sensitive to morphological stressors and can be separated from the rest of the riparian zone by any linear structure.

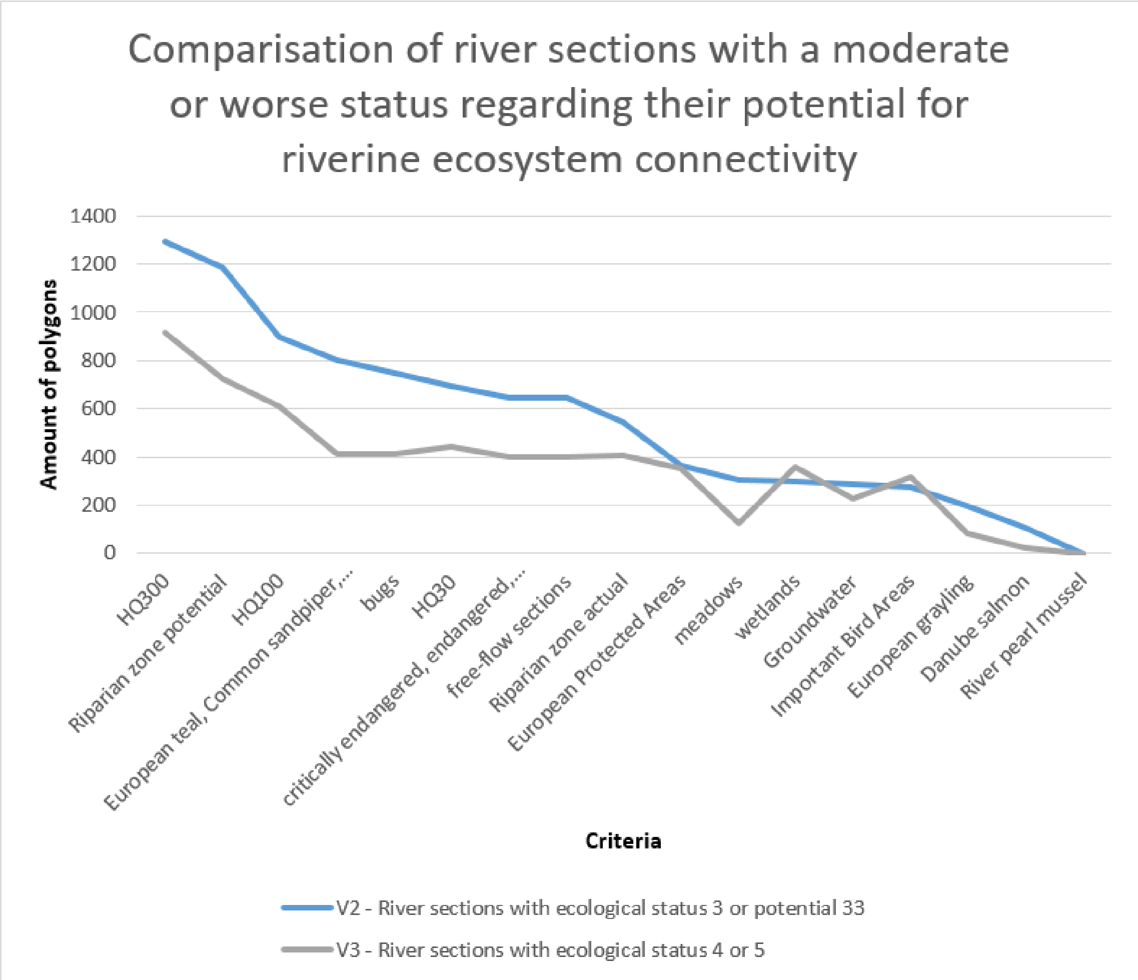

Figure 79: Comparison of river sections with a moderate or worse ecological status regarding their potential for riverine ecosystem connectivity

Hydromorphologically sensitive waterbodies react very sensitive to stressors like railway infrastructures. Any additional intervention reduces the remaining hydromorphologically naturally intact sections and prevents the natural reproduction of fish populations and macrozoobenthos and thus the achievement of the target for the ecological status of the waterbodies by 2027.

This thesis aimed to detect sensitive river sections and areas with clear needs for protection. Nevertheless, both the preservation of sensitive riverine ecosystems and optimizing railway infrastructures are part of public interests. There will always be interfaces between these two. Following this aspect some of more or less railway related threats to the environment should be minimized in the best possible way. For this, practicable measures and solutions are recommended to accept the challenge to maintain the railway capacity. Saving sensitive habitats while keeping high-capacity railway infrastructures where necessary can be managed through adequate mitigation and compensation measures. In terms of construction, bridge structures or culverts can be widened and made permeable to the bed. Railroad embankments along rivers should also be equipped with amphibian tunnels and crossing aids. In particularly sensitive areas, consideration can be given with the help of organizational measures. Railroad management can take account of the breeding season, fish migration times and spawning times by reducing travel speeds or travel intervals (day/night).

Regarding different impacts and special protection needs, further GIS-based research activities on concrete types of barriers and disturbances could demonstrate the potential of taking compensatory measures in sensitive areas. There probably can also be found some synergies, which can be used for further planning. Maybe there are potential synergy measures, which consider both flood plains and nature reserve areas, i.e. by adding or even removing passageways under railway dams.

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12.Graphic References

13.Annex

Annex 1. Endangered, critically endangered and vulnerable bird species extracted of the Red List Austria (Umweltbundesamt, 2017 supplemented by Cichy, 2021, in italics)

ENDANGERED	
Anas crecca (Linnaeus, 1758)	Krickente
Anas clypeata (Linnaeus, 1758)	Löffelente
Aythya ferina (Linnaeus, 1758)	Tafelente
Phalacrocorax carbo (Linnaeus, 1758)	Kormoran
Nycticorax nycticorax (Linnaeus, 1758)	Nachtreiher
Egretta garzetta (Linnaeus, 1766)	Seidenreiher
Milvus migrans (Boddaert, 1783)	Schwarzmilan
Haliaeetus albicilla (Linnaeus, 1758)	Seeadler
Circus pygargus (Linnaeus, 1758)	Wiesenweihe
Aquila heliaca (Savigny, 1809)	Kaiseradler
Falco cherrug (Gray, 1834)	Sakerfalke
Charadrius alexandrinus (Linnaeus, 1758)	Seeregenpfeifer
Numenius arquata (Linnaeus, 1758)	Brachvogel
Limosa limosa (Linnaeus, 1758)	Uferschnepfe
Actitis hypoleucos (Linnaeus, 1758)	Flussuferläufer
Larus canus (Linnaeus, 1758)	Sturmmöwe
Otus scops (Linnaeus, 1758)	Zwergohreule
Athene noctua (Scopoli, 1769)	Steinkauz
Asio flammeus (Pontoppidan, 1763)	Sumpfohreule
Luscinia svecica cyanecula	*Weißsterniges Blaukehlchen*
Saxicola rubetra (Linnaeus, 1758)	Braunkehlchen
Passer italiae	*Italiensperling*
Carpodacus erythrinus (Pallas, 1770)	Karmingimpel
Emberiza calandra (Linnaeus, 1758)	Grauammer

CRITICALLY ENDANGERED	
Anas acuta (Linnaeus, 1758)	Spießente
Podiceps nigricollis (C. L. Brehm, 1831)	Schwarzhalstaucher
Circus cyaneus (Linnaeus, 1766)	Kornweihe
Falco vespertinus (Linnaeus, 1766)	Rotfußfalke
Porzana porzana (Linnaeus, 1766)	Tüpfelsumpfhuhn
Burhinus oedicnemus (Linnaeus, 1758)	Triel
Charadrius morinellus	*Morellregenpfeifer*
Gallinago gallinago (Linnaeus, 1758)	Bekassine
Tyto alba (Scopoli, 1769)	Schleiereule
Strix uralensis (Pallas, 1771)	Habichtskauz
Coracias garrulus (Linnaeus, 1758)	Blauracke
Anthus campestris (Linnaeus, 1758)	Brachpieper
Luscinia svecica svecica	*Rotsterniges Blaukehlchen*
Lanius excubitor (Linnaeus, 1758)	Raubwürger
Emberiza hortulana (Linnaeus, 1758)	Ortolan

VULNERABLE	
Tadorna tadorna (Linnaeus, 1758)	Brandgans
Anas querquedula (Linnaeus, 1758)	Knäkente

Aythya nyroca (Güldenstädt, 1770)	Moorente
Bucephala clangula (Linnaeus, 1758)	Schellente
Mergus merganser (Linnaeus, 1758)	Gänsesäger
Perdix perdix (Linnaeus, 1758)	Rebhuhn
Phalacrocorax pygmaeus	*Zwergscharbe*
Botaurus stellaris (Linnaeus, 1758)	Rohrdommel
Ixobrychus minutus (Linnaeus, 1766)	Zwergrohrdommel
Ardea purpurea (Linnaeus, 1766)	Purpurreiher
Platalea leucorodia (Linnaeus, 1758)	Löffler
Milvus milvus (Linnaeus, 1758)	Rotmilan
Porzana parva (Scopoli, 1769)	Kleines Sumpfhuhn
Crex crex (Linnaeus, 1758)	Wachtelkönig
Otis tarda (Linnaeus, 1758)	Großtrappe
Recurvirostra avosetta (Linnaeus, 1758)	Säbelschnäbler
Charadrius dubius (Scopoli, 1786)	Flußregenpfeifer
Tringa totanus (Linnaeus, 1758)	Rotschenkel
Larus melanocephalus (Temminck, 1820)	Schwarzkopfmöwe
Larus michahellis	*Mittelmeermöwe*
Caprimulgus europaeus (Linnaeus, 1758)	Ziegenmelker
Apus melba (Linnaeus, 1758)	Alpensegler
Jynx torquilla (Linnaeus, 1758)	Wendehals
Anthus pratensis (Linnaeus, 1758)	Wiesenpieper
Monticola saxatilis (Linnaeus, 1766)	Steinrötel
Acrocephalus melanopogon (Temminck, 1823)	Mariskensänger
Remiz pendulinus (Linnaeus, 1758)	Beutelmeise
Serinus serinus (Linnaeus, 1766)	Girlitz

Annex 2. Austria's main railway routes

Austria's main railway routes
Absdorf - Krems
Absdorf - Stockerau
Abzw Asten 2 - Linz Vbf Ost - Linz Hbf
Abzw Hallwang-Elixhausen (Kasern) - Salzburg Gnigl
Abzw n Mauthausen - Abzw n Enns (Ennsdorfer Schleife)
Abzw nach Götzendorf - Mannersdorf (ers. 2.Teil v. KmSys 92)
Abzw Pusarnitz 1- Staatsgrenze n. Weitlanbrunn (I)
Abzw Wien Meidling Lainzertunnel - KmBruch Lainzertunnel
Abzw. Bruck Stadtwald - Abzw. Übelstein
Abzw. Donaukai W158 - W141 - Freudenau Zollfreihafen
Abzw. Gummern2 (Lind) - Abzw. Drauweiche (Tauernschleife)
Abzw. Hieflau - Hieflau Vbf.
Abzw. Neuhaus a. d. Gail - Villach Süd Gvbf Einfahrgruppe
Abzw. Oswaldgasse (A) - Wien Meidling (A)
Abzw. St. Michael Ost - Abzw. St. Michael West
Abzw. St.Veit/Wien - Hütteldorf
Abzw.Freudenau W141 - W131 - Pachthafen
Abzw.Wien Albern W121 - AB BP, Gleis 3b
Abzww Einfahrunterwerfung v. Simmering - Wien Zvbf Einfahrgr

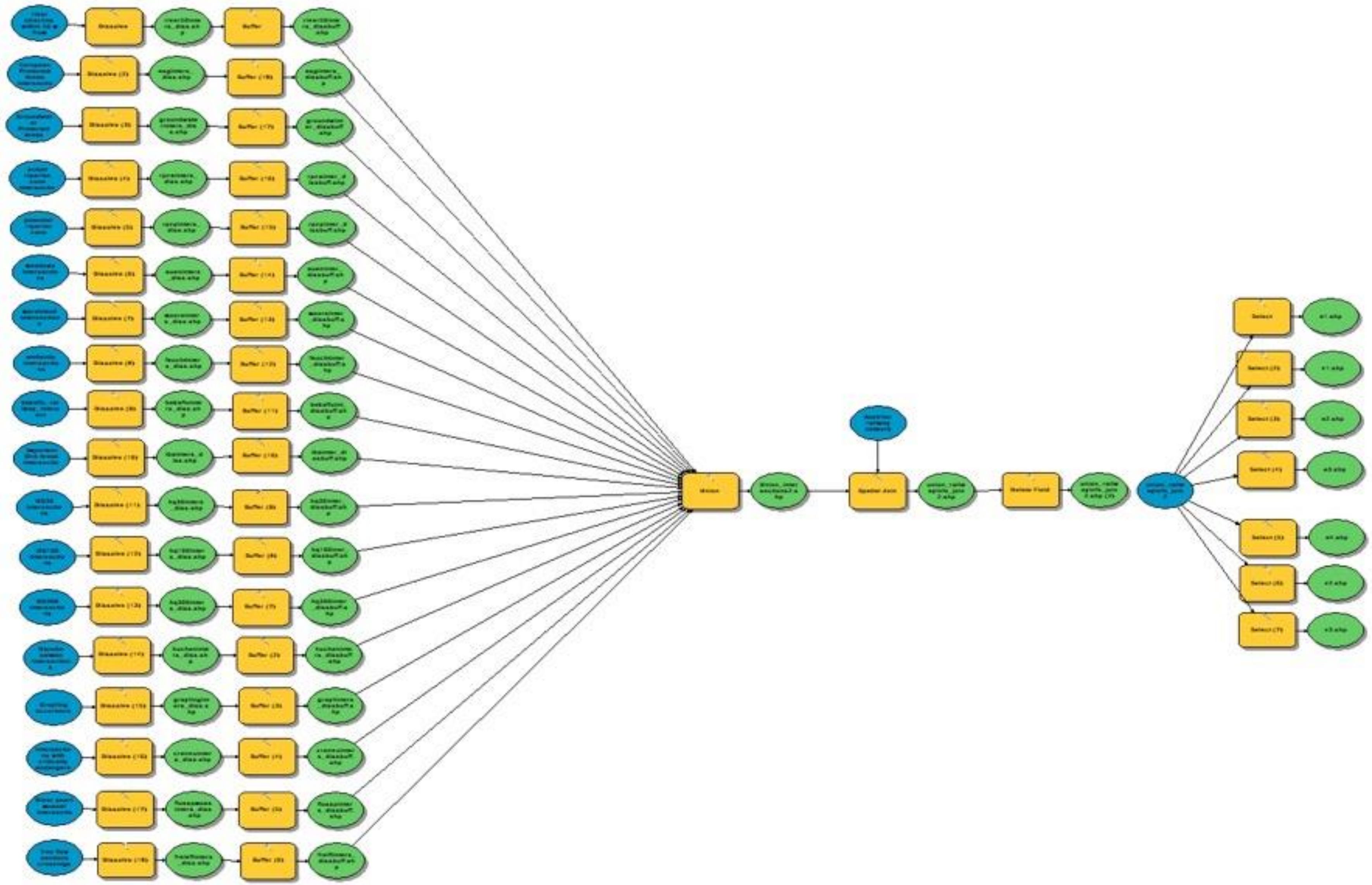
Abzww. Marchtrenk - Abzww. Nettingsdorf (Schleife bei Traun)
Amstetten - Abzw n Weyer (Kastenreith)
Aspang - Friedberg
Bad Fischau - Wöllersdorf
Bf. Traun, Gleis 8
Bischofshofen - Selzthal
Bruck/Mur - Abzw Leoben 2
Drösing - Zistersdorf
Einf Gaisbach/Wartberg - Summerau - Horni Dvoriste
Einfahrt Ebenfurth - Ausfahrt Ebenfurth(Umfahrung Ebenfurth)
Einfahrt Meidling - Abzweigung Altmannsdorf
Feldkirch - Buchs
Freilassing - Salzburg
Gänserndorf - Marchegg
Gänserndorf - Pirawarth - (Gaweinstal - Mistelbach (LB))
Gödersdorf - Fürnitz (Gödersd. Schl.)
Graz - Klagenfurt (in Bau: Koralmbahn)
Hadersdorf am Kamp - Sigmundsherberg
Heiligenstadt - Brigittenau
Herzogenburg - Krems
Hetzendorf - Meidling (Schnellbahnunterwerfung)
Innsbruck - Bludenz
Innsbruck - Staatsgrenze n. Scharnitz
Inzersdorf Ort - Inzersdorf Ost (Gleis 41)
Inzersdorf Ort (km 11,713) - Winterhafenbrücke
Inzersdorf Ost - Inzersdorf Metzgerwerke
Jedlersdorf - Leopoldau (Floridsdorfer Hochbahn)
Klagenfurt West
KmBr Lainzertunnel - Kn Hetzendorf - KmBr n Kn Hadersdorf
KmBruch bei St. Veit a. d. Glan - Staatsgrenze n. Rosenbach
KmBruch n Knoten Hadersdorf - Tullnerfeld - Abzw Wagram
KmBruch n Wien Matzleinsdorf - Wien Praterstern
KmBruch v Abzw Altmannsdorf - Wr.Neustadt(Pottendorferlinie)
KmBruch Wien Hbf - KmBruch Wien Hbf Ost
KmBruch Wien Hbf - Spielfeld/Straß - Sentilj
Knoten Hetzendorf (Lainzer Tunnel) - Inzersdorf Ort
Knoten Rohr - Umfahrung Enns (Neubautrasse d.neuen Westbahn)
Knoten Wagram - Knoten Rohr (GZU)
Korneuburg - Hohenau
Lauterach Süd - Lauterach West
Leoben - Vordernberg
Leobersdorf - St. Pölten
Leopoldau - Süßenbrunn Mitte (Verbindungsschleife)
Liefering - Salzburg
Lindau - Bludenz

Linz - Gaisbach/Wartberg
Linz - Kleinmünchen, Gleis 7b
Linz - Selzthal
Linz Anschluß I - Voestschleife - Abzw n Voestschleife(W931)
Linz Gleisdreieck Weiche 4 - Linz Urfahr
Linz Hbf - KmBruch Linzer Lokalbahn
Linz Hbf - Lokgleis 1L - Abzw. Nestle n. Gleisdreieck
Linz Kleinmünchen-Vbf West-Logistikcenter-Vbf Duchfahrgruppe
Linz Urfahr - Aigen/Schlägl
Linz Vbf West - Abzw. n. Voestschleife (W937)
Linz Vbf West (W688) - Gleisdreieck - Lokgleis 2L - Linz Hbf
Linz. Vbf Ost - Gleisdreieck
Linz. Vbf Ost (Stw. 11) - Abzw. n. Voestschleife (W937)
Mallnitz - Abzw n Kaponig (Neubautr. Kaponig-,Ochenigtunnel)
Marchtrenk - Traun
Mauthausen - Grein
Maxing - Abzw. Altmannsdorf
Mistelbach Verbindungsschleife
Mitte Leithabrücke - Ebenfurth
Nußdorf - Albern Winterhafenbrücke
Oberlaa - Wien Zvbf Ausfahrgruppe
Parndorf - Staatsgrenze Kittsee
Penzing - Heiligenstadt (Vorortelinie)
Penzing - KmBruch n Wien Matzleinsdorf (Verbindungsbahn)
Pöchlarn - Kienberg/Gaming
Pottenbrunn) - Abzw Wagram - Prinzersdorf (Staugleis)
Rennweg - Wolfsthal
Salzburg - Wörgl
Salzburg - Wörgl Tr2
Salzburg Hbf - Güterzuggleis (Vbf) - Salzburg Gnigl Ausfahrt
Salzburg Hbf - Salzburg Gnigl Vbf (Güterzuggleis)
Salzburg Mitte ÖBB-Grenze - Abzw Salzburg Mitte
Schnellbahngleis Wien Hbf. (parallel KMSYS 331) Gl 14, 16
Schnellbahngleis Wien Hbf. (parallel KMSYS 5) Gl 14, 16
Schwarzach/St. Veit - Spittal
Schwarzenau - Martinsberg/Gutenbrunn
Simmering Ostbahn (Gl.123) - Wien Zvbf - Zvbf Ausfahrgruppe
St. Margrethen - Staatsgr. n. Lustenau - Lauterach Nord
St. Michael - Leoben
St. Valentin - EhGr. n. Thörl-Maglern (Tarvisio B.)
St. Valentin - Mauthausen
St.Veit.a.d.Glan-KmBruch bei St.Veit.a.d.Glan
Staatsgrenze n. Bleiburg - Spittal-Millstättersee
Staatsgrenze n. Kufstein - Staatsgrenze n. Brenner
Staatsgrenze n. Kufstein-Radfeld-Baumkirchen (neue Trasse)

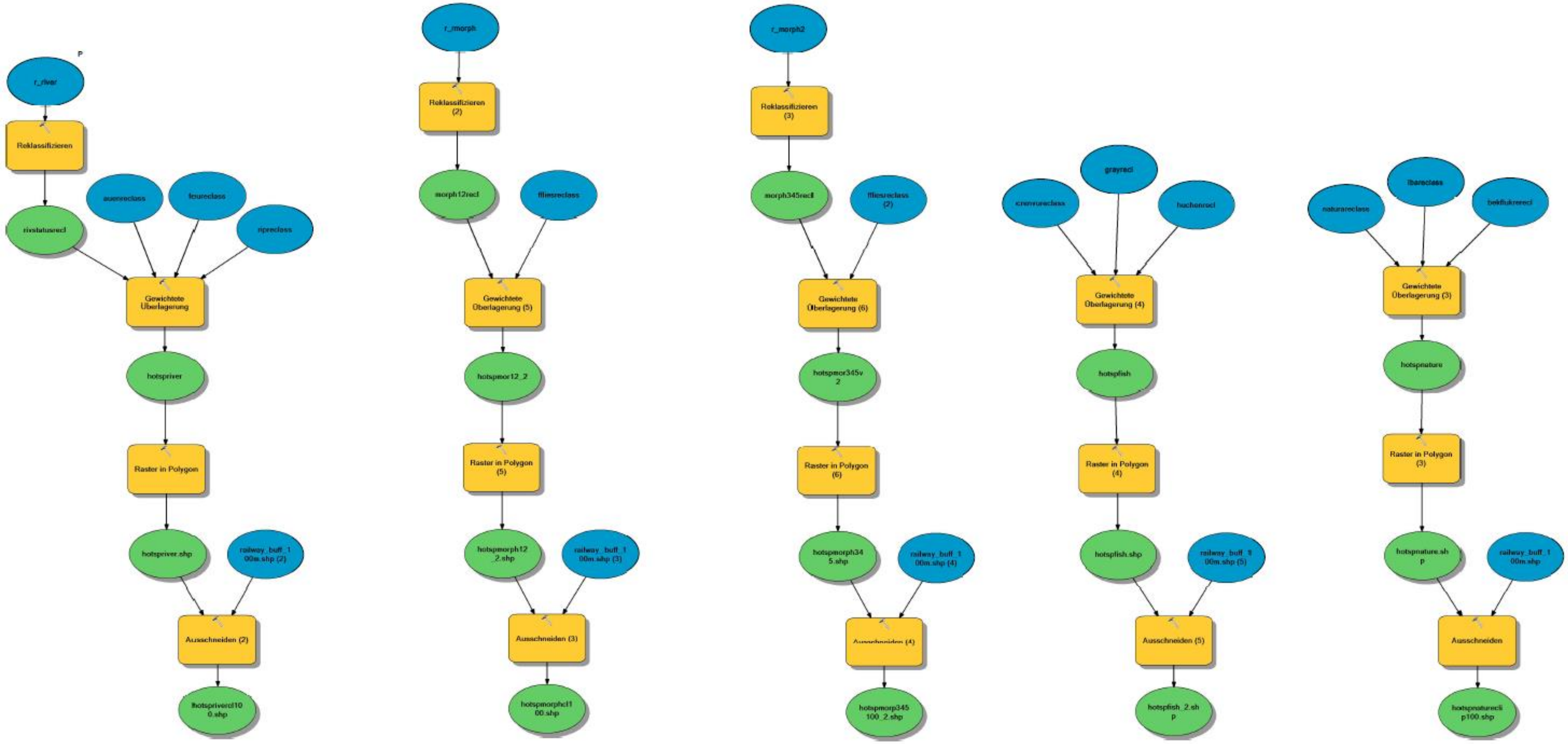
Stadlau - Marchegg - Devinska nova Ves
Stainach/Irdning - Schärding
Steindorf bei Straßwalchen - Abzw Mining 1
Stetteldorferschleife n. Absdorf
Südumfahrung Innsbruck
Süßenbrunn Mitte - Süßenbrunn (Gleis31- Nordschleife)
Süßenbrunn Süd - Süßenbrunn (Gl. 32 - Südschleife)
Süßenbrunn West - Süßenbrunn Brücke (Gleis 22- Westschleife)
Süßenbrunn West - Süßenbrunn Nord (Gleis21 - Westschleife)
Szentgotthard - Staatsgr.n.Mogersdorf - Graz
Traisen - St.Ägyd - (Kernhof)
Tulln - Judenau (alte Trasse) - St. Pölten
Tullner Westschleife - Ausf Tulln Stadt
Tullnerfeld Nord - Tullnerfeld - Michelhausen
Tullnerfeld Nord - Tullnerfeld Ost (Ostschleife)
Umfahrung Enns - Linz Hbf (Neubautrasse der neuen Westbahn)
Umfahrung Enns (Neubautrasse der neuen Westbahn)
Umfahrung Lambach (Westbahntrasse - Kalvarienbergtunnel)
Umfahrung Schlierbach
Verbindungsschleife Ostbahn - Flughafenschnellbahn
Villach Hauptbahnhof-Villach Westbahnhof
Villach Hbf
Villach Süd Gvbf Ausfahrgruppe - Villach Süd Gvbf Auen
Villach Süd Gvbf Ausfahrgruppe - Villach Süd Gvbf Fürnitz
Villach Süd Gvbf Fürnitz - Abzw Gödersdorf 2
Villach Süd Gvbf-Auen - Rosenbach
Wampersdorf - Gramatneusiedl
Wels - Passau
Wien - St.Pölten - Salzburg
Wien Erdbergerlände - Abzw Donaukaibf.
Wien FJB - Staatsgrenze n. Gmünd - Ceske Velenice
Wien Floridsdorf - Retz - Satov
Wien Hbf - Spielfeld/Straß - Sentilj
Wien Hütteldorf - Ausfahrt Unter Purkersdorf (Nahverkehrsgl)
Wien Nord (Einfahrt) - Bernhardsthal - Breclav pred
Wien Nordwestbf. - Wien Brigittenau Nord (Nordschleife)
Wien Nordwestbf. - Wien Brigittenau Süd (Südschleife)
Wien Ost- KmBruch Wien Hbf Ost - Staatsgrenze n. Nickelsdorf
Wien Süd Ostbh - KmBruch Wien Hbf Ost - Laa a. d. Thaya
Wien Zvbf Ausfahrgr - Zvbf Ost - Zvbf Nord (Westschleife)
Wien Zvbf Ausfahrgruppe - Wien Zvbf Süd (Ausfahrüberwerfung)
Wien Zvbf Einfahrgruppe - Wien Erdbergerlände
Wiener Neustadt - Aspang
Wittmannsdorf- Gutenstein
Wr. Neustadt - Ausfahrbf. - Abzw. Wr. Neustadt Ausfahrbf

Wr. Neustadt - Puchberg
Wr. Neustadt - Staatsgr.n. Loipersbach/Schattendorf - Sopron
Wulkaprodersdorf - Abzw Parndorf Ort
Zvbf Ausfahrgruppe - KmBruch nach Abzww.Felixdorf (km 2,384)
Zvbf Ost - Klein Schwechat (Schwechater Schleife)

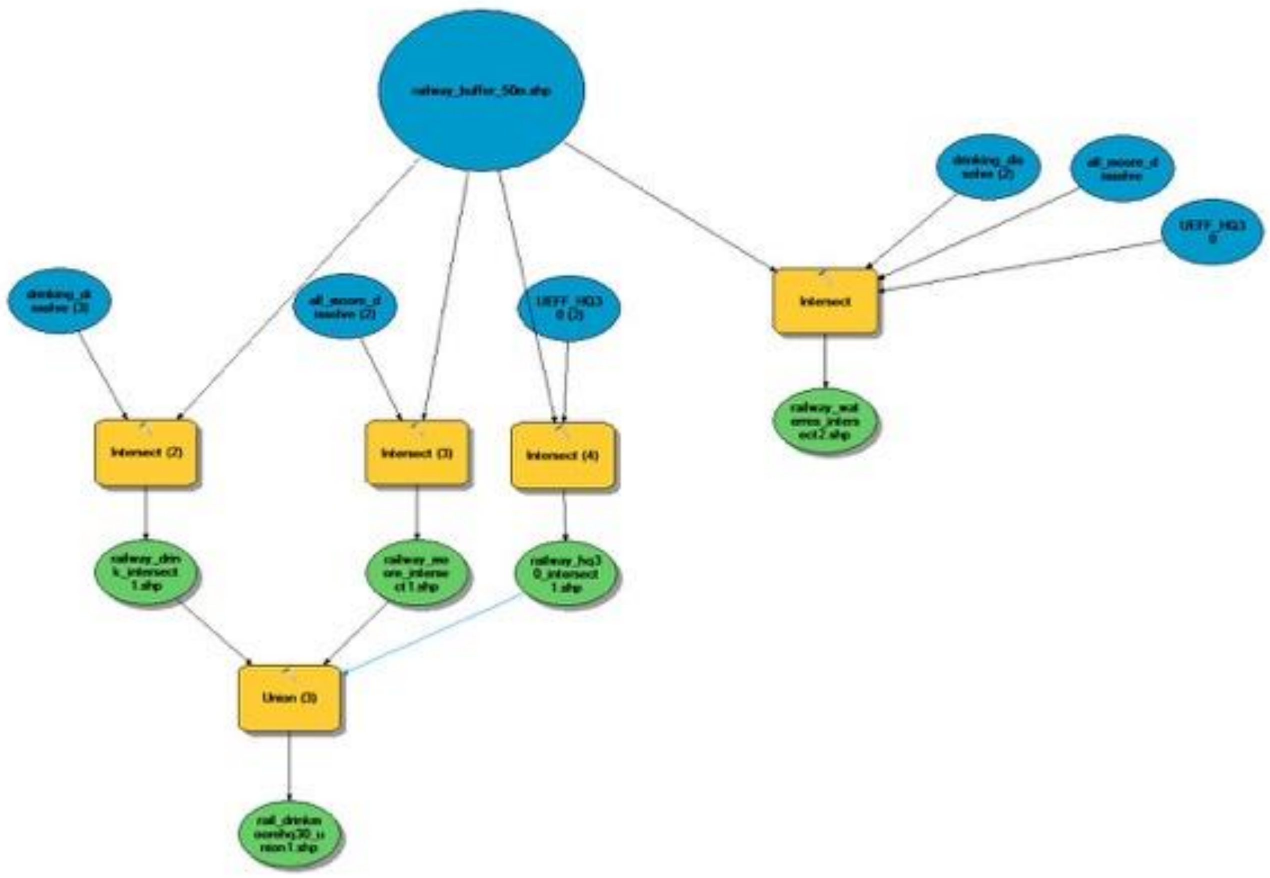
Annex 3. Schematic overview of the analysis to identificate sensitive river sections along the railway infrastructure



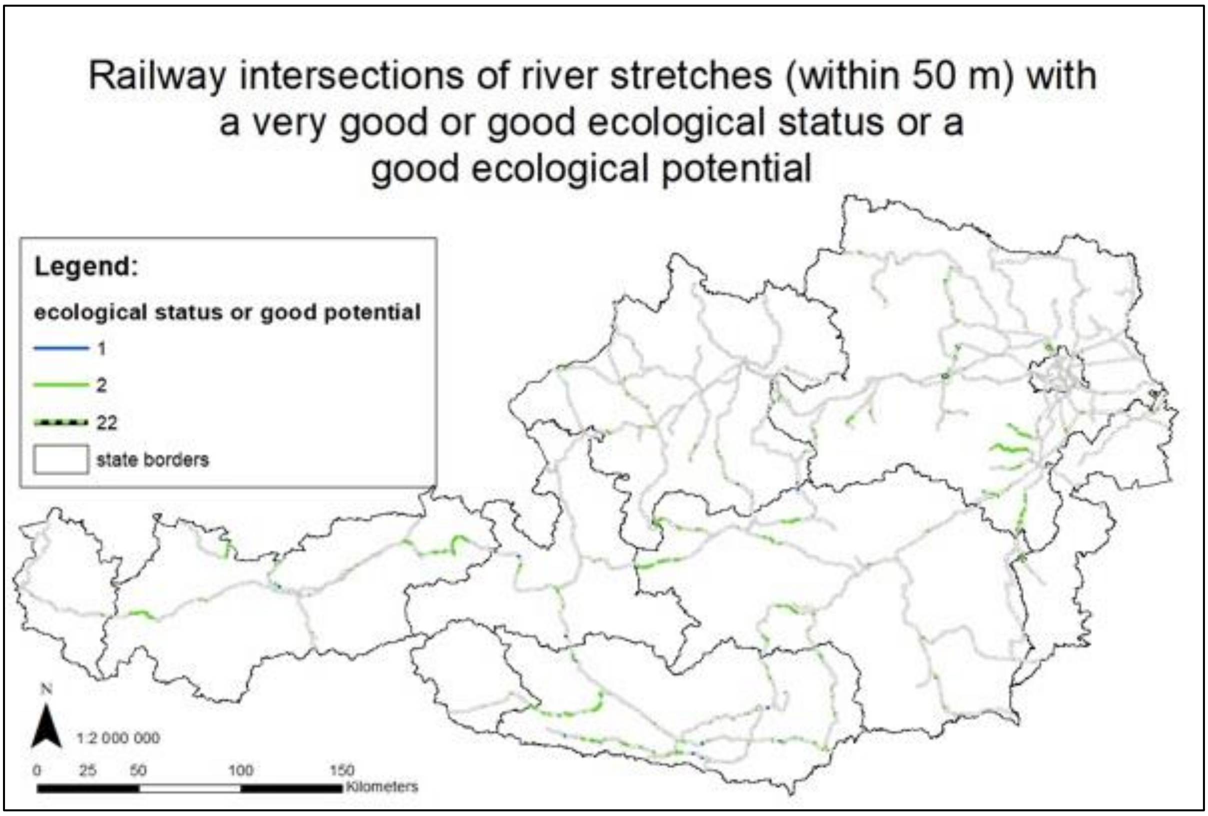
Annex 3.1 – Schematic overview of hot spot analysis

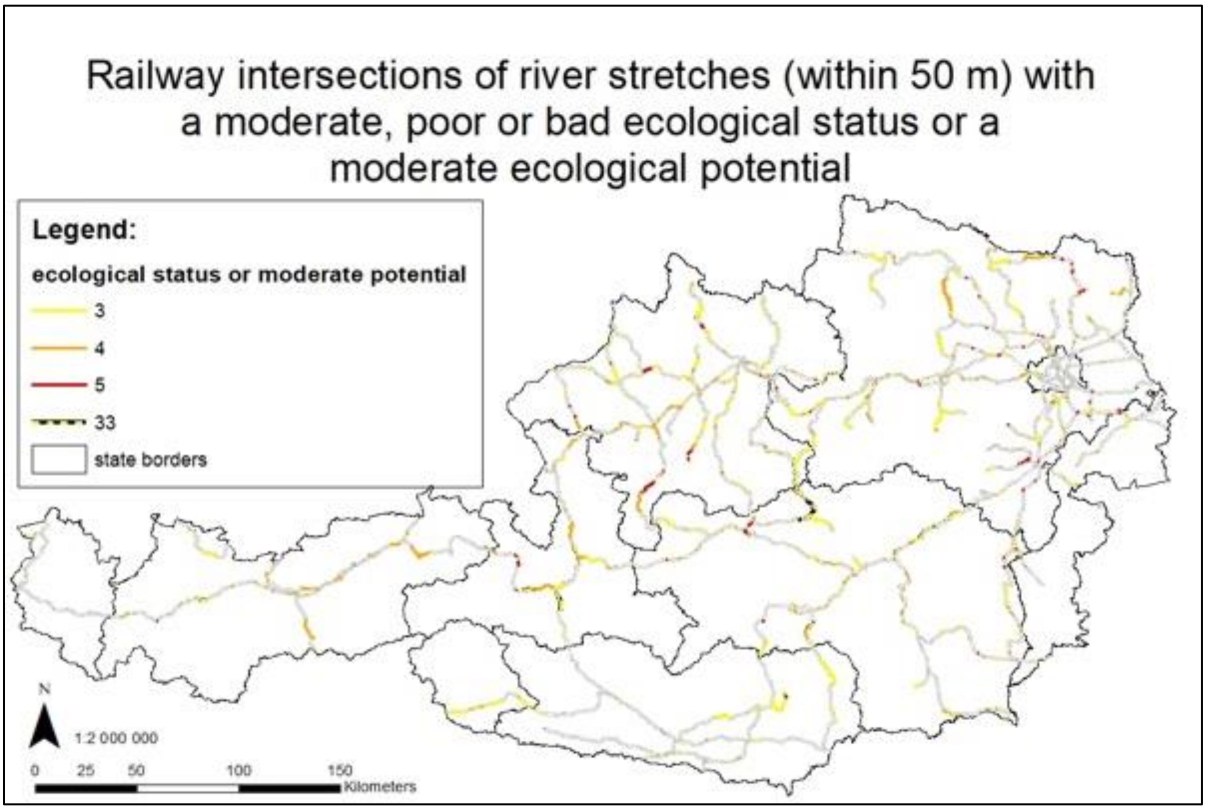


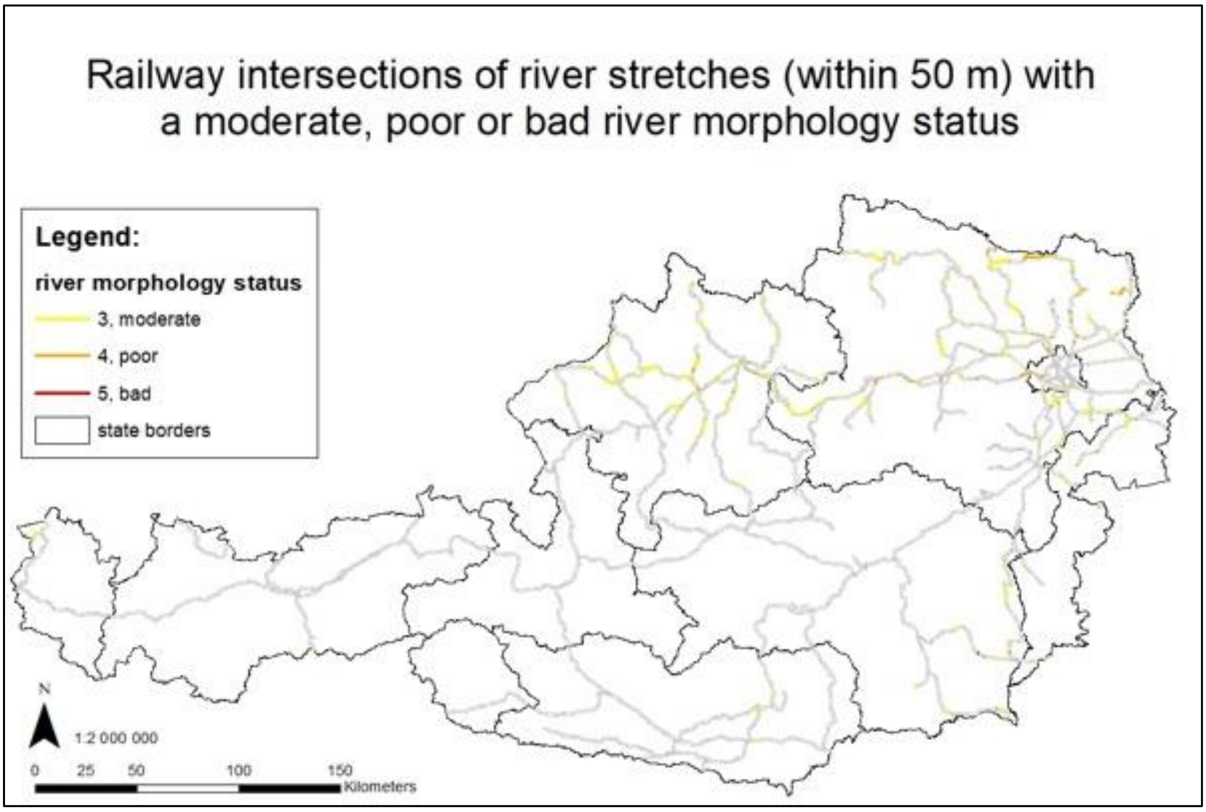
Annex 3.2 - Schematic overview Hot spots with water storage function

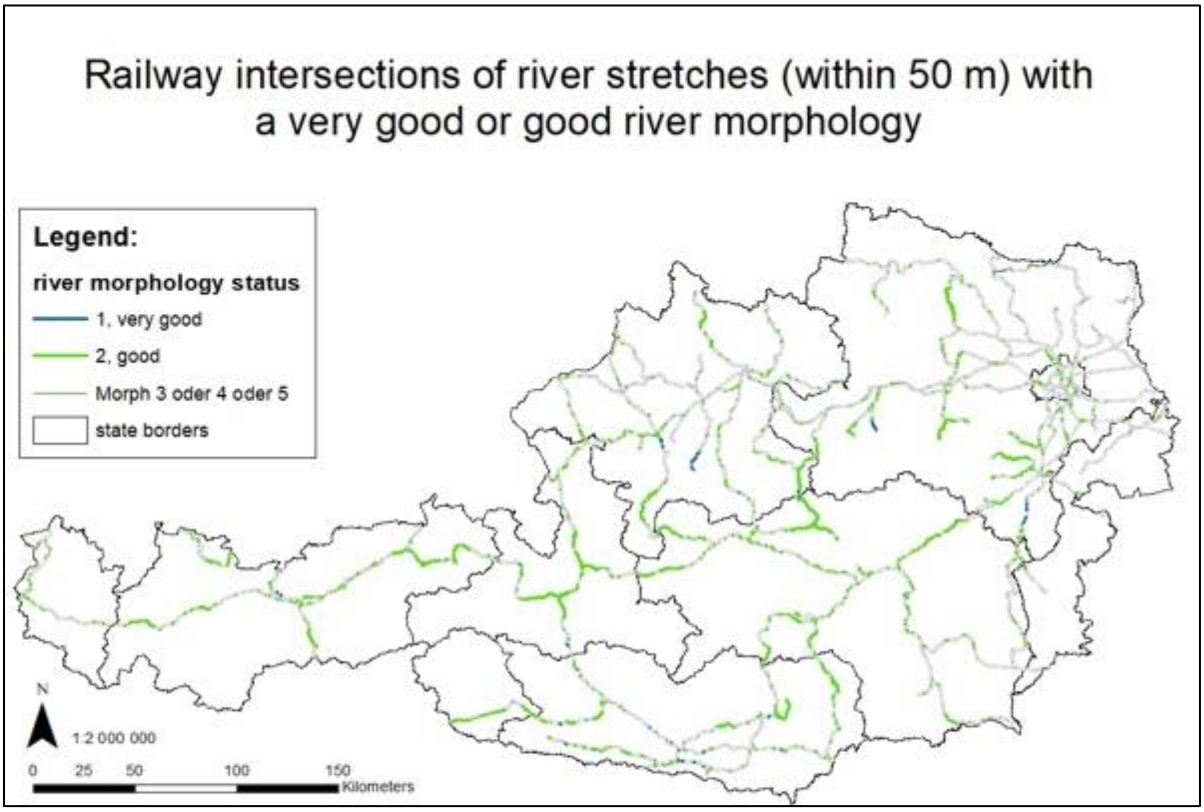


Annex 4 - – Railway intersections with waterbodies separated in their ecological status and ecological potential

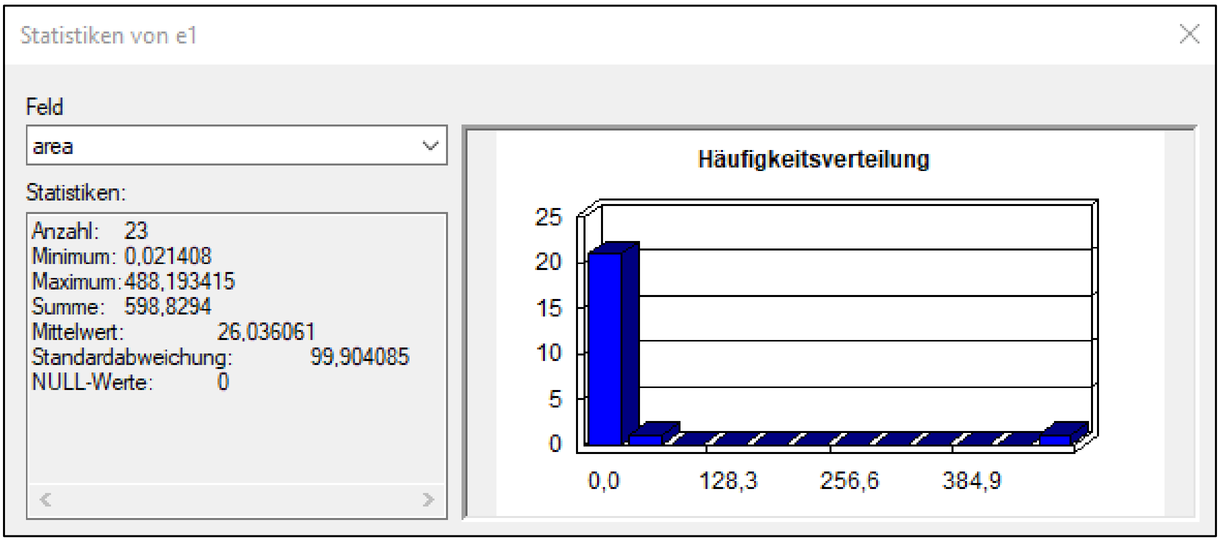


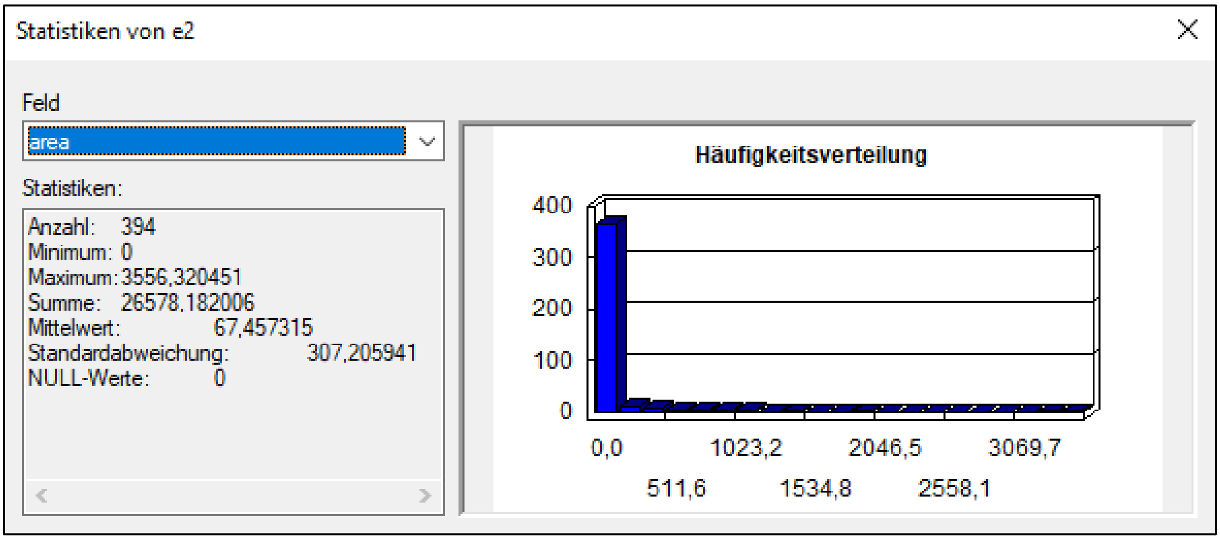


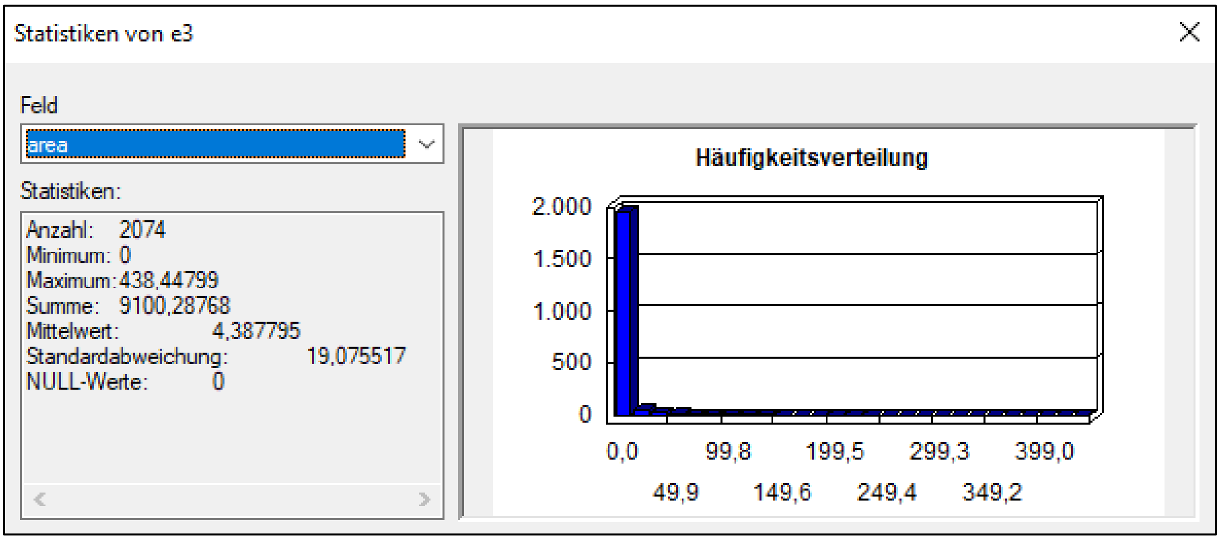

Railway intersections of river stretches (within 50 m) with a moderate, poor or bad river morphology status
Legend:
river morphology status
3, moderate
4, poor
5, bad
state borders
N
1:2 000 000
0 25 50 100 150
Kilometers

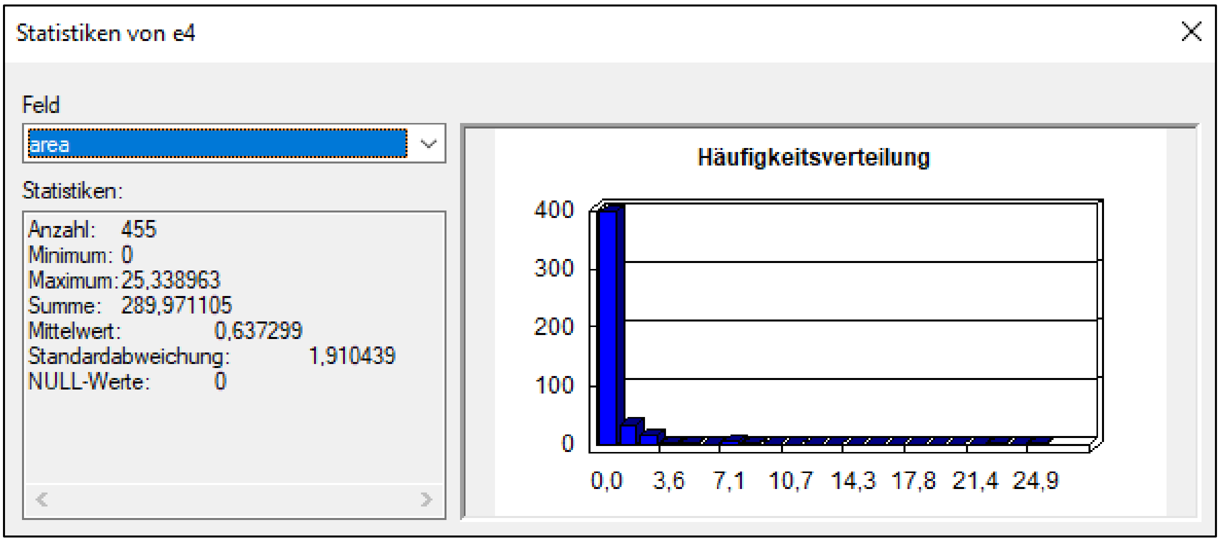

Railway intersections of river stretches (within 50 m) with a very good or good river morphology
Legend:
river morphology status
1, very good
2, good
Morph 3 oder 4 oder 5
state borders
N
1:2 000 000
0 25 50 100 150
Kilometers

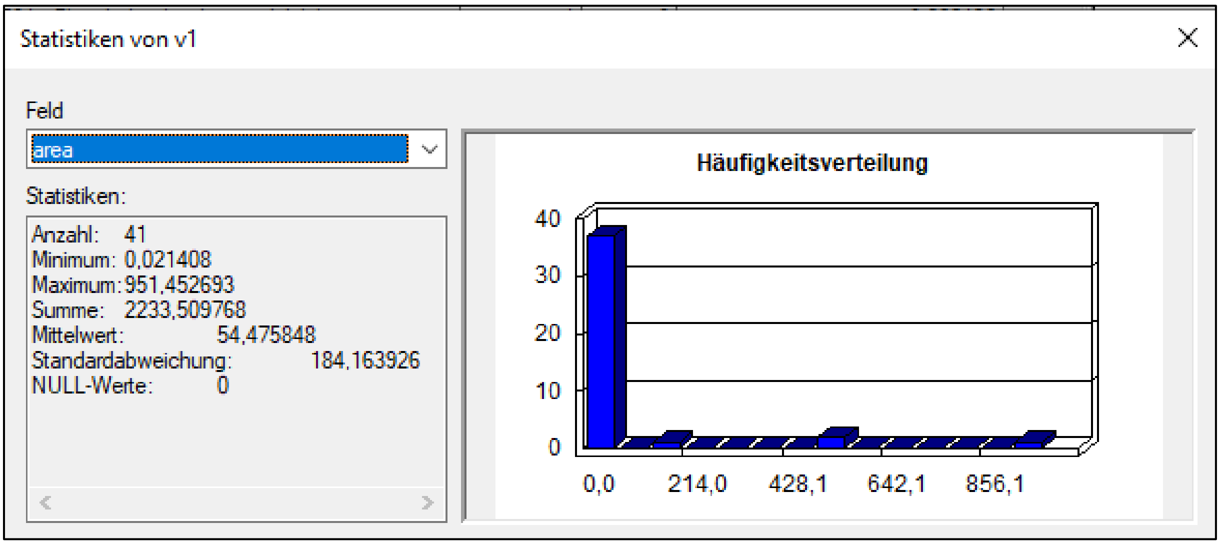
Annex 5 - – Tables of frequency distribution of overlapping polygons and their areas (in hectares) out of the identification of sensitive river sections along the railway network

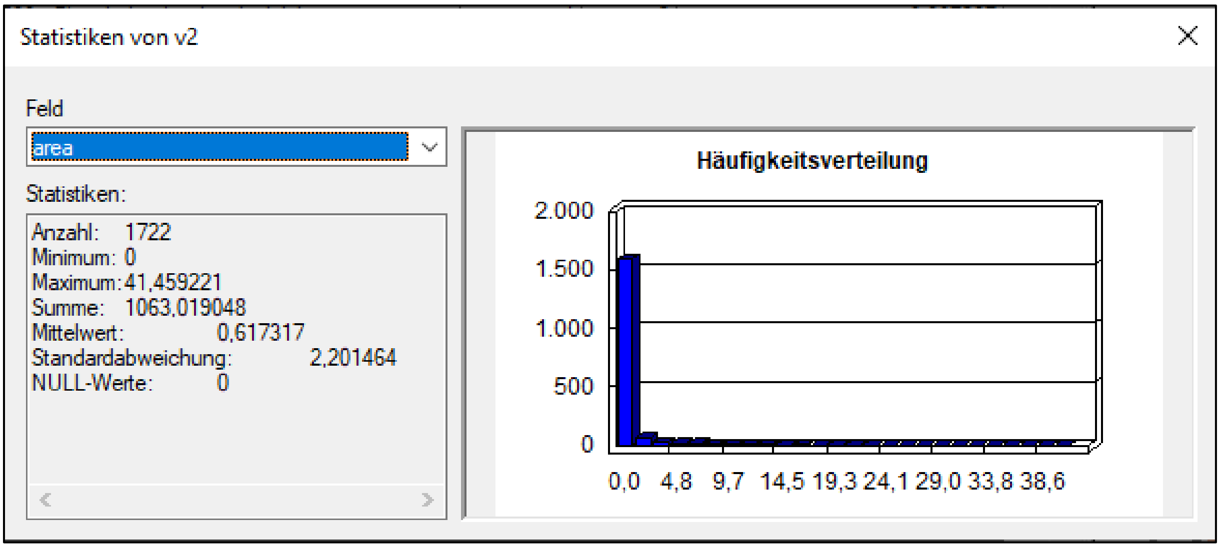


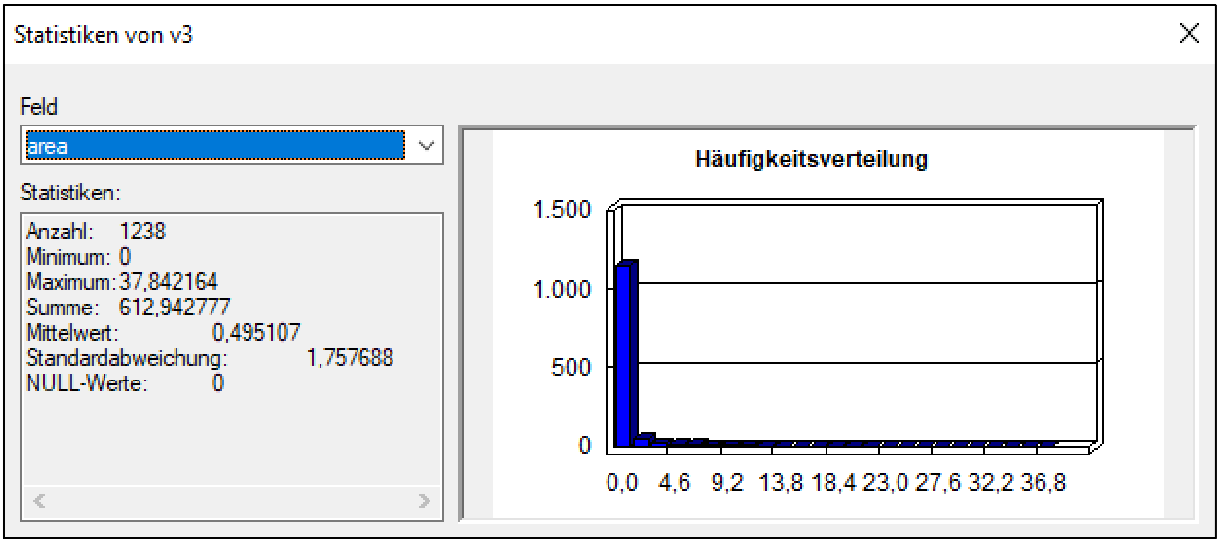





Statistiken von e4
Feld
area
Statistiken:
Anzahl: 455
Minimum: 0
Maximum: 25,338963
Summe: 289,971105
Mittelwert: 0,637299
Standardabweichung: 1,910439
NULL-Werte: 0
Häufigkeitsverteilung
400
300
200
100
0
0,0 3,6 7,1 10,7 14,3 17,8 21,4 24,9


Statistiken von v1
Feld
area
Statistiken:
Anzahl: 41
Minimum: 0,021408
Maximum: 951,452693
Summe: 2233,509768
Mittelwert: 54,475848
Standardabweichung: 184,163926
NULL-Werte: 0
Häufigkeitsverteilung
40
30
20
10
0
0,0 214,0 428,1 642,1 856,1


Statistiken von v2
Feld
area
Statistiken:
Anzahl: 1722
Minimum: 0
Maximum: 41,459221
Summe: 1063,019048
Mittelwert: 0,617317
Standardabweichung: 2,201464
NULL-Werte: 0
Häufigkeitsverteilung
2.000
1.500
1.000
500
0
0,0 4,8 9,7 14,5 19,3 24,1 29,0 33,8 38,6


Statistiken von v3
Feld
area
Statistiken:
Anzahl: 1238
Minimum: 0
Maximum: 37,842164
Summe: 612,942777
Mittelwert: 0,495107
Standardabweichung: 1,757688
NULL-Werte: 0
Häufigkeitsverteilung
1.500
1.000
500
0
0,0 4,6 9,2 13,8 18,4 23,0 27,6 32,2 36,8