LANDSCAPE CONNECTIVITY FOR LARGE CARNIVORES AND WILD UNGULATES IN THE ALPS

LARGE CARNIVORES, WILD UNGULATES AND SOCIETY WORKING GROUP (WISO) of the Alpine Convention

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1. PREFACE

Alps are among the most preserved and biodiversity rich areas in Europe (Rahbek et al. 2019). A key part of the Alps biodiversity is a rich mega- and mezzo-fauna that was preserved through the history. Species such as brown bear (*Ursus arctos*), wolf (*Canis lupus*), Eurasian lynx (*Lynx lynx*), wild boar (*Sus scrofa*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), chamois (*Rupicapra rupicapra*) and endemic alpine ibex (*Capra ibex*) can still be found in many areas in the Alps. Those are keystone species with a significant influence on alpine ecosystems structure, biodiversity and nutrient cycling (Ripple et al. 2014). Many conservation and management efforts were undertaken in the past to protect those species, increase their population sizes, reintroduce them in areas where they were locally extinct and mitigate conflicts and damages. Thanks to that, population sizes of large carnivores and wild ungulates in Alps are increasing and recolonization of suitable habitats can be observed for most of the mentioned species. Some of the ungulates, such as wild boar and red deer are becoming even overabundant in some regions of the Alps (population sizes that exceed current social acceptance of the species). However, some species, especially bears and lynxes, are still living in small and isolated populations, which are too small to ensure long-term survival of those species in the Alps (Kaczensky et al. 2012). Regardless of the current status of large mammals in the Alps it is necessary to ensure sufficient gene flow within and between populations. Sufficient gene flow produces healthy populations that are adaptable to various stochastic events and risk factors. In human-dominated alpine landscapes sufficient gene flow can only be ensured by management of landscape connectivity. Therefore, Landscape connectivity is becoming one of the key aspects of modern wildlife management.

Physical movement barriers (hereafter barriers), such as urban areas, intense agriculture areas, transport infrastructure and tourist areas, are among the most important factors of habitat fragmentation. Because of this, barriers significantly alter species movement and are considered as critical points of landscape connectivity (Scott et al. 2011). Identifying barriers and restoring landscape connectivity within them is therefore the most important part of active wildlife landscape connectivity management

Alps are relatively densely populated and an important tourist destination. Currently Alps are a subject of intense anthropogenic landscape changes due to urbanization pressure and transport or tourist infrastructure development (Walzer et al. 2013, Santolini et al. 2016). As a result, open spaces (i.e. natural areas of sufficient habitat) are becoming increasingly scarce in Alps (Job et al. 2020). Despite the fact that most of large carnivores and wild ungulates can move great distances, barriers alter their movements between suitable habitats (Tucker et al. 2018). Because of this, it is becoming increasingly important to reassess landscape connectivity for large carnivores and wild ungulates in the Alps. Especially to identify barriers that alter movement of those species. In barriers, strategic planning of management actions is advised to improve and restore landscape connectivity. For large carnivores and ungulates this means (re)establishment and necessary protection of green movement corridors and green bridges across transport infrastructure (Gilbert-Norton et al. 2009).

Within the current WISO (Large carnivores, wild ungulates and society) working group mandate (2021-2022) our goals was to a.) Provide an overview of the work so far conducted on the topic of landscape connectivity and barriers in the Alps, b.) Reassess landscape connectivity for large carnivores and ungulates in the Alps, c.) Identify barriers for large carnivores and wild ungulates in the, d.) Provide an overview of landscape connectivity management actions already conducted in the barriers and e.) Propose further management actions to increase landscape connectivity in the identified barriers.

2. A BRIEF OVERVIEW ON LANDSCAPE CONNECTIVITY CONCEPT AND ACTIVITIES IN ALPS

Landscape connectivity, the extent to which landscape facilitates movement of organisms and their genes, faces increasing threats from both habitat fragmentation and habitat loss (Rudnick et al. 2012). The migration and dispersion of organism is vital to ensure sufficient gene flow between populations to prevent population isolation (Tabor 2019). Population isolation is one of the biggest threats to long-term species conservation, especially for small populations where inbreeding can occur with higher rates (Lynch et al. 1995). Maintaining and restoring landscape connectivity to mitigate negative impacts of fragmentation on species is therefore identified as one of the key wildlife management activities in 21th century (Tabor et al. 2019) and recently landscape connectivity has received increasing attention in researches, projects and management actions around the globe, including Alps. In the following chapter we are providing a short overview on landscape connectivity concept important for further understanding of our work. In addition, we are presenting also a review of activities conducted on large carnivores and wild ungulates landscape connectivity in the Alps so far.

The landscape connectivity concept

Landscape connectivity approaches can be divided into two main concepts, structural and functional connectivity (Rudnick et al. 2012, Taylor et al. 2010). Structural connectivity focus on describing physical characteristics of a landscape that influence movements of organisms, such as land cover and topography and identifying corridors, barriers and other important connectivity areas. On the other hand, functional connectivity approaches are focusing on measuring actual gene flow and individual movement in the landscape. Researches and projects dealing with structural connectivity are much more represented in the literature, including the Alpine region. This is mostly because the sufficient data on actual gene flow and individual movement is still lacking for most landscapes (Taylor et al. 2010). In addition, functional connectivity concept cannot be used in areas which are not yet colonized by the species in focus. On the other hand, results of a structural connectivity analysis approach can be only valid, if there is a sufficient knowledge, that identified corridors could be used by species of interest, therefore knowledge on species movement behaviour is vital (Taylor et al. 2010).

Another important question regarding (structural) landscape connectivity is also how to assess connectivity and connected management actions for multiple species at once, especially for biodiversity rich areas, such as Alps. This is namely often the wish of managers, spatial planners and decision makers (Walzer et al. 2013). However, analysing landscape connectivity for multiple species can be a difficult task. In particular, if species with different ecological and behaviour characteristics are in focal point because of the lack of common connectivity indicators (Gilbert-Norton et al. 2009). Such results can be invalid or even misleading, as at least some species will not be able to use identified important connectivity areas (Taylor et al. 2010). Therefore, it is much better to evaluate connectivity for specific species or taxon's with similar ecological and behavioural characteristics (Gilbert-Norton et al. 2009).

Landscape connectivity activities review in the Alps

The most comprehensive study on landscape connectivity in the Alps and its surroundings was till now conducted within the Econnect (www.econnectproject.eu) and ALPBIONET2030 (https://www.alpine-space.org/projects/alpbionet2030/en/home) projects. One of the key results of Econnect project (project duration: 2008-2011) was to model habitat suitability and landscape connectivity for a number of key alpine species, including brown bear, wolf, Eurasian lynx and red deer (Belardi et al. 2011). This was one of the first attempts to model landscape connectivity for the whole Alpine region (Belardi et al. 2011). At the time GIS tools for modelling structural landscape connectivity for such a large area were just in development. So the results of this modelling are presented on a very coarse spatial scale, which is hindering the use of this results in detailed landscape connectivity management planning. Nevertheless, Econnect project set important foundations to landscape connectivity management in Alps.

Following the Econnect project and a number of other landscape connectivity initiatives in the Alps (see Plassman et al. 2019 for review), the ALPBIONET2030 project was conducted in the period of 2016 – 2019. The purpose of the project was to investigate for the first time to what extent the alpine landscapes are facilitating ecological connectivity in the European Macro-regional Strategy for the Alps (EUSALP) study area (Plassman et al. 2019). To do this, an innovative spatial approach was used, the Continuum Suitability Index (hereafter referred as CSI). CSI summarizes different landscape connectivity indicators; land use, fragmentation by transport infrastructure, environmental protection, population pressure, altitude and slope. Main results of the CSI analysis were three categories of strategic alpine connectivity areas (i. e. SACA areas). The three categories are (Figure 1); areas in which connectivity is still preserved and sufficient (i. e. Ecological Conservations Areas – SACA 1), areas in which connectivity is still preserved to some extent, but would benefit from enhancements (SACA 2) and areas where landscape connectivity is not working any more (SACA 3 – barriers). This approach categorised alpine landscapes and regions for the first time according to how good their landscape connectivity is preserved. With this approach also general management actions can be proposed for enhancing connectivity in each SACA category, such as environmental protection, corridor establishment and restoring connectivity, respectively. Although this approach is very novel and promising, it was originally set for analysing connectivity for a broad scope of species. During our review, we observed that some connectivity indicators (e.g. fragmentation, environmental protection and population pressure) and some indicator values (e.g. indicator values for forests in land use) are not representing well the connectivity and habitat requirements of large carnivores and large ungulates. As this can produce erroneous results (Gilbert-Norton et al. 2009), we therefore advice caution when applying these results to large carnivores and wild ungulates.

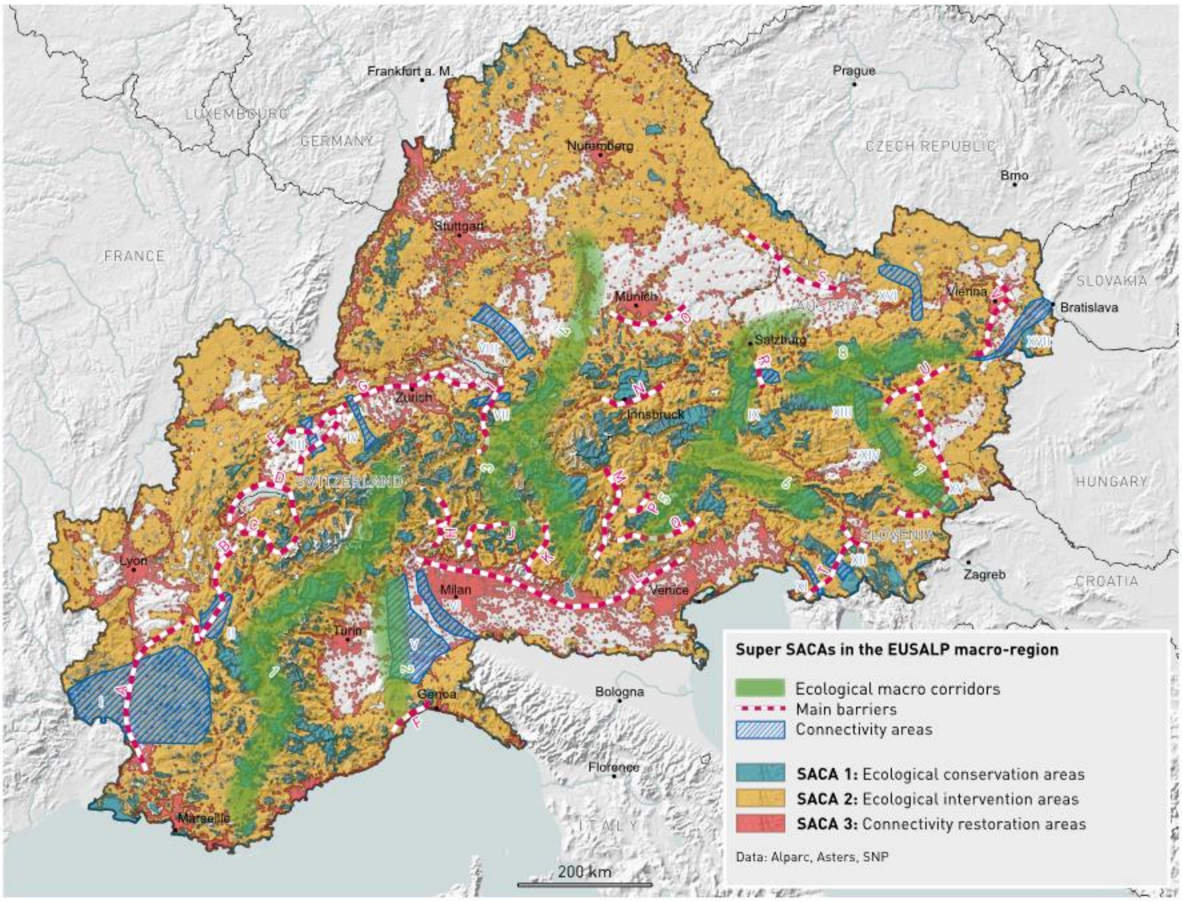

Figure 1: Strategic Alpine connectivity areas (SACAs) in the EUALP macro-region as determined within the ALPBIONET2030 project. Source: Alparc, Asters, SNP.

To the best of our knowledge, no results are available that would consider landscape connectivity specific for large carnivores and wild ungulates for the whole area of the Alps. There are researches and projects however, that focused on analysing landscape connectivity on smaller, regional scale.

During the LIFE DINALP BEAR project (https://dinalpbear.eu/home-page-1/) a habitat suitability map for brown bear for south-eastern Alps was produced (Recio et al. 2021). In the same studies landscape connectivity for brown bear in the same region was assessed by classifying habitat patches based on their importance for the whole south-eastern Alps brown bear population (Figure 2).

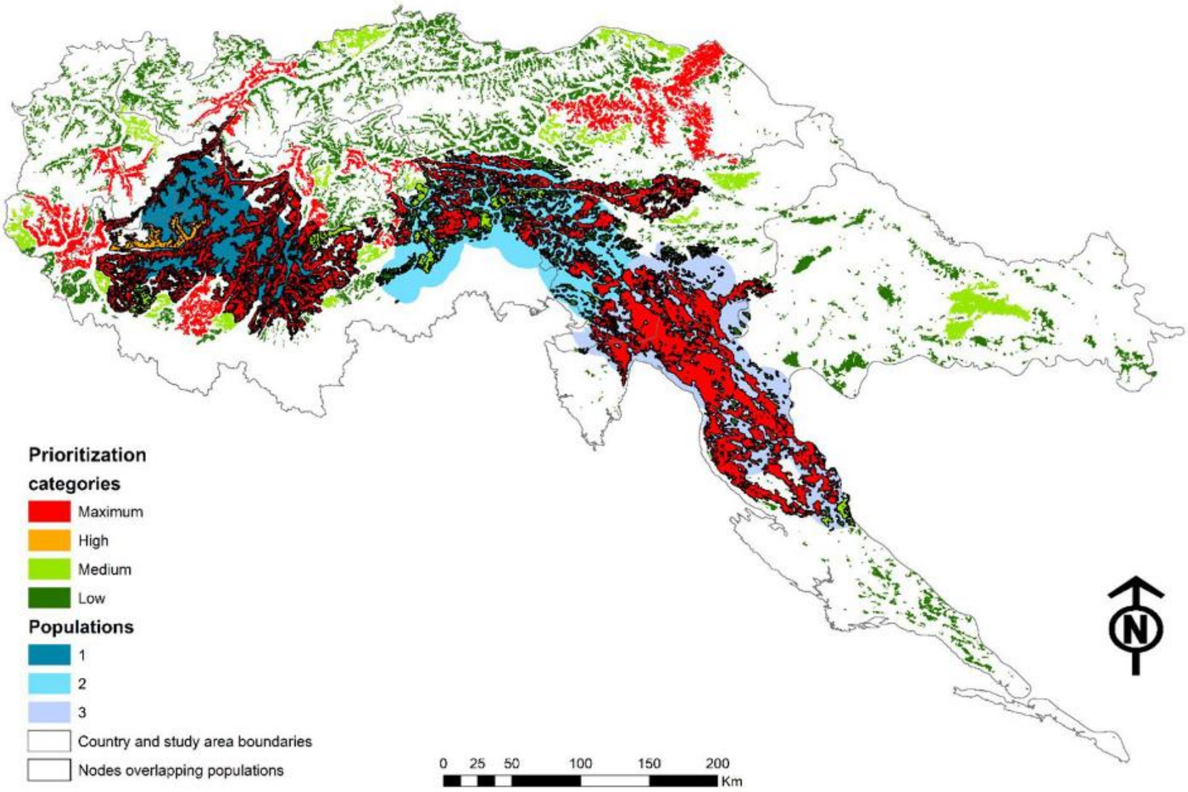

Figure 2: Brown bear habitat patches for the Dinaric (3), south-eastern alps (2) and Trentino (1) brown bear populations categorized based on their importance for landscape connectivity (Prioritization categories). Source: Recio et al. 2021.

Brown bear structural landscape connectivity was studied more specifically also in the Autonomous province of Trento where there is a reintroduced population of brown bears (Peters et al. 2015). The Adige valley is well known to be the most important barrier for brown bear movement in Trento (Černe et al. 2017). The study of Peters et al. 2015 identified two potential corridors or brown bear across the Adige valley.

Landscape connectivity is intensively studied also in the border region of Alps. This is because of the efforts to ensure ecological connection between Alps and other neighbouring biodiversity hotspots area. One of such hotspots are Dinaric Mountains, which are the most important origin area for the brown bear natural recolonization of Alps (Kaczensky et al. 2003). Currently DINALPCONNECT project (https://www.kis.si/en/Project_collection/DINALPCONNECT_EN/) is underway and one of the main goals of DINALPCONNECT project is to assess structural connectivity between Dinaric Mountains and Alps. To achieve this similar methodology (CSI index) as in ALPBIONET2030 project will be used (Laner et al. in preparation). Structural landscape connectivity for large carnivores and wild ungulates in the transition zone between Dinarics and Alps in Slovenia was assessed also in the study of Javornik et al. (in preparation). The goal of this study was to identify potential regional corridors between large carnivores and wild ungulates habitat patches in Slovenia (Figure 3) and to provide a solution for legal protection of these corridors within the established forest and wildlife management planning system in Slovenia.

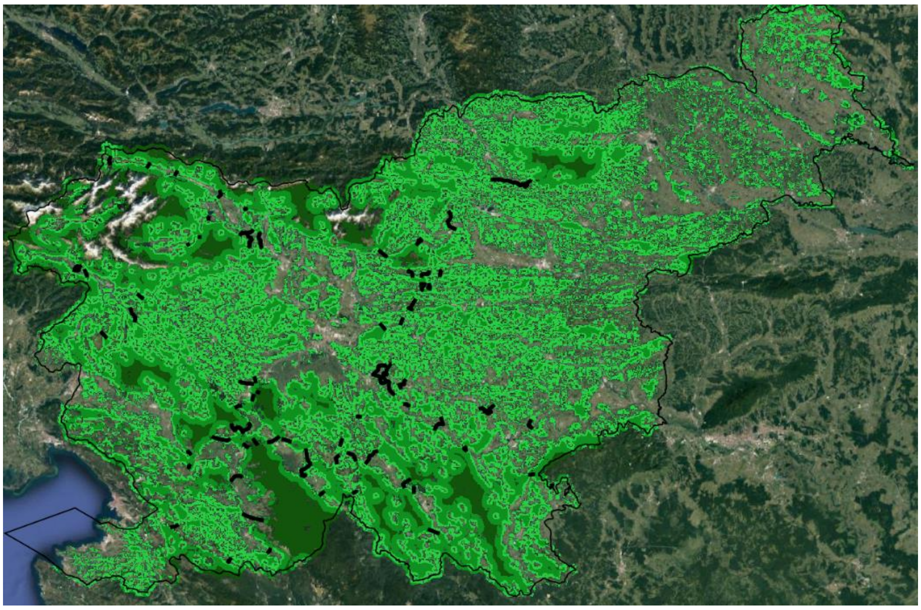

Figure 3: Established regional wildlife corridors (in black) connecting habitat patches for large carnivores and wild ungulates in Slovenia. Source: Javornik et al. in preparation.

Landscape connectivity was assessed also in other boundary parts of the Alps. Including Carpathians and Alps (the "Alpen-Karpaten-Korridor project"; https://www.wwf.at/artikel/alpen-karpaten-korridor/), Jura mountains and Alps in Switzerland (Trocme 2005), Massif Central and Alps in France (Gurrutxaga et al. 2011) and between Northern Apennines and Central Alps in Italy (Dondina et al. 2020).

3. REASSESEMENT OF LANDSCAPE CONNECTIVITY AND BARRIER IDENTIFICATION FOR LARGE CARNIVORES AND UNGULATES IN THE ALPS

Background

Our literature review on the landscape connectivity in Alpine region revealed, that there are no studies up to date focussing on the landscape connectivity for large carnivores and wild ungulates for the whole area of Alps (see Chapter 2). We therefore conducted an analysis of landscape connectivity for large carnivores and wild ungulates for the entire Alpine region (Alpine Convention perimeter). Specifically, we decided to do one connectivity model for all three species of large carnivores, red deer and wild boar, because this species are expressing similar habitat and movement characteristics and are living in fragmented populations thought the Alpine arc. On the other hand, we excluded roe deer, chamois and Alpine ibex from the model, because this species have very different habitat and movement requirements from the ones mentioned above. Although we believe establishing landscape connectivity for roe deer, chamois and Alpine ibex is very important, they thrive and move on a much smaller scale, which would be difficult for us to model on such a macro regional Alpine scale. Therefore, we advise, that landscape connectivity for roe deer, chamois and Alpine ibex is considered on regional scales for specific cases of interest.

Methods

Our landscape connectivity model for large carnivores, red deer and wild boar in the Alps is based on the CSI methodology, which was for the first time developed and used within the AlpBioNet2030 project (Plassman et al. 2019). We choose this methodology, because weighted average indexes of various relevant connectivity indicators are computational relatively fast and therefore among the most suitable methods for landscape analysis on such a large geographic scale.

However, the original CSI methodology in the Alpbionet2030 project (hereafter original CSI analysis; Plassman et al. 2019) was set to analyse landscape connectivity for a broad scope of species. Therefore, we adopted the CSI index for our target species. The reasons for our decision is based on the fact that some connectivity indicators and their values were not representing the connectivity requirements of our target species. We provide explanations for our decision in the following paragraphs.

Land use (or land cover) is the most important landscape connectivity indicator, because it represents species habitat selection. Therefore, it is very important that indicator values are set in accordance with target species habitat selection. We saw that indicator values for some land cover classes in the original CSI analysis were not set in accordance to our target species, therefore we decided to change them in accordance with the knowledge of their habitat selection (Table 1). For example, forests and other dense woody vegetation are the most important habitat types for connectivity for large carnivores and wild ungulates because they offer cover. Because of this they must get a higher weight in the analysis (Table 1).

Table 1: Indicator values for Corine land cover classes used in our Continuum suitability index (CSI) modelling. Values were set based on the current knowledge on the large carnivores and wild ungulates movement ecology and habitat selection with the most important criteria's being the amount of anthropogenic disturbance and natural (vegetation) cover.

Land Cover Class	Indicator value (0 – 10)
1.1.1. Continuous urban fabric	0
1.1.2. Discontinuous urban fabric	0
1.2.1. Industrial or commercial units	0
1.2.2. Road and rail networks and associated land	0
1.2.3. Port areas	0
1.2.4. Airports	0
1.3.1. Mineral extraction sites	0
1.3.2. Dump sites	0
1.3.3. Construction sites	0
1.4.1. Green urban areas	0
1.4.2. Sport and leisure facilities	0
2.1.1. Non-irrigated arable land	3
2.1.2. Permanently irrigated land	3
2.1.3. Rice fields	3
2.2.1. Vineyards	3
2.2.2. Fruit trees and berry plantations	3
2.2.3. Olive groves	3
2.3.1. Pastures	3
2.4.1. Annual crops associated with permanent crops	3
2.4.2. Complex cultivation patterns	3
2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation	5
2.4.4. Agro-forestry areas	5
3.1.1. Broad-leaved forest	10
3.1.2. Coniferous forest	10
3.1.3. Mixed forest	10
3.2.1. Natural grasslands	5
3.2.2. Moors and heathland	10
3.2.3. Sclerophyllous vegetation	10
3.2.4. Transitional woodland-shrub	10
3.3.1. Beaches, dunes, sands	2
3.3.2. Bare rocks	2
3.3.3. Sparsely vegetated areas	5
3.3.4. Burnt areas	10
3.3.5. Glaciers and perpetual snow	2
4.1.1. Inland marshes	5
4.1.2. Peat bogs	10
4.2.1. Salt marshes	1
4.2.2. Salines	1
4.2.3. Intertidal flats	3
5.1.1. Water courses	3
5.1.2. Water bodies	3
5.2.1. Coastal lagoons	0
5.2.2. Estuaries	0
5.2.3. Sea and ocean	0

Next, topography in Alps is also of high importance for species movements in Alps, because of the diverse relief determined by the changes in altitude and slope. Altitude and slope parameter are even more important in habitat selection of large carnivores and wild ungulates, because of the avoidance of humans and their activities. Based on our observations our target species are selecting stepper slopes and higher Altitudes to minimize the risk of encountering humans. This seems to be especially the case for large carnivores, such as brown bear and lynx. Therefore, we performed a slope and altitude selection analysis based on the data from GPS collared bears and lynx individuals from Trentino (20 bears and 1 lynx individual) and Slovenia (6 lynx individuals from Julian Alps area)). We then used the results from this analysis to set the indicator values for slope and altitude (table 2).

Table 2: Indicator values for altitude and slope that were used in our Continuum suitability index (CSI) modelling. Values were set based on a slope and altitude habitat selection study conducted on the GPS collared brown bears and lynxes in Slovenia and Trentino.

Altitude indicator values (0 – 10)		**Slope indicator values (0 – 10)**	
< 800	7	< 10°	7
800 – 1700	10	10° - 45°	10
1700 – 2600	7	45° - 75°	7
2600 – 3000	2	> 75°	1
> 3000	1		

The third important landscape connectivity indicator is road infrastructure or fragmentation. Highways pose the most significant barrier for large carnivores and wild ungulates movement. This is because highways are often fenced, wide, vehicles are moving with a high speed and there is a significant traffic frequency also during the night. On the other hand, non-highway roads that are not fenced are not known to represent a movement barrier for our target species (Javornik et al. in preparation). Therefore, we decided to simplify fragmentation indicator used in the original CSI analysis and include only highways as the most important fragmentation agent.

CSI index analysis undertaken in this report is based on three indicators adopted to the large carnivores, red deer and wild boar movement ecology; land use indicator, topography indicator and highway presence indicator. The topography indicator consists of two factors altitude and slope. As in the original CSI analysis undertaken in the AlpbioNet2030 project the land use and topography indicator values are ranging from 0 (not suitable for connectivity) to 10 (maximum connectivity suitability). However, we undertook the following changes to the model set up. Firstly, the model is checking for settlement presence in the spatial unit. If a settlement is present in a spatial unit all indicator values, including the topography are set to 0. Secondly, our model is checking for the highway presence in the spatial unit. If the highway is present all indicator values for land use and topography are set to 0. Finally, if there is no settlements and/or highways in the unit, then the CSI is calculated as a weighted average of land use and topography indicator (figure 4).

1. Check for the settlement presence in the land use indicator; if "YES" CSI = 0, if "NO" go to the second step.

2. Check for the highway presence; if "YES" CSI = 0, if "NO" calculate the index as:

$$CSI = land\ use + 0.5*(altitude + slope) / 2$$

Figure 4: A scheme of the CSI model structure used in our landscape connectivity reassessment and barrier identification.

Data compilation and indicator values classification

Spatial data for the land use indicator calculations in our CSI analysis was CORINE Land Cover 2018 raster with 100m x 100 m resolution (CLC 2018). We reclassify the CLC 2018 land cover classes according to our expert opinion and a number of habitat selection research of target species (Table 1). To each land cover class, we assigned a value between 0 (not suitable for habitat/connectivity) and 10 (the most suitable habitat/connectivity area). The final land use indicator map can be seen in Annex 1 of this report.

The base raster dataset for the topography indicator analysis was the European Digital Elevation Model with the spatial resolution of 25 m x 25 m (EU DEM, Copernicus programme, European commission). In the first step of the data preparation we rescaled the EU DEM layer to our working spatial resolution of 100 x 100 m. From the rescaled EU DEM layer we generated a slope raster layer. We set the altitude and slope indicator values (Table 2) based on the altitude and slope derived from data of GPS collared bear and lynx individuals from Trentino (20 bears and 1 lynx individual) and Slovenia (6 lynx individuals from Julian Alps area)). The altitude and slope indicator maps can be seen in Annex 2 and 3 of this report.

We compiled the highway spatial data layer from the open source road map of the Open Street Map (OSM road map). Road data was downloaded from online repository for each country/region separately in a vector format. Firstly, we merged the road spatial layers of each country within the area of our analysis. Secondly, we clipped the merged layer to the exact border of our analysis area. From this merged and clipped road network dataset we created a subset layer containing only highways without highway bridge/viaduct or tunnel sections longer than 100 m. The reasoning behind the exclusion of above mentioned sections is based on the empiric observation that highway crossings longer than 100 m do not represent a barrier for the target species movement. Finally we rasterized the compiled highway vector layer to a working resolution of 100m x 100 m. The final highway map used can be seen in Annex 4 of this report.

We did all of the clipping of the used spatial data in QGIS. We performed all other data preparation in R, using packages "raster", "sf" and "Tidyverse".

Continuum suitability index (CSI) calculation and barriers identification

Our study area was the Alpine Convention area represented by the Alpine convention perimeter (Alpine Convention spatial data repository). We also set a 50 km buffer around the study area to analyse the landscape connectivity also in the boundary parts of the Alps.

Finally, we calculated the CSI index for our analysis area using the prepared spatial data described above and our CSI index model. The calculations were done using the “mosaic raster” function in “raster” package in R. To define the CSI index value range that represents barriers for our target species we used the GPS data of brown bears and lynxes in Trentino and Slovenia (dataset described above). We analysed the distribution of the bear and lynx GPS data in the relation of the CSI index and set the lower 2.5 percentile of this distribution as a barrier for the target species movement. The identified lower 2.5 percentile CSI index value was < 5, which is identical to the CSI value that defines a barrier in the AlpBionet2030 project landscape connectivity analysis.

We then used the calculated CSI index analysis with the defined CSI barrier range to identify the main barriers for large carnivores, red deer and wild boar landscape connectivity in the Alps. This was performed using the “raster sieve” analysis in R, which removes all barriers smaller than a defined criterion. We defined the criteria area value to < 9200 ha, which is representing a theoretical rectangle with a length of 20000 m and width of 4600 m. The length of 20000 m (20 km) is the maximum natal dispersal distance of red deer, which are the poorest dispersing species of the target species in focus. The width of 4600 m corresponds to the maximum recorded distance made by female brown bears into the non-habitat in Alps and Dinaric mountains (Recio et al. 2020 – cite!).

The highway barriers defined in our analysis are sections of highways that do not have important highway crossing (bridge, viaduct or tunnel longer than 100m on a section of highway that is longer than 20000 m, the maximum natal dispersal distance for red deer. To identify highway barriers we first identify important highway crossings that connect areas of CSI index value > 5 (non-barriers). Then we clipped the compiled OSM highway vector layer with the identified important highway crossings in the QGIS program. Finally, we used the clipped highway vector layer to perform a line section analysis in R to identify the line sections without crossings (highway) longer than 20000 m (20 km).

Results

Our CSI calculation results for large carnivores, red deer and wild boar in the Alps and surroundings (50 km buffer from Alpine convention perimeter) are shown on Figure 5. We showed that in many areas in Alps (i.e. Alpine convention area) landscape connectivity for large carnivores, red deer and wild boar is still well preserved. Especially when compared to the Alps surroundings. Namely, in the Alps the majority of areas have a CSI value above 5 (Figure 5). We expected such a result, as also previous studies showed, that in Alps there is still a lot of suitable habitat for our target species .

Barriers (CSI value 5 or less) are much less abundant according to our results (Figure 5). This is because barriers are mostly located within alpine valleys in which settlements, infrastructure and agricultural activities are aggregated. Importantly to note is also that the density of barriers is higher in northern Alps, north-western Alps and southern Alps compared to other areas (Figure 5).

Although the CSI analysis results are promising in general, there are a number of very important barriers for large carnivores and wild ungulates movements in Alps. **We identified 27 such barriers across the whole study area (Figure 6 and Table 3)**. Those are barriers represented by large densely populated Alpine areas and/or long highway section (> 20 km) with no existing suitable highway crossing (> 100 m). Those barriers represent important movement obstacles for large carnivores and wild ungulates, because they are hindering dispersion, mating excursions and seasonal movements. **Barriers listed in Table 3 and showed Figure 6 are therefore priority areas in Alps for executing management actions necessary for restoring/enhancing landscape connectivity for large carnivores and wild ungulates in the Alps. Management actions aimed for improving landscape connectivity in identified barriers are also among the most important aspects of joined Alpine transboundary population level species management.**

With our analysis we also identified the most important existing highway crossings in Alps and the most important Landscape connectivity areas that are connecting Alps to neighbouring mountain massifs (Figure 6). The most important existing highway crossing are highway bridges and tunnels that are longer than 100 m and are located in the areas that are highly suitable for target species connectivity (CSI values >5). **Identified existing highway crossing by our analysis are very important for highway permeability, therefore they should be treated with the same importance as main barriers. Their surroundings should be protected as corridors to prevent fragmentation of suitable connectivity habitat that lead to these highway crossings.**

Our identified priority areas for connectivity towards Alps (Figure 6) are very similar as they were identified also by other studies (see Trocme 2005 Gurrutxaga et al. 2011, Recio et al. 2021) and are connecting Alps with Dinaric Mountains, Jura Mountains, Bohemian forest, Massif Central and Apennines. **It is vital to preserve landscape connectivity in those areas. Especially in areas where landscape connectivity is good preserved. Such area is the connection between Apennines and the Alps in northwestern Italy (Liguria and Piedmont regions; Figure 6). We advise suitable wildlife corridors establishment in this areas to prevent further possible connectivity habitat fragmentation. In all other important landscape connectivity areas (Figure 6), management measures for enhancing and restoring connectivity are advised.**

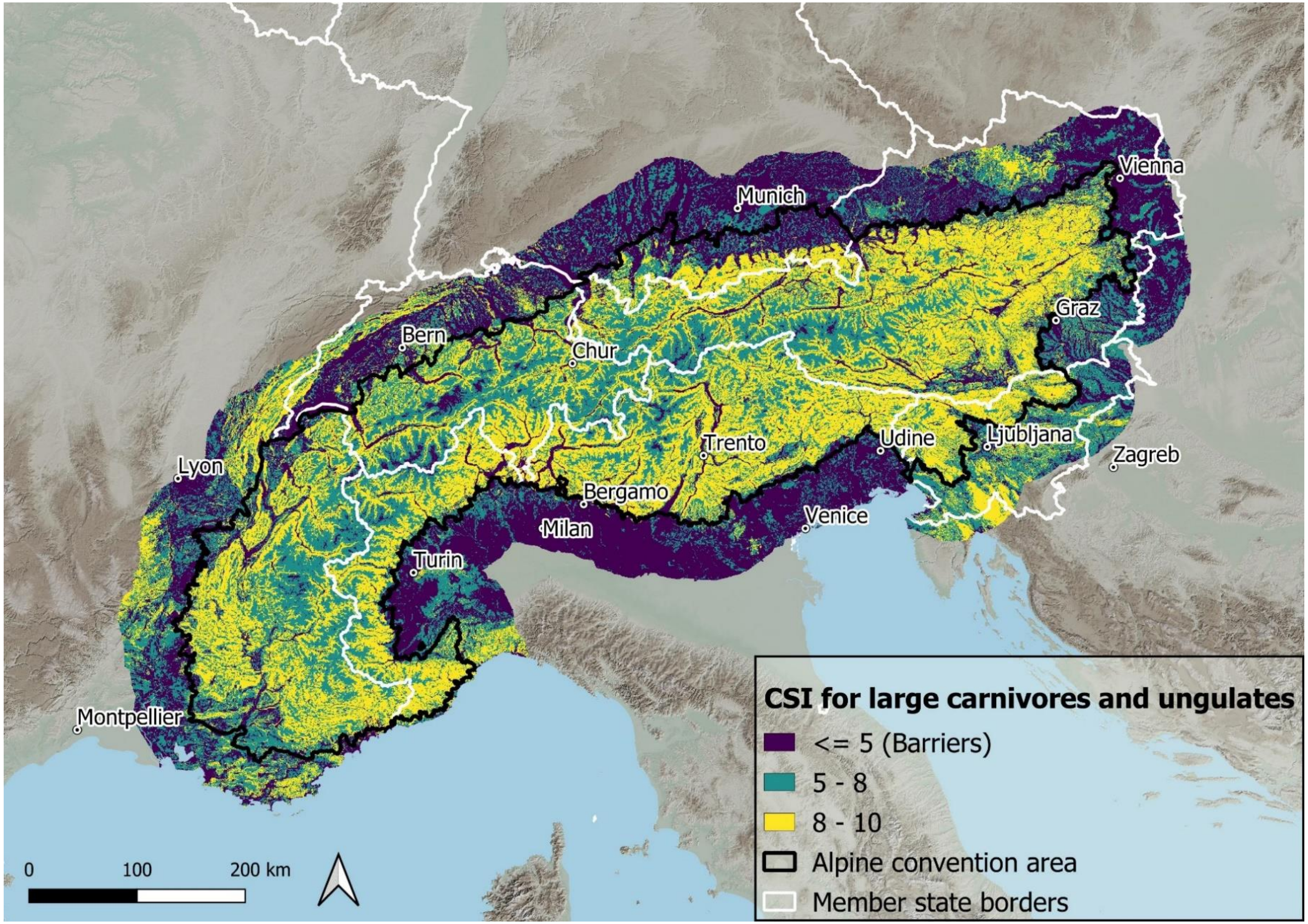

Figure 5: Results of the conducted Continuum Suitability index (CSI) modelling for large carnivores and wild ungulates in the Alps. The results are shown for the Alpine convention area perimeter with the functional surroundings (50 km buffer).

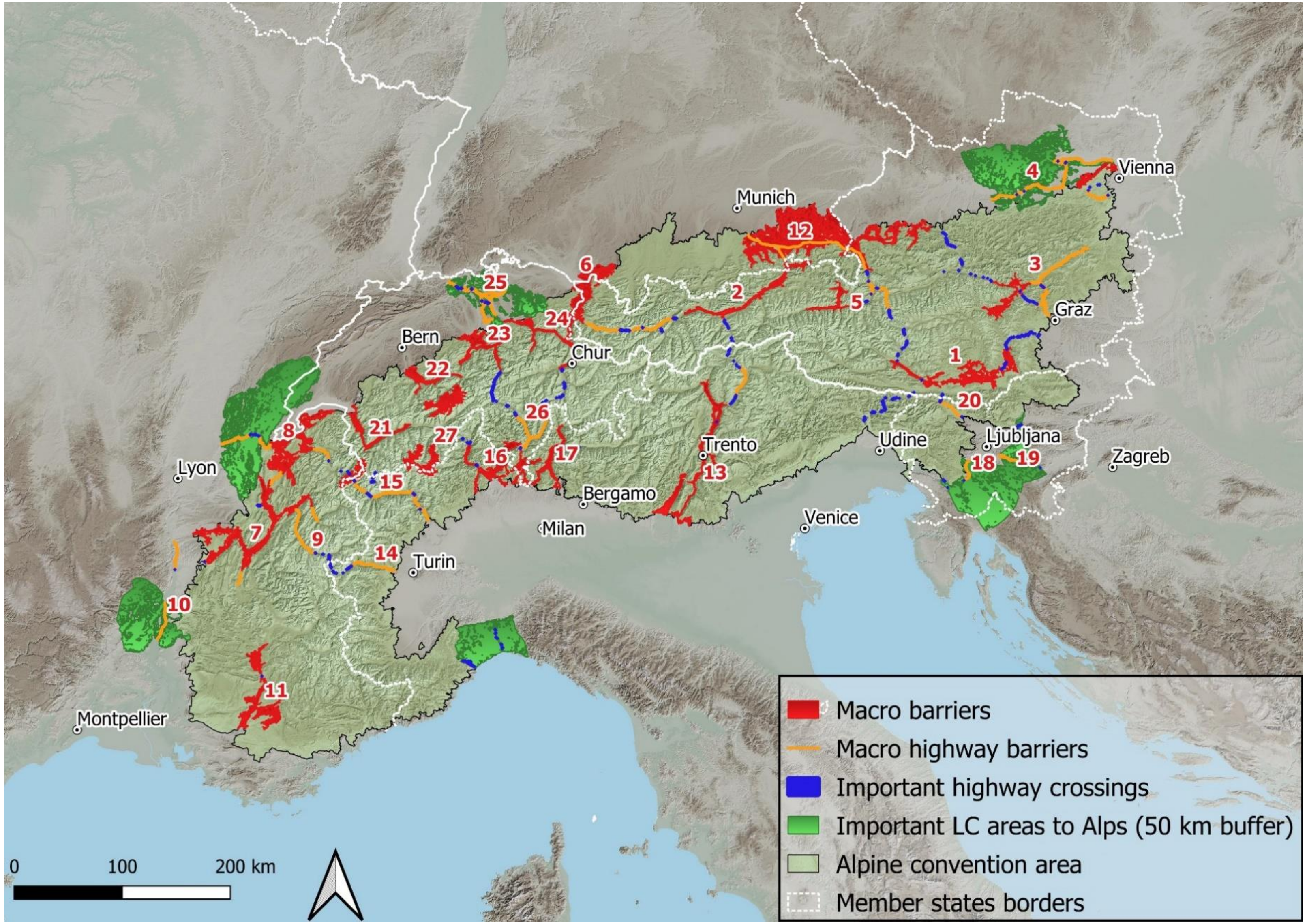

Figure 6: Identified barriers – urban and intense agricultural areas (red) and highways (orange) – together with identified important large-scale highways crossings (blue) and important landscape connectivity areas (green) in the Alps. The results are shown for the Alpine convention area perimeter with the functional surroundings (50 km buffer).

Table 3: Identified barriers for large carnivores and wild ungulates movement in the Alps. Barriers are listed for each Contracting Parties in alphabetical order. The barrier ID number correspond to those on Figure 6. An approximately length of each barrier is given together with the recommended management actions.

Barrier	Member State	Length	Recommended Management actions
1. DRAU VALLEY AND KLAGENFURT BASINT-LAVANT VALLEY	Austria	150 km	corridors establishment
2. INN VALLEY	Austria	>240 km	corridors establishment and green bridge infrastructure
3. MUR AND MÜRZ VALLEY	Austria	80 km	Corridors establishment and green bridge infrastructure
4. St. PÖLTEN – VIENNA HIGHWAY	Austria	140 km	Established corridors incorporated into regional development plans
5. SAALACH-SALZACH VALLEY	Austria	45 km	Established corridors maintenance
6. LOWER RHINE VALLEY	Liechtenstein, Switzerland, Austria and Germany	>70 km	Corridors establishment and green bridge infrastructure
7. "GRENOBLE – CHAMBERY" BARRIER	France	200 km	Corridors establishment and green bridge infrastructure
8. THE "GENEVA BARRIER"	France	>100 km	Corridors establishment and green bridge infrastructure
9. HIGHWAY "AITON-MODANE"	France	50 km	Corridors establishment and green bridge infrastructure
10. HIGHWAY "AVIGNON-VALENCE"	France	40 km	Corridors establishment and green bridge infrastructure
11. DURANCE VALLEY	France	90 km	Corridors establishment
12. THE INNTAL AND NUMBER "8" HIGHWAYS BARRIER	Germany	140 km	Corridor establishment, improvement of existing highway underpasses and incorporation of landscape connectivity into construction planning of the new "Intall railway"
13. ADIGE RIVER VALLEY	Italy	>150 km	None.
14. "TURIN-MODANE" HIGHWAY	Italy	80 km	green bridge infrastructure
15. "CHAMONIX-IVREA" HIGHWAY	Italy	100 km	corridors establishment
16. LAKE MAGGIORE	Italy	90 km	corridors establishment
17. LAKE COMO	Italy	80 km	corridors establishment and green bridge infrastructure
18. "LJUBLJANA – KOPER" HIGHWAY	Slovenia	50 km	Established corridors maintenance and green bridge infrastructure

19. "LJUBLJANA- NOVO MESTO" HIGHWAY	Slovenia	40 km	Established corridors maintenance and green bridge infrastructure
20. "LJUBLJANA-JESENICE" HIGHWAY	Slovenia	30 km	Established corridors maintenance
21. RONA RIVER VALLEY	Switzerland	80 km	Established corridors maintenance and green bridge infrastructure
22. THUNER- AND BRIENZERSEE BARRIER	Switzerland	50 km	Established corridors maintenance and green bridge infrastructure
23. "LUZERN BARRIER"	Switzerland	90 km	Revision of established corridors
24. UPPER REN VALLEY – WALENSEE BARRIER	Switzerland	90 km	green bridge infrastructure
25. "WINTERTHUR-ZÜRICH-ZUG" HIGHWAYS BARRIER	Switzerland	100 km	green bridge infrastructure
26. THE LUGANO-BELLINZONA BARRIER	Switzerland	80 km	Revision of established corridors
27. BERNESE, PENNINE AND GRAIAN ALPS	Switzerland	-	None (natural barrier)

4. CONCLUSIONS AND RECOMMENDATIONS FOR ENHANCING AND RESTORING LANDSCAPE CONNECTIVITY WITHIN THE BARRIERS

Barriers and important landscape connectivity areas in the Alps for large carnivores and wild ungulates movement are listed in Table 3 and Figure 6. **These are priority areas in the Alps for transboundary management activities for enhancing and restoring landscape connectivity**. In the following chapter we provide a short description for each identified barrier, a list of connectivity improvement action that were already conducted and our recommendations for further actions necessary to facilitate landscape connectivity. Barriers are listed according to the contracting parties and the barrier numbers are corresponding to those in Table 3 and Figure 3.

Barriers listed by Contracting Parties with management recommendations

Austria

1. DRAU VALLEY AND KLAGENFURT BASIN-LAVANT VALLEY

With a length of more than 150 km this is one of the largest barriers in the Alps. The direction of barrier is west-east and it stretches from the city of Spittal in the west across Villach and Klagenfurt towards Wolfsberg on the east. The barrier consists of urban fabric, agricultural land, river Drava and few larger lakes. There is a highway going through the whole length of the barrier. Because of its size and west-east direction, this is one of the most important barriers for wildlife movement in the eastern Alps. It affects the movement of target species from high valuable habitats in the southern Alps (Julian Alps, Karawanken, Friuli-Venezia Giulia region) towards highly valuable habitats in the northern Alps in Austria.

Conducted management actions for improving landscape connectivity.

Within the LIFE project “Schütt-Dobratsch” (LIFE00 NAT/A/007055) a 92m wide green bridge was constructed for bears and other wildlife in 2004 (http://www.schuett.at/life/massnahmen_gruenbruecke.php).

The “Freiraumkonzept Kärnten” registers open spaces and wildlife corridors. Within the regional development plans every commune shall determine areas kept free from further development (Leitner et al. 2016).

Further actions for improving connectivity

Both west and east from the barrier there are areas of highly permeable landscape, therefore it is important to prevent fragmentation of landscape in these areas. Especially important is the mountain range east from the barrier (east of Wolfsberg, i.e. “Koralpen") with highly permeable habitat (CSI>8) and a high density of existing suitable highway crossings. Nevertheless, due to the size of the barrier we recommend to undertake measures to increase the connectivity also within the barrier. Therefore, we recommend establishing wildlife corridors within the barrier. There are two potential areas for corridors within the barrier. The first one is just at the village of Weißenbach. In this location, there is a bridge across the highway and some forest patches connecting the valley. These forest patches are intersected with some industrial units, but we predict that there is still enough connection for a wildlife corridor. Therefore, this area needs protection from further fragmentation. The second area is a forested ridge east of Griffen with a series of bridges and tunnels across the highway. This area is sparsely populated with well-connected forest patches and it has a big potential for a wildlife corridor.

2. INN VALLEY BARRIER

The valley of river Inn stretches on the direction of southwest-northeast. With more than 240 km in length this is one of the biggest barriers for wildlife in the Alps, although the valley itself is more or less narrow. It stretches from Landeck in the west to Rosenheim (northeast) in Germany. A highway and fenced railway are running through the valley together with other types of transport infrastructure. From Roppen downstream the valley becomes wider and opens to a dense urban fabric and agricultural lands.

Conducted management actions for improving landscape connectivity.

Three possible sites for green bridges have been determined by the ASFINAG from Roppen to Kufstein. Proposed areas are east of Telfs, east of Stans and between Radfeld and Kundl (Völk et al. 2001, Proschek 2005, BMVIT 2006). No determined green bridge was built to date.

Further actions for improving connectivity

We recommend realizing planned green bridge infrastructures. In addition, it would be important to establish wildlife corridors in the functional vicinity of the green bridge infrastructure. In addition to the planned locations, another potential wildlife corridor could be discerned near the town of Schwaz. Some forest patches along the Vomper Bach could in the current state act as corridor if a green bridge would be built across the highway.

3. MUR AND MÜRZ VALLEY

Mur and Mürz valley represents together with the “S6” and “S36” highways a wildlife movement barrier which is around 80 km long. The barrier is directed southwest towards northeast. In the Southwest and northwestern part the barrier consists mostly of the urban fabrics of the Judenburg, Knittefeld and Leoben cities and on the east the barrier is represented mostly by the S6 and S36 highways.

Conducted management actions for improving landscape connectivity.

A green bridge is planned close to the town of Kraubath an der Mur (Völk et al. 2001, Proschek 2005, BMVIT 2006). For large carnivores and wild ungulates, an especial important location for a green bridge is between the villages of Altendorf and Leising, where there is an area of connected forest patches across the valley of Mura, which could become a movement corridor across the valley to the north. A planned alternative location for green bridge location is also by the village of St. Stefan ob Leoben.

Green zones and ecological corridors have been designated in the enacted regional plans (Leitner et al. 2016).

Further actions for improving connectivity

We recommend to establish planned green bridge and wildlife corridors green infrastructure.

4. "St. PÖLTEN - VIENNA" BARRIER

In the Northeast of Austria there is an area between the cities of St. Pölten and Amstetten which may allow the connection between the Alps and the Bohemian (Šumava) Massif in the North (figures 5 and 6). Some connected forest patches are preserved in this area, especially along the Donau river and in the eastern vicinity of the city Amstetten. "The western" highway cuts through this area. Also the river Donau is a strong natural barrier here that should be taken into account.

Conducted management actions for improving landscape connectivity.

A green bridge was constructed in the commune of Bergland (ASFINAG press release, 21.10.2015; https://www.ots.at/presseaussendung/OTS_20151021_OTS0047/asfinag-gruenbruecken-als-lebensraum-verbindung-ueber-autobahnen-und-schnellstrassen). The corridor passing the commune of Bergland between the Alps and the Bohemian (Šumava) Massif was also highlighted in the Interreg project "Crossborder Habitat Network and Management – Connecting Nature AT-CZ". The action plan developed within the project presents ways how to incorporate the protection of wildlife corridors into the regional development planning. (Frey-Roos et al. 2021)

Further actions for improving connectivity

We recommend to incorporate the planned wildlife corridor into the regional development planning.

5. SAALACH-SALZACH VALLEY BARRIER

The Saalach-Salzach valley barrier is a small barrier that is 45 km long and mostly around 1,5 km width. It "runs" in two directions, west-east and south-north and is representing a wildlife movement barrier in the direction southeast- northwest. The barrier consists mostly of small settlements and intensive agricultural land.

Conducted management actions for improving landscape connectivity.

A number of regional and supra-regional "Green corridors" crossing the Saalach-Salzach valley in the district of Pinzgau were legally established between Mittersill and Taxenbach within the regional programs (Regionalprogramm Pinzgau and Regionalprogramm Oberpinzgau; https://www.salzburg.gv.at/themen/bauen-wohnen/raumplanung/ueberoertliche-raumplanung/regionalplanung). The corridors are situated close to Uttendorf, Lengdorf, Niedernsill, and Bruck an der Glocknerstraße.

Further actions for improving connectivity

The protection of existing wildlife corridors should be maintained.

Liechtenstein

6. LOWER RHINE VALLEY BARRIER (AUSTRIA, LIECHTENSTEIN, SWITZERLAND AND GERMANY)

The Rhine valley barrier is located in the territories of three countries, Austria, Liechtenstein and Switzerland, however the majority of its area is in Austria. The Rhine valley runs in the direction of south north and is a wide, densely populated valley, especially towards the northern part and with high density of traffic infrastructure.

Conducted management actions for improving landscape connectivity.

In the mentioned barrier between the municipalities Weite/Wartau and Balzers/Triesen a highway crossing (green bridge) is at the beginning of an implementation process. The same is the case for the location between the municipalities Buchs/Grabs/Gams/Sennwald (Switzerland) and Schaan/Eschen (Liechtenstein) about 12 km in northern direction.

Further actions for improving connectivity

In the context of a package of measures that was adopted by the Government of the Principality of Liechtenstein in 2020, the improvement of wildlife corridors within the potential migration corridors of red deer must be reviewed. The Office of Environment has been tasked with developing a concept with proposals for the implementation of habitat connectivity elements and optimized migration corridors (Massnahmenpaket zur Verbesserung der Waldverjüngung...). On the border between Liechtenstein and Switzerland between the municipalities of Weite/Wartau (Switzerland) and Balzers/Triesen (Liechtenstein) an establishment of a corridor needs to be considered. In this area there are few settlements and some patches of riparian forest by the river Rhine that could serve as a needed vegetation cover. There is also a highway (A13) running parallel along the river Rhine in this area. If a corridor could be established in the area this would be an important area connecting Alps and

Jura Mountains (Via the “Churfirsten”, see barrier description number 24. Rhine valley - Walensee barrier in Switzerland.). This area between Weite/Wartau and Balzers/Triesen is part of the forthcoming reviews. Provided that the implementation process runs as planned, Rhine valley crossing wildlife corridors could be achieved within the next 10-15 years.

France

7. THE “GRENOBLE-CHAMBERY-ALBERTVILLE” BARRIER

The valley of Grenoble, Chambery and Albertville in France is a barrier that stretches from Voiron and Saint-Marcelin on the west to Chambery and Alberville in the east. The direction of the barrier is southwest – northeast. All together this barrier is more than 200 km long and more than 5 km wide on the widest part. This barrier is important because it is affecting the connectivity between Alps and Jura mountains.

Conducted management actions for improving landscape connectivity.

A 12-meters-wide green bridge across highway A43 has been put into service at the start of 2022, south of Chambéry, on the territory of the Porte-de-Savoie municipality.

A 12-meters-wide green bridge has been put into service at the start of 2022, on the Aix-les-Bains / Annecy section of the A41 motorway, south of Annecy, on the territory of the Montagny-les-Lanches municipality.

Further actions for improving connectivity

Within the barrier, the most important part regarding the connectivity is located on the northeastern part, between Aix-les-bains and Annecy. This area is a landscape of fragmented forest mosaics and agricultural lands and it is still sufficiently connected according to our CSI analysis (CSI between 6 and 8). Therefore, it represents the best existing connection on an axis towards Jura. The highway A41 is the most problematic here. We recommend establishing a wildlife corridor in the vicinity of the new green bridge across A41 in the Montagny-les-Lanches municipality to facilitate movement across this green bridge. An existing possible A41 highway crossing is also the highway bridge crossing the river Cheran. Therefore, we also recommend that river Cheran and surrounding riparian forest are protected as wildlife corridor.

8. THE “GENEVA BARRIER”

This is a larger barrier in the vicinity of Geneva and lake Leman on the border with Switzerland. It consists of urban areas around the cities of Geneva, Annecy and Thonon-les-Bains.

Conducted management actions for improving landscape connectivity.

The construction of a green bridge has been launched in spring 2022, on the Annecy-Geneva section of the A41 highway, north of Annecy, on the territory of the former Pringy municipality. Works are expected to end in spring 2023.

Further actions for improving connectivity

We recommend that the forest surrounding the planned green bridge across the “A41” on the territory of the former Pringy municipality is protected as wildlife corridor to facilitate species movement in this area. We also recommend that possibilities for further green bridge locations are considered if possible.

9. HIGHWAY “AITON-MODANE”

The section of the A43 highway between Aiton and Modane is around 50 km long and goes from the city of Aiton to Modane across a narrow, partly densely populated area. With the exception of the southern most part near Modane it has no major suitable highway crossing, therefore it is problematic in terms of target species connectivity.

Conducted management actions for improving landscape connectivity.

No information has been communicated regarding this barrier.

Further actions for improving connectivity

We recommend undertaking measures establishing and improving connectivity on this highway. This includes green bridge infrastructure. The most promising parts for a green bridge location is just south of the Saint-Marie-de-Cuines settlement on the southeastern border of the Saint-Marie-de-Cuines municipality. At this location, the valley is the narrowest and no settlements are located.

10. HIGHWAY “AVIGNON-VALENCE”

A 40 km long section of the highway A7 Avignon-Valence is intersecting two potential forested corridors south and north of the Montelimar municipality which are connecting the Alps with the Massif Central. In addition to the highway, a natural barrier intersecting those corridors is also the river Rhone together with some small settlements and industrial/commercial units.

Conducted management actions for improving landscape connectivity.

No information has been communicated regarding this barrier.

Further actions for improving connectivity

We recommend protecting the existing forested corridors to minimize the risk of further fragmentation. In addition, we recommend a green bridge infrastructure across the A7.

11. DURANCE VALLEY BARRIER

The majority of this barrier is situated in the Durance river valley from Manosque in the south to La Saulce in the north. The barrier is more than 90 km long and up to 9 km wide. It includes a hydraulic canal over all its length, a highway A51 and a railway line over a part of the valley. Moreover, the Durance itself is a watercourse, which creates a natural barrier between the two sides of the valley. Within the barrier, especially two locations in the north of the identified barrier (in the territory of La Saulce and Ventavon municipalities) are considered as “black spots”, where landscape connectivity needs to be improved as a priority. The valleys of Durance’s tributaries are not considered as parts of a barrier, as they are not concerned by any major infrastructure.

Conducted management actions for improving landscape connectivity.

The A51 motorway is a relatively recent motorway, with wide wildlife crossings in operation since its construction. In addition, competent authorities carry out actions in the two priority sectors referred to above (La Saulce and Ventavon), to improve the understanding of landscape connectivity problems and promote remediation actions.

Further actions for improving connectivity

The barrier is the narrowest by Vallée (on the territory of the Salignac municipality), where there is also a highway bridge across Durance river. In this location, there are also forested areas with permanent cover and with no large settlements nearby. We recommend establishing a wildlife corridor at this location to prevent further fragmentation and reconnect this area.

<u>Germany</u>

12. THE INNTAL AND NUMBER “8” HIGHWAYS BARRIER

In the vicinity of Rosenheim and west of Salzburg (south-eastern Germany; Figure 6) the habitat for our target species is very fragmented with many agricultural lands and small settlements intersecting forested areas. However, because of many good connected forest patches, we believe connectivity of this area is still sufficient. Nevertheless, management actions are needed to enhance connectivity. The strongest barriers in that region are the “number 8” highway, which is running east-west from Salzburg to Munich, and the “Inntal” highway “number 93” which is located in the River Inn valley.

Conducted management actions for improving landscape connectivity.

Concerning the upgrading of the “number 8” highway from Salzburg to Rosenheim some minor measures for enhancing wildlife landscape connectivity are planned on the existing underpasses of creeks and river valleys. The construction of specific green bridges for wildlife crossing is currently not in discussion.

For the Inntal-highway “number 93”, no measures for improving landscape connectivity is currently planned.

Further actions for improving connectivity

During the upgrading of highway “number 8” planned improvements of existing underpasses should be carried out as planned. Those measures should be aimed also in preserving and connecting small existing forest patches and/or hedges to guide animals towards these underpasses.

For the highway “number 93”, the planning process of the new railway tracks should be used for discussing and implementing a concept for a better landscape connectivity of the German part of the Inn valley. A transboundary planning approach with Bavarian/Tyrol authorities is recommended (Bavarian Agency of Environment, 2008).

Italy

13. THE ADIGE RIVER VALLEY

Adige river valley, going all the way from the vicinity of Verona across Trento to Bolzano and Merano, is one of the most important barriers for wildlife movement in the Alps. This barrier is almost 150 km long and is therefore one of the largest barriers in the Alps also due to the presence of highway, railways, urban areas and intensive agricultural areas. A reintroduced population of brown bears is living in the forested habitat west of Trento and this is the only population of brown bears with recorded reproduction in the Alps. The Adige valley barrier is hindering the movement of bears to east towards a large area of suitable habitat and the area where bears for the Dinaric population are present. Nevertheless several cases of crossing from bears (successful and unsuccessful) have been reported, together with cases of car accidents with them and other wildlife species, mainly ungulates. Regarding the wolf, we believe that the valley is more permeable, due to the higher adaptation of this species, but no data have been yet collected for wolf crossing. Therefore this barrier is not impermeable, however landscape connectivity is in general poor. Especially in the section between Bolzano and Merano.

Conducted management actions for improving landscape connectivity.

No actions have been undertaken to improve connectivity or are expected, also due to the fact that the ration costs/benefits would be too low.

Further actions for improving connectivity

No actions are expected due to the high financial input needed to increase connectivity. Studies have documented that the only existing suitable highway crossings are located north of Bolzano (a documented case of bear accident in 2012 between Bolzano and Merano; Figure 6). These highway crossings are of very high importance for connectivity in the Alps and must be protected as wildlife corridors. In addition, adaptations of these existing crossings would be beneficial to increase and direct animal movement. North of Trento a suitable potential corridor exists, but was not accepted as suitable.

14. “TURIN-MODANE” HIGHWAY

This highway is located at the western part of Piedmont region and runs for approximately 80km. Several cases of accidents with wildlife (wolves and ungulates) have been reported on this highway.

Conducted management actions for improving landscape connectivity.

The LIFE WOLFALPS EU (www.lifewolfalps.eu/en/) project is conducting a specific action aimed to improve ecological connection in this barrier. In 2020 a study on the ecological corridors present in the valley and the most critical points have been identified. In 2021, in close collaboration with the infrastructure management society, ANAS, RFI and SITAF, numerous inspections were carried out to identify solutions for the number of accidents and reduce road mortality in the various critical points.

Further actions for improving connectivity

Management actions for improving wildlife connectivity are planned by Life WolfAlps Eu project; this measurement includes establishments of suitable green bridge infrastructure or adaptation of existing infrastructures for wildlife crossing.

More detail information about these activities can be obtained at the following address; https://www.lifewolfalps.eu/proseguono-i-lavori-per-ridurre-gli-investimenti-di-lupi-lungo-la-ferrovia-e-le-statali-in-alta-valle-di-susa/

15. THE “CHAMONIX-IVREA” HIGHWAY

The highway leading from Chamonix in France to Ivrea city in Italy is around 100 km long. Across the length of the highway there are four locations of suitable wildlife highway crossing. These locations are north of Entreves, by Derby-Villaret, at Borgo and finally at Bard.

Conducted management actions for improving landscape connectivity.

No information.

Further actions for improving connectivity

The four mentioned highway crossings are of the most importance for connectivity in the Alps and should be maintained and fragmentation of forests prevented via suitable corridors establishment. In addition, adaptations of these existing crossings would be beneficial to increase and direct animal movement.

16. LAKE MAGGIORE BARRIER

This barrier largely consists of the lakes Maggiore and d´Orta with their surroundings. To the northwest this barrier continues to the Toce river valley. A highway goes throughout the barrier. The barrier is around 90 km long.

Conducted management actions for improving landscape connectivity.

In that barrier studies have been conducted about ecological corridors in order to elaborate a specific map of ecological networks and critical points for wildlife crossing.

Further actions for improving connectivity

Lake Maggiore and d´Orta with urban surroundings are absolute barriers. However, in Toce river valley there are three locations with suitable wildlife highway crossings. Especially important is the viaduct by Albo, which is situated in the middle of the barrier. All these highway crossings are important for connectivity. Maintenance with the prevention of the deforestation and protection as corridors is important.

17. LAKE COMO BARRIER

This barrier which is around 80 km long is represented by the lake Como, which is a natural barrier, and the highway "Strada statale 36" which runs from lake Como into Valtellina valley. On the east part of lake Como the highway is in many parts in tunnels, therefore this section is not problematic for connectivity.

Conducted management actions for improving landscape connectivity.

In the lower part of Valtellina in order to improve connectivity a design for the improvement of ecological connectivity (project "greeway dell'Adda"; https://naturachevale.it/wp-content/uploads/2021/12/Greenway-Adda-in-bassa-Valtellina.pdf) was approved in 2021 and shared by the municipalities involved . The design of the local ecological network foresees actions for the improvement of landscape connectivity, the preserving of the major corridors and the design of major bridges for defragmentation.

Further actions for improving connectivity

Planned activities are listed in the greeway dell'Adda project documentation;
https://naturachevale.it/wp-content/uploads/2021/12/Greenway-Adda-in-bassa-Valtellina.pdf

Slovenia

18. THE “LJUBLJANA – KOPER” HIGHWAY

The forested area of Dinaric mountains plateaus between the town of Vrhnika on the east and the village Razdrto on the west (Figure 6) are of the most important corridors for large carnivores and ungulates connecting Dinaric mountains and Alps. Based on the suitable connectivity habitat the area would be highly permeable for target species. Especially between towns of Vrhnika and Unec and between Unec and Postojna where large continuous forest areas are preserved. However, the highway intersecting those areas with very few suitable wildlife crossings is a barrier importantly hindering animal movement.

Conducted management actions for improving landscape connectivity.

A green bridge is planned between Unec and Postojna and currently a spatial planning document is being prepared. A wildlife corridor is established in the area protecting forests in the functional vicinity of the planned green bridge (Javornik et al. in preparation). Corridors are also established in the functional vicinities of important existing highway crossings, such as “Ravbarkomanda” bridge near Postojna and on three locations in the vicinity of Razdrto, Senožeče and Podnanos (highway towards Ajdovščina).

Further actions for improving connectivity

The vicinity of the only existing largescale highway crossing between Unec and Postojna, the “Ravbarkomanda” bridge, is already very fragmented. A study is needed to assess the functional connectivity of the “Ravbarkomanda” bridge.

19. THE “LJUBLJANA- NOVO MESTO” HIGHWAY

East of Ljubljana another important landscape connectivity area from Dinaric mountains towards Alps is located (figure 6). It consists of connected forest patches at the vicinity of the towns Grosuplje and Ivančna Gorica in the south and leads towards the mountainous areas of Zasavje and from there towards the Menina planina Plateau in the eastern Slovenian Alps. Important barrier that intersects this landscape connectivity area is the highway “Ljubljana-Novo mesto”.

Conducted management actions for improving landscape connectivity.

A number of small-scale green bridges are constructed on the highway section. However, currently it is unknown if this green bridges are functional in providing target species connectivity. A recent landscape connectivity study made by the Slovenia Forest Service (Javornik et al. in preparation) showed that the most important connectivity area is between Grosuplje and Ivančna Gorica at the villages of Peč and Višnja Gora. These area was therefore protected as wildlife corridor within the forest and wildlife management plans. However, at this location there are no existing green bridges.

Further actions for improving connectivity

A detailed study on the highway permeability is recommended focusing on the functional connectivity of the existing green bridges. A construction of green bridge at the villages of Peč and Višnja Gora should be considered.

20. THE "LJUBLJANA-JESENICE" HIGHWAY

The "Ljubljana-Jesenice" highway leads northwest from the vicinity of Ljubljana ("Sorško polje") towards Jesenice and Austria. It intersects and affects the connectivity between Julian Alps on the west and Karawanken Alps on the east.

Conducted management actions for improving landscape connectivity.

There are two important bridges on this highway located at Ljubno and Žirovnca-Moste. At both of these locations forest patches are connecting the valley. Therefore, we assess that both areas still provide functional connectivity (Javornik et al. in preparation). Therefore, forests in the functional vicinity of those locations are protected as wildlife corridor within the forest and wildlife management plans.

Further actions for improving connectivity

The protection of existing wildlife corridors should be maintained and deforestation of those corridors prevented.

Switzerland

Switzerland has a large number of corridors recognized by the Federal Roads Office (FEDRO) all over the country. All information about the status of the corridor with the cartography can be found on the cartography portal of the Swiss confederation. Link Interregional Wildlife corridors. Each corridor has a specific ID (i.e. corridor VD-22.1/VS-12). We are referring to this ID number through the text.

Furthermore, a program of remediation of a large number of corridors is under responsibility of the Federal Roads Office (FEDRO). Further information can be found on the link: Teilprogramm Sanierung der Wildtierkorridore 2021 (in German).

21. THE RONA RIVER VALLEY

Barrier in the Rona valley is around 80 km long and 1 km to 6 km wide. It consists of urban areas and agricultural land. The largest urban areas are located around the cities of Sion, Monthey and Sierre. A highway goes through the valley with no suitable tunnels or bridges for animal crossing.

Conducted management actions for improving landscape connectivity.

Three wildlife corridors exist in this section of the Rona River (from Chablais to Sierre). One green bridge has been built on Saint-Barthélémy River (corridor VD-22.1/VS-12) and was finished in 2021. Further north from this one (corridor VD-20.1), another bridge is in planned.

Further east in the valley, near to Sierre, another corridor does exist (corridor VS-42) which is currently disturbed mainly by vineyard surfaces. Major traffic disruptions (highway and rail are partially buried, which will improve the permeability of the corridor.

Further actions for improving connectivity

Construction of a green bridge is currently in the process of planning within the corridor VD-20.1 in the vicinity of the town of Chessel and Versvey.

22. THE THUNER- AND BRIENZERSEE BARRIER

This barrier consists of a densely populated area around the Thunersee and Brienzersee lakes. At the far north of the barrier there is the city of Thun. This barrier is around 55 km long and 1-10 km wide.

Conducted management actions for improving landscape connectivity.

Within this barrier three wildlife corridors are recognized by the Federal Roads Office (FEDRO). The first is in the eastern most part the barrier by Innertkirchen (corridor name BE-17). Within the BE-17 corridor no wildlife passage is necessary due to its intact status and because the barrier is passable (cantonal road). The connectivity in these corridors is so far provided.

Secondly, there is a wildlife corridor between the two lakes in the vicinity of Interlaken (corridor name BE-15). This corridor is largely interrupted and measurement for increasing landscape connectivity are needed.

Finally there is a third corridor (corridor name BE – 11a at Kiesen, north of Thurn.

Further actions for improving connectivity

Within the wildlife corridor BE-11a the construction of an underground wildlife crossing at Kiesen is in progress.

At Interlaken (BE-15) the construction of a wildlife crossing on the highway A8 is necessary but not yet planned by the FEDRO (Federal Roads Office) program. Wildlife-friendly development of the roadway and navigation channel environs should be undertaken. Nevertheless, further east of the corridor BE-15, the highway is partially buried which may serve as passage of large fauna.

23. THE "LUZERN BARRIER"

This barrier represents a densely populated area in the vicinity of the city of Luzern. It stretches from the cities of Sarnen on the west to Luzern in the north and from Schwyz on the east to Altdorf on the south.

Conducted management actions for improving landscape connectivity.

In this area, there are several wildlife corridors recognized. Due to urbanization and agriculture development these wildlife corridors are mainly interrupted and disturbed. In some of them green bridges were already build to facilitate large mammal's connectivity and others have no measures planned yet:

- In the corridor OW-2 the study of a wildlife crossing bridge is in progress (status July 2021).
- Corridor SZ-05: the construction of a wildlife green bridge at Röten Goldau is in progress.
- Corridor ZG-06: the study for a wildlife bridge at Bürglen Risch has been approved.
- Corridor LU-02: the construction of a wildlife bridge in Neuenkirch is in progress.

Further actions for improving connectivity

Corridor SZ-06: currently no measures are planned but corridor is included in the FEDRO (Federal Roads Office) remediation program. Improvements of the under passage or the construction of a wildlife bridge are proposed but not planned yet. The current status of the corridor is largely interrupted.

The following corridors all have a disturbed (but not interrupted) status and have no measures planned and are not included in the remediation program of the FEDRO: SZ-04; AG-28/LU-01/ZG11; LU-22; LU-23; LU-03; LU-04; LU-24; LU-09. Still, wildlife should be able to cross and the connectivity more or less provided.

24. THE UPPER REN VALLEY – WALENSEE BARRIER

This barrier stretches from Obersee lake across Walensee lake and up the Ren valley to the city of Chur. This barrier is connected to the "Ren valley" barrier, which crosses the territory of Switzerland, Lichtenstein, Austria and Germany (see Liechtenstein). This barrier is approximately 87 km long and 1-7 km wide. A highway runs through the whole barrier with no suitable large-scale crossings for wildlife within our analysis.

Conducted management actions for improving landscape connectivity.

In this area, there are several wildlife corridors recognized. The following wildlife corridors within the barrier are not interrupted and because of this have no improvement programs:

- GR-02: intact corridor due to a wildlife bridge already constructed prior to the FEDRO remediation program.
- SZ-01 and SZ-03: intact corridors.

- GL-05: corridor disturbed but no improvement program planned.
- GR-45/SG-06: corridor disturbed but no improvement program planned.

Disturbed corridors should still be more or less crossable for wildlife even if barriers and disturbances in the area are not unneglectable.

Other wildlife corridors are currently part of the FEDRO remediation projects:

- GL-07/SG-02/SZ-07: remediation of a lower wildlife crossing completed.
- GR-01/SG-26: Landscape connectivity improvements completed.
- SG-06: Landscape improvements completed.
- SG-09: Landscape improvements on the existing cantonal road bridge completed.
- GR-06: Wildlife bridge is planned: preliminary design study in progress.
- GL-06: Wildlife bridge is planned: preliminary design study in progress.
- SG-04: Wildlife bridge is planned: preliminary design study in progress.
- SG-07: Wildlife bridge is planned: preliminary design in progress
- SG-08: Wildlife bridge is planned: preliminary design in progress.
- GL-04: Wild warning system: not planned yet but foreseen in the FEDRO remediation program.

Further actions for improving connectivity

Following actions for existing wildlife corridors are planned within the FEDRO remediation projects:

- SZ-11/SG-27: Upper wildlife crossing planned but studies did not started yet (study starts in 2023 and construction in 2031).
- GR-06: Green bridge is planned: preliminary design study in progress.
- GL-06: Green bridge is planned: preliminary design study in progress.
- SG-04: Green bridge is planned: preliminary design study in progress.
- SG-07: Green bridge is planned: preliminary design in progress
- SG-08: Green bridge is planned: preliminary design in progress.
- GL-04: Wild warning system: not planned yet but foreseen in the FEDRO remediation program.

25. THE “WINTERTHUR-ZÜRICH-ZUG HIGHWAYS” NETWORK

This barrier consist of a network of highways around Zürich, Zug and Winterthur. These highways are important as they intersect a number of forested ridges connecting Alps with Jura mountains. There are two important continuous areas that could serve as potential corridors connecting Alps and Jura. One goes west from Zürich and Obersee Lake and the other east, near the city of Winterthur. The later corridor, which leads to the Churfirsten ridge in Alps is wide and more connected, but is intersected with two highways near Winterthur. In addition, the Churfirsten ridge is cut off from the rest of the Alps with the Ren valley and Walensee barrier (number 24.). The western corridor runs thought more fragmented forested landscape, but is more connected to Alps with high density of suitable highway crossings.

Conducted management actions for improving landscape connectivity.

Within the barrier several wildlife corridors are recognized by the FEDRO (Federal Roads Office) – see below. For more details about the status of corridors in this barrier see link: Interregional Wildlife corridors .

Further actions for improving connectivity

Within this highway network, some wildlife crossing projects are included in the FEDRO remediation program:

- ZH-18: Green bridge projects with studies not yet started.
- ZH-20: Green bridge projects with studies not yet started.
- ZH-21: Green bridge projects with studies not yet started.
- AG-29: Green bridge not yet planned but in the program foreseen.
- AG-01: Preliminary design underway.

Other corridors are already largely interrupted and there are no remediation projects at this time:

- For example ZH-09.

26. THE LUGANO-BELLINZONA BARRIER

The valley of Lugano, Lugano lake and the city of Bellinzona represent a west-east barrier that is more than 80 km long. Together with “lake Como” and “lake Maggiore barriers” (both in Italy see, numbers 16. and 17.), the “Lugano-Bellinzona barrier is representing a network of barriers in central-southern Alps. All three valleys are representing a movement barrier running west-east. The direction south-north however is well connected.

Conducted management actions for improving landscape connectivity.

North of Lugano, the corridor named TI29-30 has been remediated with a green bridge above the highway A2. This green bridge and the corridor are supposed to connect the Lugano and Bellinzona areas. North of Bellinzona the landscape connectivity is the most interrupted; two of the wildlife corridors in this area are largely interrupted (TI-24 and TI-21,-25).

Further actions for improving connectivity

For this barrier, the landscape connectivity is not studied in details and projects are quite scarce. Some further actions on improving connectivity are still planned:

- TI-15-19: Arrangement works are in progress.
- TI-20/GR-11: A preliminary project for an ecological under passage is in progress.

The TI-24 is largely interrupted but no remediation project is planned in this corridor. Same for TI-44, TI-21,-25.

27. BERNESE, PENNINE AND GRAIAN ALPS

The Bernese and Pennine Alps in Switzerland are together with the Graian Alps on the border between Switzerland and France the largest areas of higher altitudes in the Alps (Figure 6). Nevertheless, they are natural (geomorphological) barriers that should be taken into account when considering large carnivores, red deer and wild boar connectivity, because such altitudes are considered to be unsuitable habitat for those species.

Conducted management actions for improving landscape connectivity.

None (natural barrier).

Further actions for improving connectivity

None (natural barrier).

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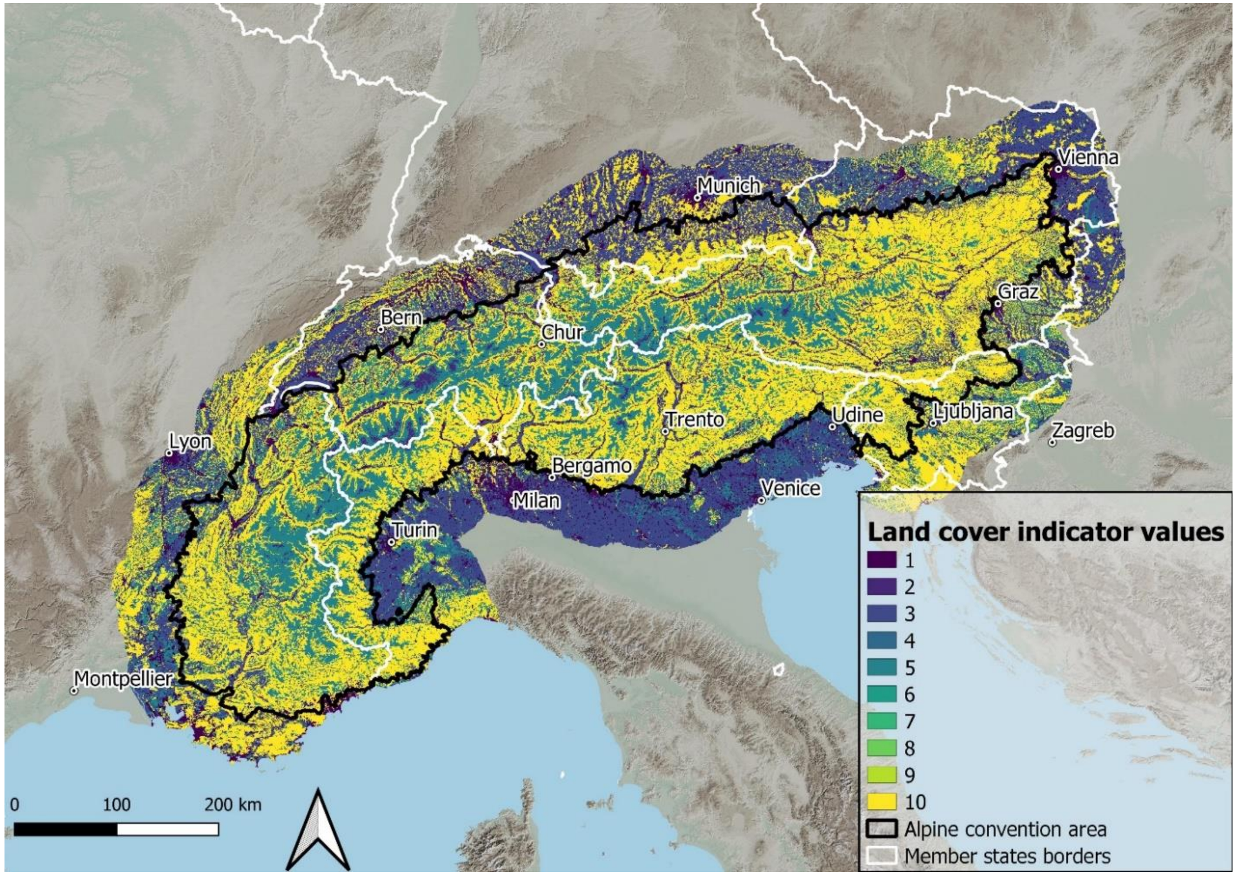
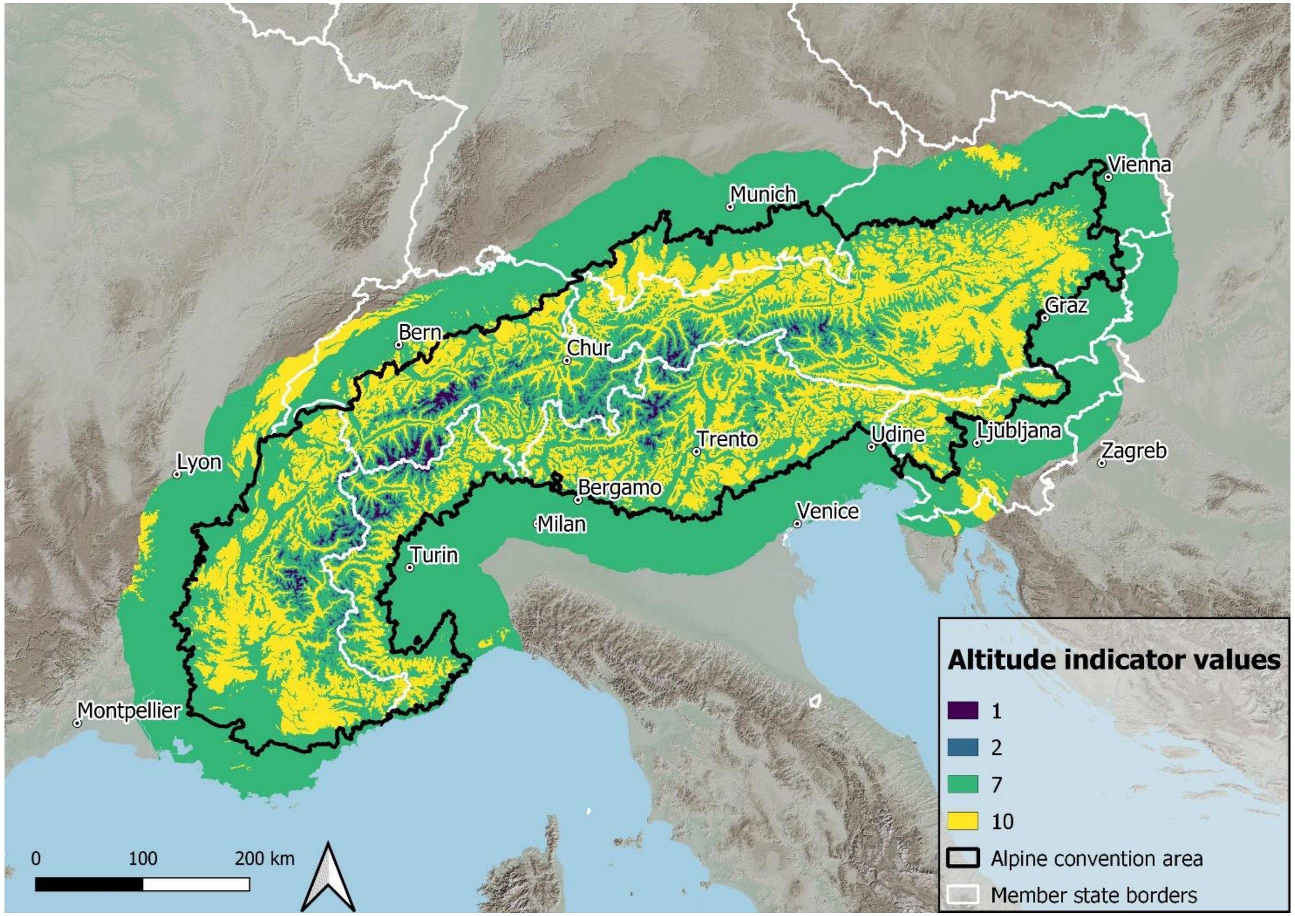
ANNEX 1



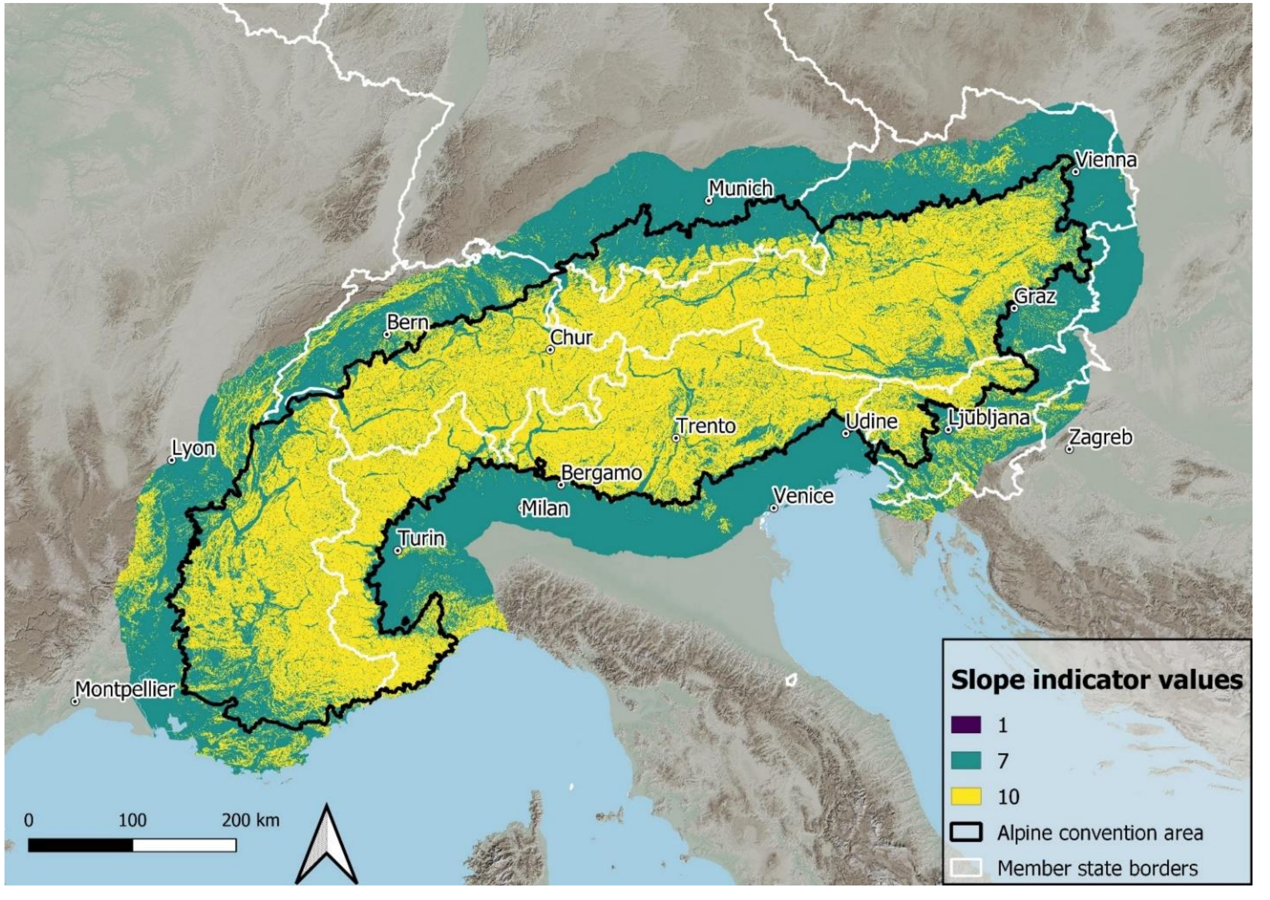
Map of Corine land cover indicator values used in our CSI modelling for large carnivores and wild ungulates in the Alps. The indicator values are shown for the Alpine convention area perimeter with the functional surroundings (50 km buffer).

ANNEX 2



Map of Altitude indicator values used in our CSI modelling for large carnivores and wild ungulates in the Alps. The indicator values are shown for the Alpine convention area perimeter with the functional surroundings (50 km buffer).

ANNEX 3



Map of Slope indicator values used in our CSI modelling for large carnivores and wild ungulates in the Alps. The indicator values are shown for the Alpine convention area perimeter with the functional surroundings (50 km buffer).