Interreg Alpine Space

Co-funded by the European Union

PlanToConnect

Ecological connectivity analysis in the South of lake Annecy, France

Mapping report identifying the GBI elements, barriers, connectivity measures in pilot areas

Activity 2.3 Case Studies 2nd step: To design a GBI network for connectivity across administrative boundaries or transnational cross-border areas in pilot sites

Reference in AF: D.2.3.1

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GLOSSARY

CIRCUIT THEORY METHOD

The introduction in 2008 of the circuit theory method as an alternative from the least-cost path method provided more accurate mapping patterns of movement of animals' route within an area. Inspired by electrical circuits, several paths are drawn by this method. It relates to the resistance distances on how an individual will behave from one point to another, assuming that the least resistance will be the path mostly chosen.

DARK INFRASTRUCTURE

"Can be defined as an ecological network of habitat patches (cores) interconnected by corridors for different environments, identified based on a level of darkness which is sufficient for nocturnal biodiversity." (Sordello *et al.*, 2019)

FOCAL SPECIES OR SURROGATE SPECIES

Considered as synonyms. "First used in the 1980s then theorised in the 1990s, these terms define many concepts used to concentrate certain aspects of an ecosystem in one or a few species, making it easier to study, understand and monitor, for research or for actual conservation" (Ducarme *et al.*, 2013)

GREEN AND BLUE INFRASTRUCTURE

Green infrastructure has been defined as "A strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity. This network of green (land) and blue (water) spaces improves the quality of the environment, the condition and connectivity of natural areas, as well as improving citizens' health and quality of life." (European Commission).

LEAST-COST PATH METHOD

Introduced in the 1990's in the field of biodiversity conservation, this method aims at finding the most cost-effective path from a starting point to another. However, it assumes that an individual will always choose and have the perfect knowledge of the most effective path, which is not in sync with reality (Dickson *et al.*, 2019).

NAP - NATIONAL ACTION PLAN

NAP is a guidance documents on biology conservation of species most at threat on a territory, based on Natura 2000 lists of species.

NNR - National Natural Reserve

Direct translation of the French designation “Réserve Naturelle Nationale”, NNR is one of the highest levels of protection of a territory in France alongside National Natural Parks and Integral Reserves. The specificity of a Natural Reserve is to have its own local environmental regulation and laws within its territory. Human activities are regulated or can be forbidden in some parts. National or regional funding, staff and a management plan are dedicated to the site and contribute to protect, manage and raise awareness.

POBP - Prefectoral Order of Biotope Protection

Direct translation of the French designation “Arrêté de protection de biotope”. It is a prefectural order with specific environmental laws applied to a territory for the protection of mineral and natural habitats. The POBP does not have a management plan, staff or funding.

SCOT – Pattern of territory consistency

Direct translation of the French designation “Schéma de Cohérence Territoirale”. It is an urban planning gathering several municipalities.

SRADDET – Pattern of regional planning and sustainable development of territories

Direct translation of the French designation “Schéma régional d'aménagement, de développement durable et d'égalité des territoires”. Management plan at a regional scale aiming for a global consistency of territories. Local plans must be aligned to the SRADDET’s purposes. Within the SRADDET, Green and Blue infrastructures are identified and are compulsory to take them into account in local planning.

EXECUTIVE SUMMARY

The study is an applied modelling of ecological connectivity in priority areas in the South of Lake Annecy.

Main issues of connectivity in the pilot area is the presence of major natural areas with rich biodiversity surrounded by urban areas and an anthropic great lake that can create an insulating effect. Poor connectivity of corridors can be caused by urban sprawling, downgrading of agricultural and natural lands into urban one on local urban planning and increase of road users.

Four areas are concerned by these issues and will be most particularly studied in this document because of their status of either protected or managed areas.

The study aims at locating disrupted corridors. We chose to study only green and blue infrastructures, categorized into three categories: Forest habitats, Open land habitats and Blue infrastructures.

To build our model we will try two different technics, the least-cost path modelling method and the circuit theory method, run by the software Graphab and Circuitscape. Both technics represent the behaviour of terrestrial animals trying to move from one place to another.

Cartographic modelling will allow to identify at a local scale the different paths of corridors, their disruption and to prioritise them in the study area. It represents a first step before assessing if they need to be maintained, protected or restored. We will most particularly focus our attention on the connectivity between protected and managed natural areas.

REPORT

1 Introduction

1.1 About the area

Annecy's basin is located in the Northern-West side of the French alpine region and is at the end of the Alpine range, a location called Alpine foothills and characterised by limestone mountains.

The region has a continental climate but the presence of elevated altitudes leads to a high range of micro-climates and temperature differences between north and south facing slopes, or summits and valleys. It results in a high diversity of natural habitats and landscapes with 14 different units identified in Annecy's basin (SRADDET, 2023)

Three main landscape units can be identified in this area:

- Low hilly reliefs, from 400m to 700m, with a high number of villages and extensive agriculture fields,
- The lake, which represents by itself a natural entity, bordered by rivers, wetlands and riparian habitats. Its surrounding is highly urbanised and the city of Annecy is located in between the lake and the previous landscape.
- The South-East is represented by limestone massif of Bornes and Bauges from a height of 450m to 2 350m. Villages are scarcer in this area and mostly located at low altitude (less than 1 400m).

The territory is composed of 41% of natural areas and 20% of the territory is identified by the regional plan as a biodiversity reservoir (SRADDET, 2020). At a regional scale, Annecy's basin plays an important role to link alpine habitats and the habitats of Rhone's valley.

At a smaller scale, differences of landscape are also visible throughout differences of land use. In the valley, the land use is mostly characterised by villages, urbanised areas and agricultural lands (SCOT, 2023).

On first slopes, the landscape is more diverse with smaller fields, hedgerows and forests.

At mid-mountain level, the forest is highly represented on the slopes, whose growth were favoured by its low accessibility and an abandonment of these areas for human activities.

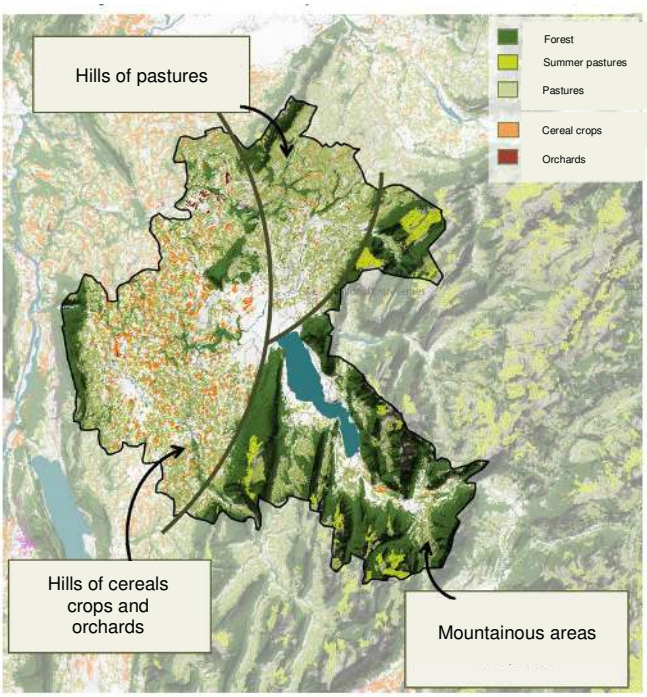


Figure 1: Major land use in the SCOT of Annecy's basin

Most of the urban sprawl is located next to Lake Annecy. Urban areas are constrained by mountainous areas and the lake, gathering all the urbanisation in valleys where some important places for ecological connectivity are located. Urban landscape is described in the regional planning document as an exploded view and dissolute urbanisation around historical villages (SCOT, 2023).

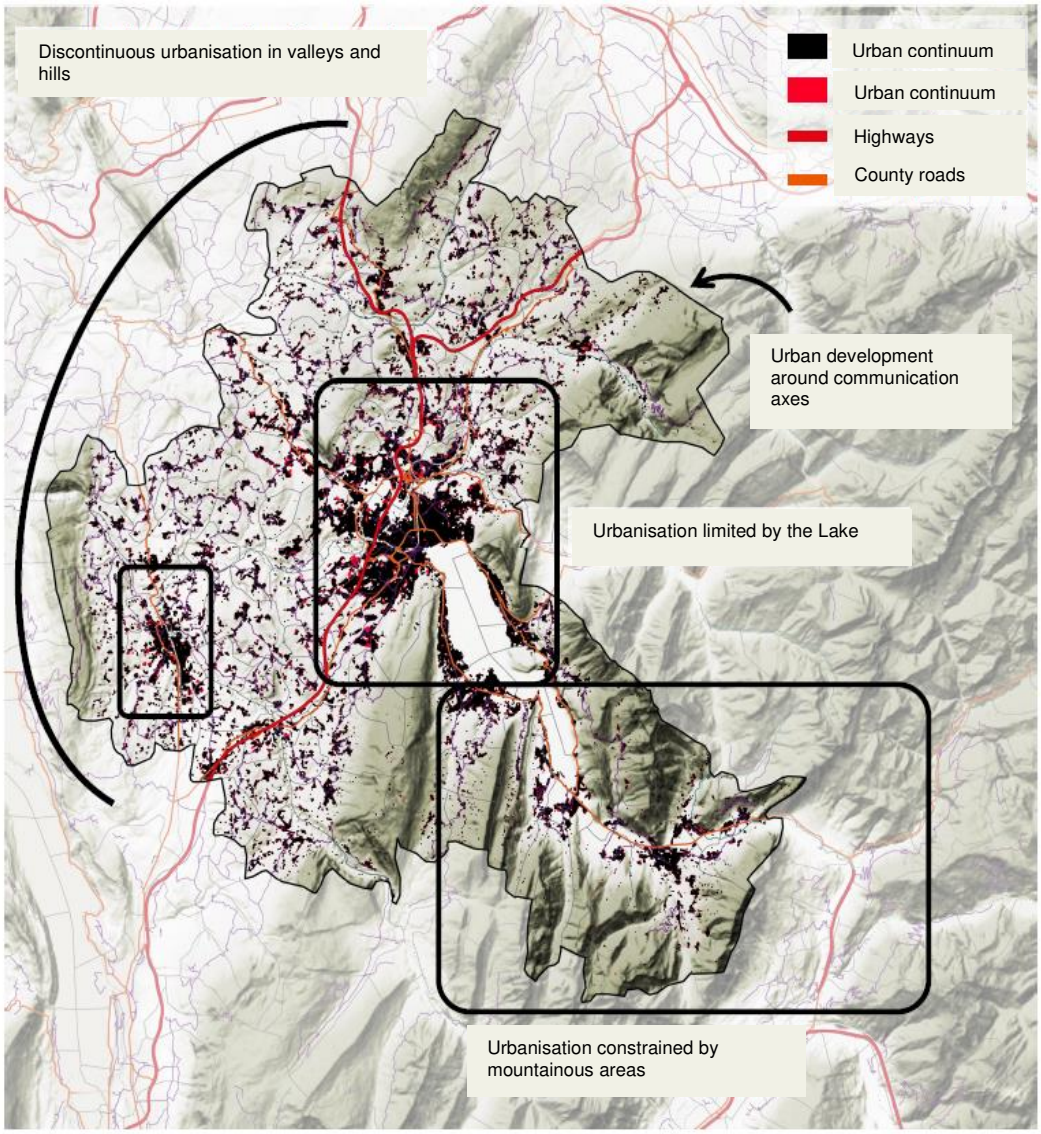


Figure 2: Urban areas in the SCOT of Annecy's basin

Several protected areas and natural valuable areas are identified in Annecy's basin with different levels of protection:

- Natural reserves have one of the highest level of protection in France, characterised by their own local regulation and dedicated guards to assure law enforcement,
- Several Sensitive Natural Areas, Prefectoral Order of Biotope Protection with a medium level of protection through land ownership and law enforcement,

- Several Natura 2000 sites and a Regional Natural Park with low protection characterised by managed areas where biodiversity is taken into consideration in local planning.

Protected areas and natural valuable areas represent biodiversity reserves in the regional plan (SRADDET) and contribute to maintain valuable core areas of biodiversity.

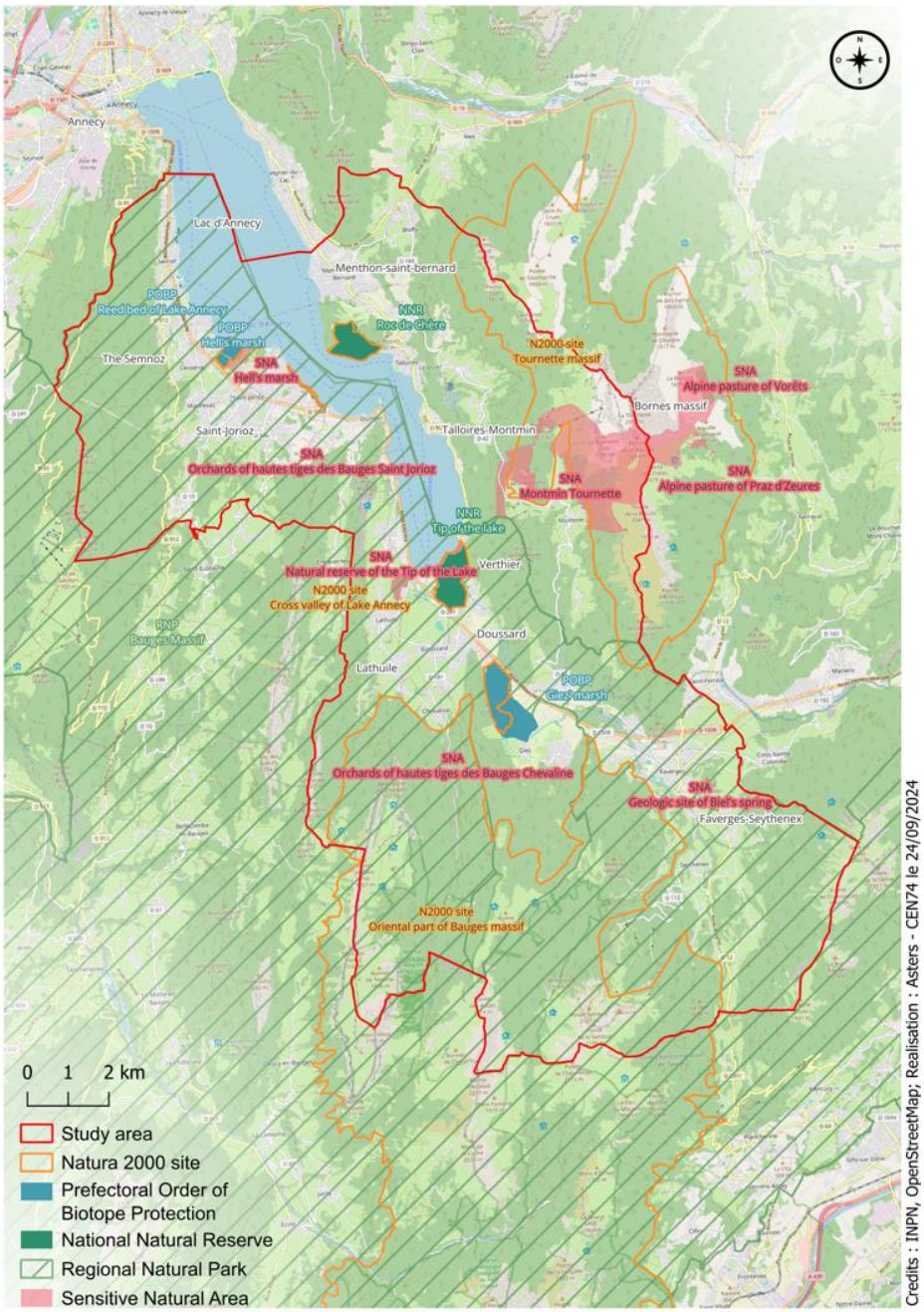
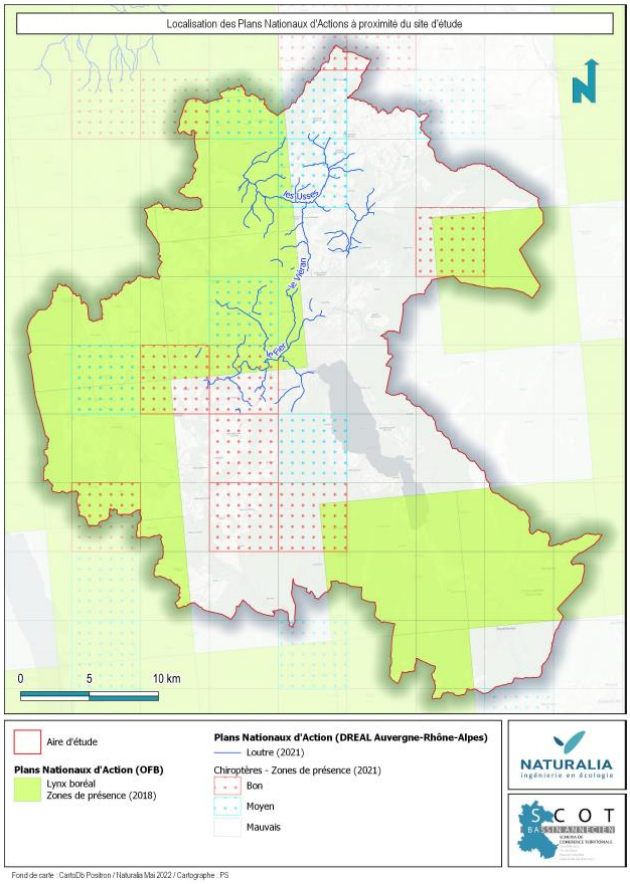
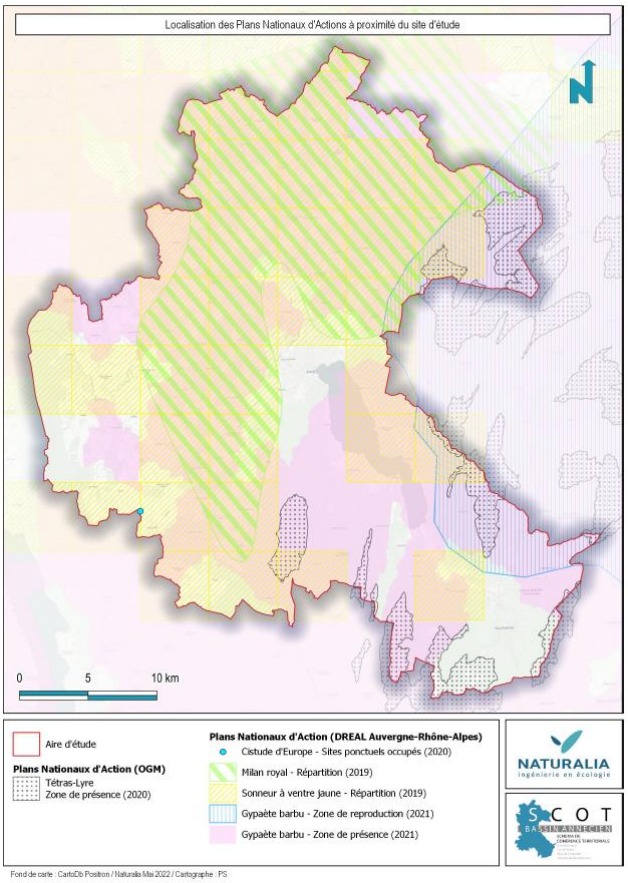


Figure 3 : Protected areas and natural valuable areas within the pilot site

Two National Action Plans are located in the pilot site. One in the South of lake Annecy indicates that lynx (*Lynx lynx*) are roaming within the area, the other concerns the middle part of the lake and its surroundings where Yellow-bellied toad (*Bombina variegata*) is located.





1.2 Objectives for the pilot area

Asters CEN74 plans to carry out a study on ecological connectivity and the functionality of green and blue infrastructures around Lake Annecy, the pilot area.

Two main issues of ecological connectivity are identified within that area. One is the presence of major natural areas with rich biodiversity surrounded by urban areas and a great lake that can create an insulating effect.

Four areas are concerned by this issue and will be most particularly studied in this document. It includes two highly protected areas, the National Natural Reserve (NNR) of Roc de Chère and the NNR of the tip of Lake Annecy, where the study of RECO-crapaud has been conducted. We will also focus our attention on two managed areas, the Prefectoral Order of Biotope Protection (POBP) of Giex's marsh and POBP of Hell's marsh. All sites are managed by Asters CEN74 which allows us to have a better understanding of ecological

dynamics surrounding and within these areas. We chose boundaries of our pilot area based on these 4 areas to assess mostly corridors linking these areas together.

The other issue of ecological connectivity is the constraint for terrestrial fauna to move from a direction East-West. Main factors of poor connectivity between ecological infrastructures in the South of Lake Annecy are urban sprawling, downgrading of agricultural and natural lands into urban ones on local urban planning and the increase of road users.

The results of the modelling work can be integrated into future management plans or help decision making for local governments. Allowing a better connection at a local scale for species to move within the territory also enables to preserve metapopulations of European common species and habitats represented at a European alpine scale.

2 Pilot area

2.1 Connection to the SACA

The pilot area is located in the French Alps at the East of the Alpine convention and Alpine space as represented in figure 4.

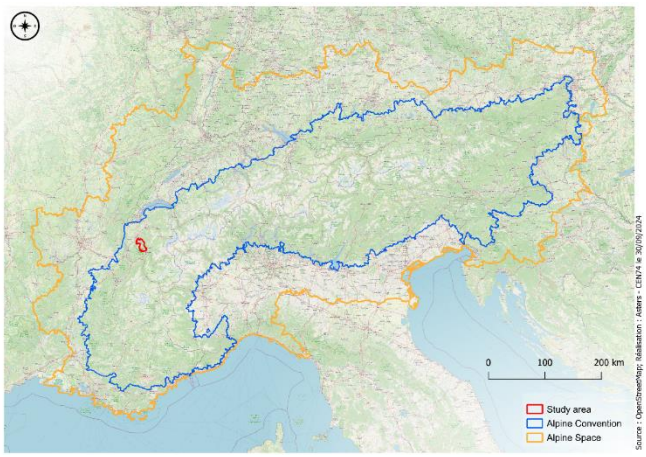


Figure 4: Location of pilot area in the context of The

In the identification of Strategic Alpine Connectivity Areas (SACA), the pilot region has mostly areas categorized as having an importance for connectivity (SACA 2). That broad analysis needs to be more accurately defined which is the purpose of this report.

Identification of SACA 1 is coherent with the local planning map but could be extended to wider areas as well as for SACA 3 which lacks details on the surroundings of the lake, where connectivity restoration needs to be represented on broader areas (figure 7).

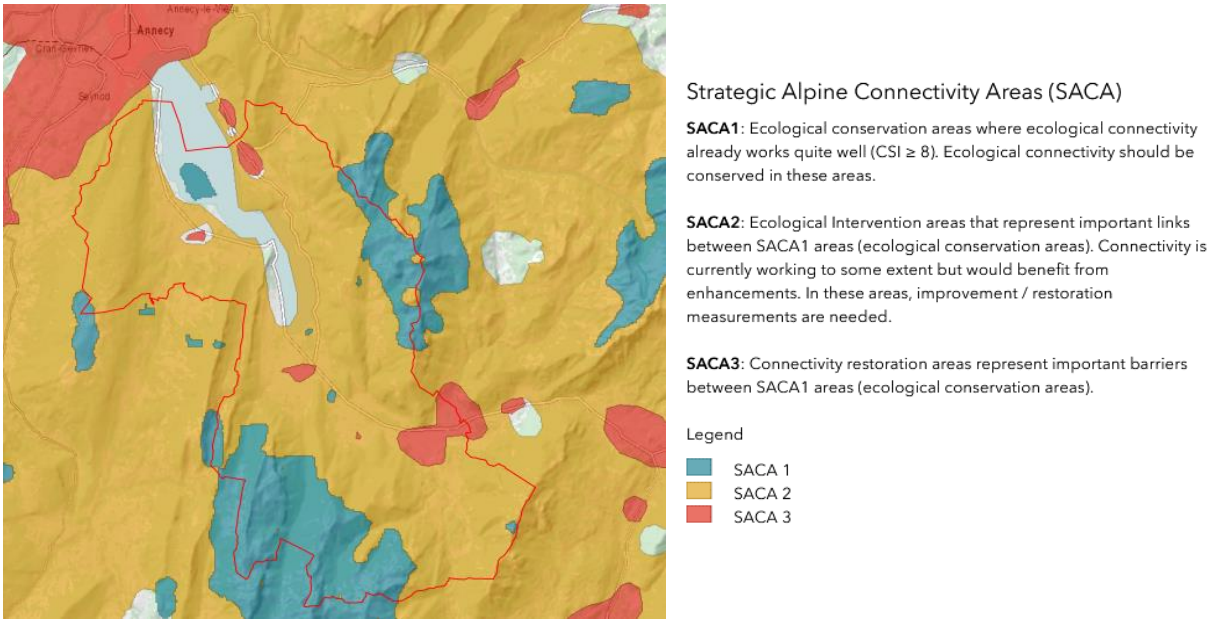


Figure 5: Overview of the pilot area in the context of SACA 1 to 3

The pilot area is located in the South of Lake Annecy and plays a strategic role at a local and inter-municipal scale for connectivity conservation.

Lake Annecy represents by itself a physical entity that restrains terrestrial animals to move through the lake. Although animals like deers and wild boars could possibly cross the water, many other smaller species would not be able to swim. Nautical activities also prevent passing through the lake or increase risks of drowning, impacts with boats, etc…

The lake can therefore be considered as a natural structural barrier for some species that lead terrestrial animals to two other areas if they need to cross in an East/West direction.

Either they head towards the North where they will find the urban area of Annecy's city. The urban area spreads widely around the North tip of the lake, urbanisation is dense and roads are numerous. Any animals wanting to pass through that anthropic barrier would be threatened by road impacts, getting lost, etc…

Either they pass by the South of the lake that is the most reasonable path to take for a terrestrial animal wanting to go to a direction East-West.

We will therefore focus our connectivity analysis on these two main corridors of interest where all the stakes seem to converge. Each have been identified in the least-cost path analysis of SACA (figure 6).

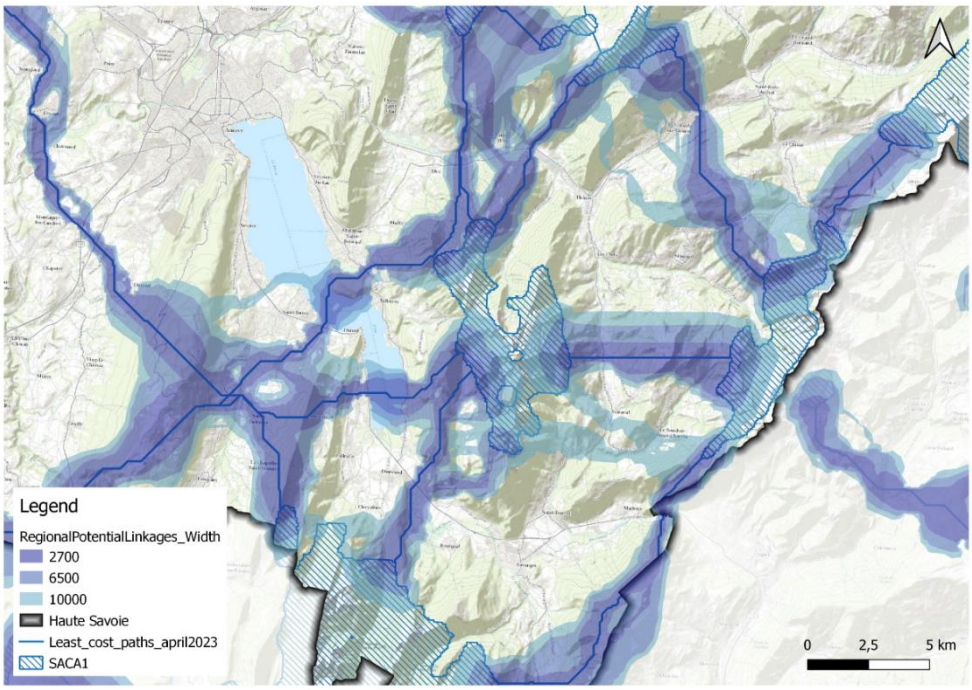


Figure 6: Regional potential linkages identified in the SACA 1 by the least cost path method at a global scale

The map from the regional planning document (SRADDET) identifies the same terrestrial corridors as SACA, except it does not take into account the crossing of the lake as a potential path.

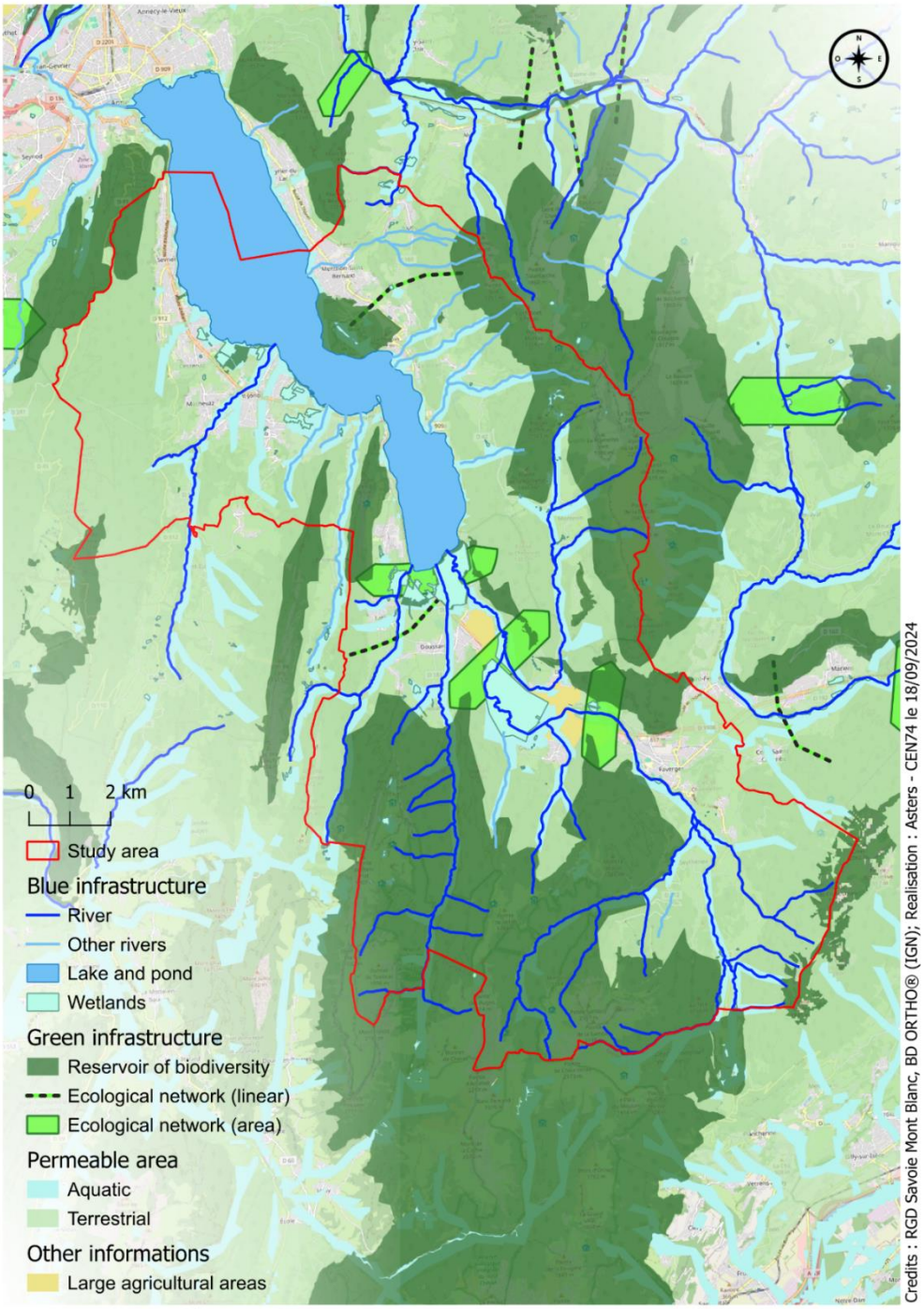


Figure 7: Ecological structures and main corridors identified at a regional scale in the regional planning document (SRADDET)

2.2 Characteristics of the land cover

The pilot region gathers a total of 21 683 hectares and encompasses 11 municipalities and 2 inter-municipalities.

Forests are the main component of the landscape, gathering almost 58% of the overall land cover. Hardwood trees are the most represented with 39% of coverage whereas softwood trees represent around 18% coverage. Most of natural areas, combined with other natural elements such as permanent meadows or bare rocks, are located in altitude, on the less accessible lands for human activities.

Therefore, even if natural areas are highly represented in the land coverage most of the continuity issues are gathered within the valleys where anthropogenic structures are the most represented such has urban continuum and discontinuity, roads or maintained grasslands.

In the valley, cultivated areas are also highly represented with 13% of the land coverage. These areas can either represent a barrier for continuity if it has fences or a permeable habitat to pass through.

Table 1: Habitats and their surface area

Main GBI Category	Area (hectare)	Percentage (%)
Lake	1910	8.81%
River	28	0.13%
Pond	2	0.009%
Wetland	1	0.005%
Maintained grassland	169	0.78%
Cultivated areas	2914	13.44%
Permanent meadow	1555	7.17%
Temporary meadow	22	0.10%
Bare rocks	516	2.38%
Mixed forest	151	0.70%
Softwoods	3857	17.79%
Hardwoods	8463	39.03%
Forestry	1	0.005%
Urban discontinuity	301	1.39%
Urban continuum	1481	6.83%
County road	123	0.57%
Local road	23	0.11%
Greenway	166	0.76%
Sum	**21 683**	**100,00%**

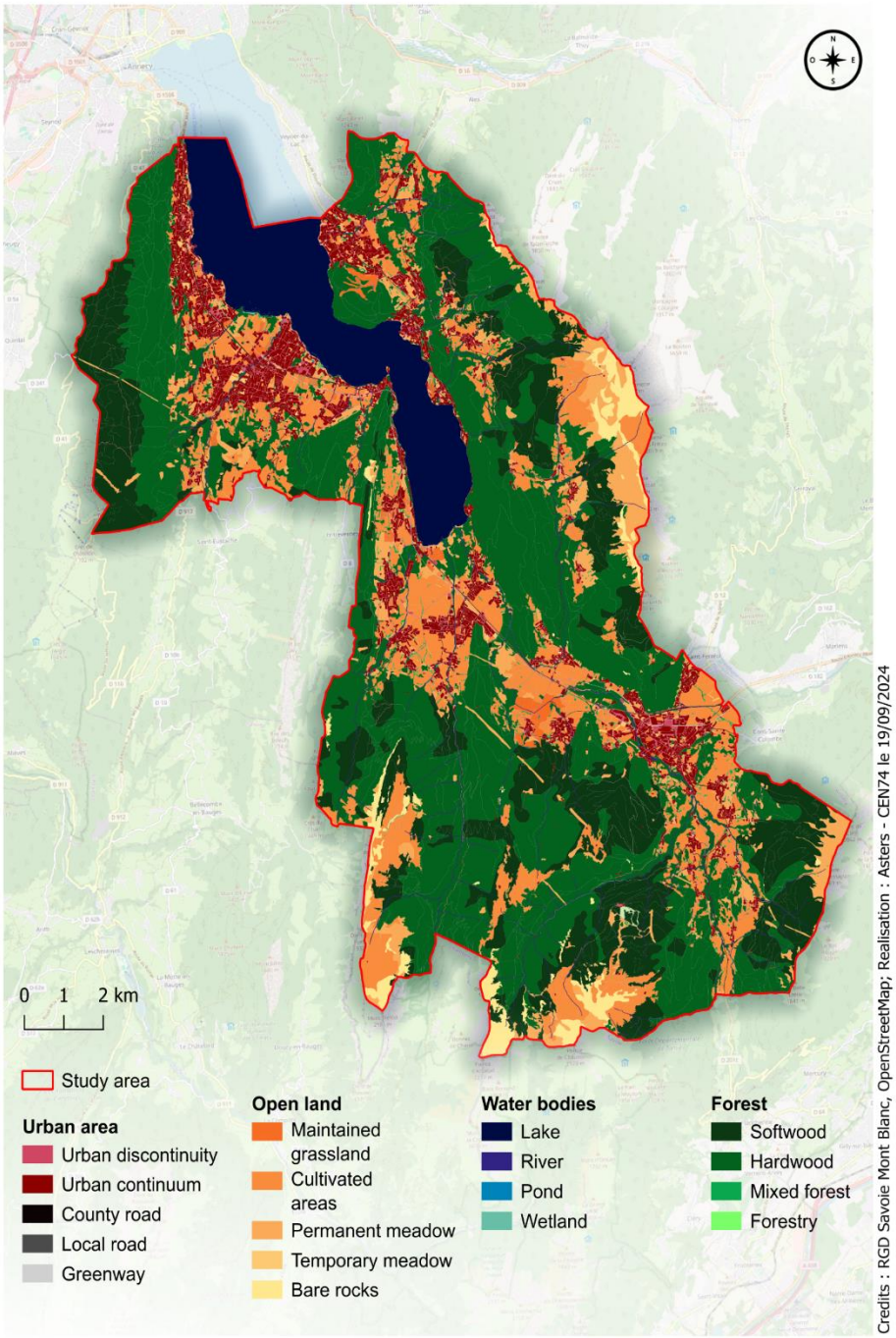


Figure 8: Land cover within the pilot area

On the land cover map, natural areas were listed in three main categories (Open land, Water bodies and Forest) that will be later used for cartographic analysis.

2.3 Stakeholders

Key stakeholders involved in the RCWG come from:

- Local public authorities (Direction Départemental des Territoires (DDT), Grand Annecy, Communauté de communes Sources du Lac, Syndicat intercommunal du lac d'Annecy (SILA)),
- Regional public authorities (Region AURA),
- Firm (SCIMABIO),
- Local NGOs (LPO74)

Most of the lands are private, representing 50,7% of the land ownership in the pilot area, whereas public lands represent 31,3% of the territory. Some non-corporate entities own 18% of the land. They include government substitute institutions such as The National Office of Forest (ONF).

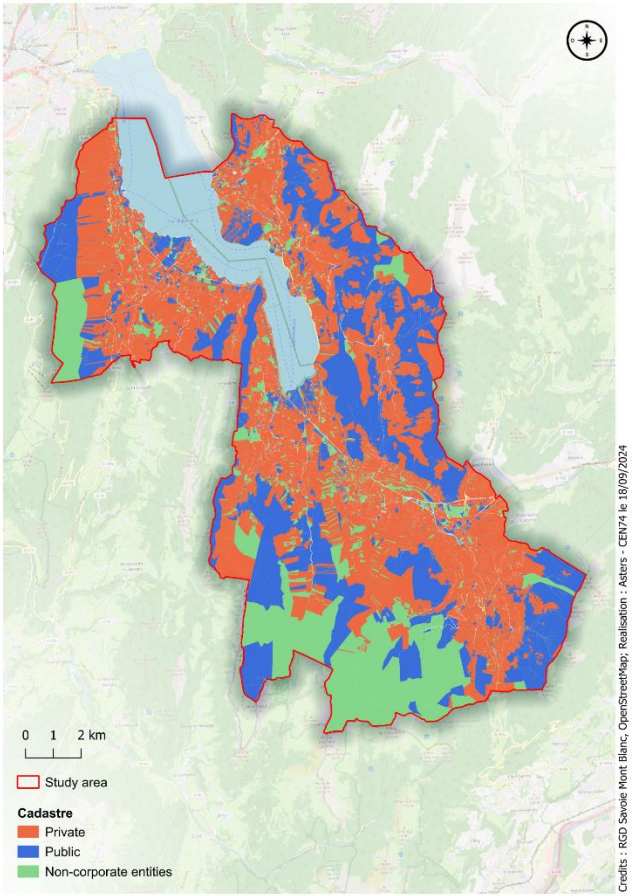


Figure 9: Land ownership representation on the pilot region

3 Methodical approach

The objective of this project is to analyse landscape frameworks to better understand the ecological connectivity issues within the pilot site. We will focus our attention on structural connectivity, where habitats can be fragmented, scarce or threatened, leading to a loss of functional interaction between species. The method used is an applied cartographic model of ecological connectivity in priority areas around Lake Annecy.

We will focus our approach on broad habitat protection of different types of habitats such as forests, hedgerows, wetlands, grasslands in order to protect species passing through or living in it. We excluded a species approach analysis.

The cartography of the functionality of corridors has already been made by Asters CEN74 in 2009 for the regional planning document (SCOT) by B. Bal. and N. David. They used land cover to assess the permeability of habitats and show disrupted corridors in Annecy's Basin. We will take inspiration from that study at different levels and update the data (See Annex 1).

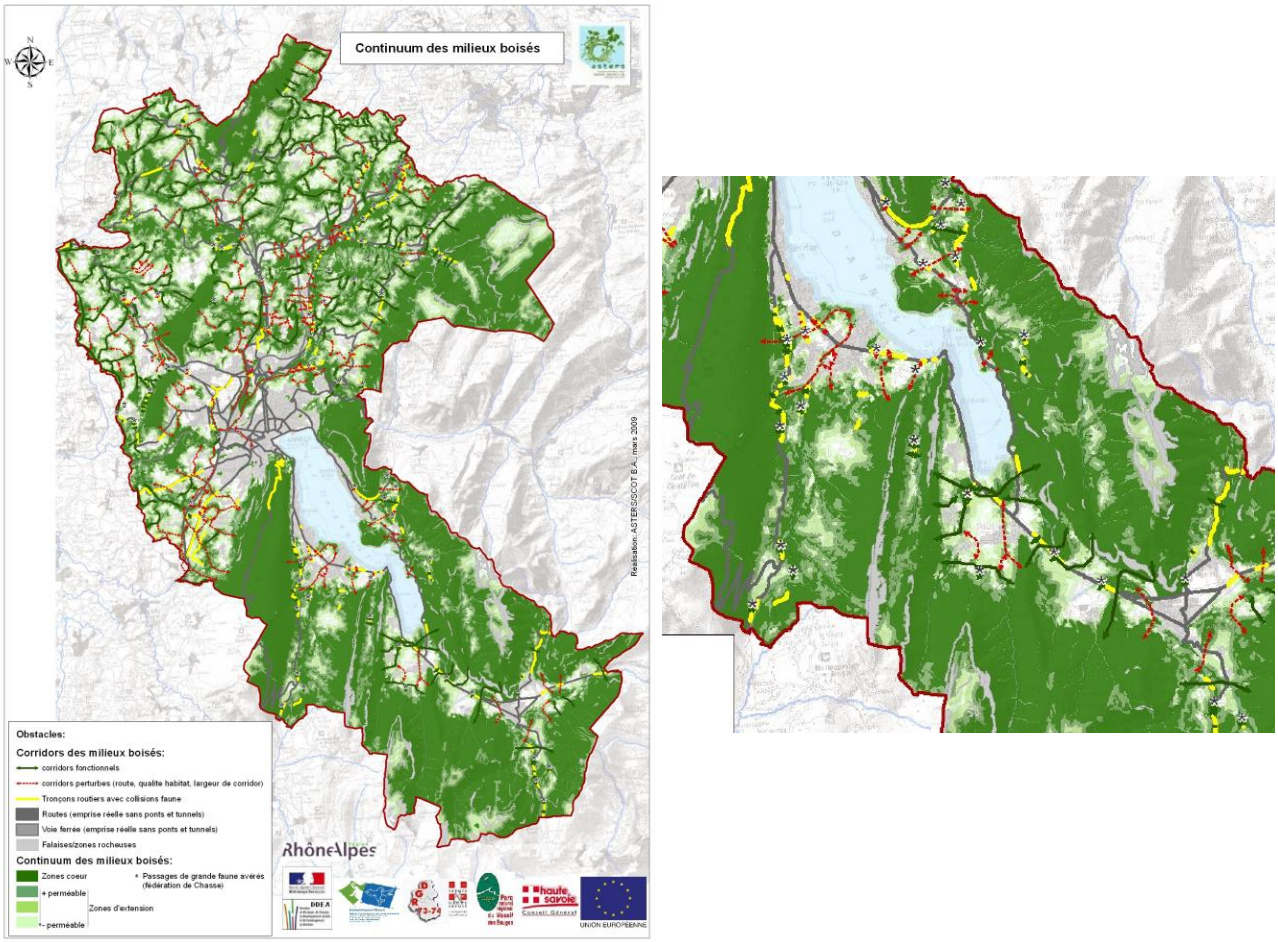


Figure 10: Corridor functionalities in B.Bal study, 2009 and a zoom on the location of the pilot area

We will at first take the same categorisation of habitats as their study, splitting the green infrastructures in two categories, the Forest and Open land habitats, and we will have a third category for the blue infrastructures. The analysis of dark corridors will be excluded due to our need to narrow our subject and to focus on specific criteria to try our methods.

Then as in the study of Bal B., we will assess permeability of each land cover (see 3.5 part) based on their matrix table, but we will modify it to fit to our own land cover qualification.

Finally, we will use the least-cost path modelling as B. Bal did, but we will also compare it with another model, the circuit theory method of Circuitscape. Both technics aim at representing the behaviour of animals moving from one place to another, but differ by their representation.

3.1 Working steps

Table 2 : General working steps

Working Step	Description
1. Assessment if protected areas are correlated to biodiversity reservoirs in the SRADDET	List of protected areas: • SPA: special protection area from Natura's 2000 network • SAC: Special Area of conservation from Natura's 2000 network • ZNIEFF 1 & ZNIEFF 2: Natural area of ecological, faunal and floristic interest • POBP: Prefectoral Order of Biotope Protection • NSA: Natural Sensitive Area • NNR: National Nature Reserve
2. Compilation and analysis of GBI elements within the corridor (connectivity evaluation)	All GBI elements within the corridor are listed and summarised according to the main categories. A land cover map is created for every theme (urban areas, blue infrastructures, forested habitats, open land habitats).
3. Definition / refinement of objectives for ecological connectivity	Our objective is to identify connections between natural areas and to locate where ecological networks can be improved. Our main natural areas will be biodiversity reservoirs from the SRADDET.
4. Compilation and analysis of regional and local data	Multiple data sources are used, a regional one made by the county of Haute-Savoie and a national one, the BD TOPO made by IGN. The first one was mostly used, the second helped to bring more cartographic precisions (for road qualification and forest habitats for example).
5. Barrier Analysis	Identification of continuity's threats such as road network, anthropic barriers and urbanisation.
6. Land use qualification on ecological and network interest	Comparison of land cover data with BD TOPO by IGN to improve our land use data (mostly for forest habitats and road qualification by creating different ranges of roads and habitats).
7. Identification of permeability of habitats	We give grades of permeability to each land cover depending on categories of habitats. Those grades are based on the resistance matrix adapted from B.Bal, 2009.
8. Use Graphab to create network graph	We run the model of the least cost paths based on the permeability grades and create 3 maps.
9. Use Circuitscape to create network graph	We run the model of the least cost paths based on the permeability grades and create 3 maps.

Working Step	Description
10. Use both analysis to solve connectivity problem and exploit connectivity potential	Identification of main corridors, their potential disruption and priorities areas. It can lead to suggestion of connectivity improvements to local authorities through protection of key areas, restauration of habitats, road signalization, etc…

3.2 Data used

A compilation of data was made from the regional land cover and agricultural practice analysis (DDT Haute-Savoie, DREAL). National data was used for agricultural practice analysis, protected areas, toponymy, administrative borders (INPN, IGN, DDFiP). Some local field data from our association was also used. We used a raster resolution of 1mx1m.

Table 3 : Summary of data used for the cartographic work

Source	Data
DDT Haute-Savoie	Land cover 2023
INPN	Protected Areas (N2000, POBP, SNA)
IGN BD TOPO	RNP
IGN BD TOPO	Municipalities
IGN BD TOPO	Places names
Asters CEN74	National Natural Reserve
Asters CEN74	Wetlands
DGFiP	Cadastre 2024
IGN	RPG 2023 (agricultural practice analysis)
DREAL	Green and Blue Infrastructure from SRADDET 2020
ONEMA	Flow obstacles

3.3 Land cover identification

All GBI elements (based on the categories of the Land cover layer made by the Departmental Territorial Directorate in 2023) within the corridor are listed and summarised according to the main categories. We used the habitats listed on the table below.

Table 4: Habitat definition

	Habitat definition	Surface area	Percentage (%) of the whole area
Permanent meadows	Areas where the herbaceous plants are natural but maintained as permanent grasslands by less intensive agricultural activities. There is also included marginal grasslands: abandoned crop invaded by grasses; areas near roads and other infrastructures; abandoned dumping sites, etc. Alpine and sub-alpine natural grassland we mean areas where the herbaceous plants are natural and Geographical limitations prevent other natural landcover.	1555	7.17%
Temporary meadows	Areas where the herbaceous plants are either natural or artificial and is maintained by ploughing and other technics, where grass is considered as a crop in the same way as cereals or others.	22	0.10%
Bare rock	Bedrock outcrops and blocky areas with little or no high vegetation (< 10 %) but can be moss or lichen covered. Gathered also cliff, scree, sandbank, etc. Sparsely vegetated areas are also included with less than 50 % field cover (herb, grass and/or scrub) at the phenological mature stage and less than 10 % tree cover.	516	2.38%
River	Natural stream of water that empties into another body of water or into the sea. Also water courses that cease to flow for part of the year, leaving a partially dry bed or water pools.	28	0.13%
Lake	Natural permanent and temporary lakes, including reservoirs.	1910	8.81%
Pond	Natural permanent and temporary pond.	2	0.009%
Wetland	Inland wetlands without a direct connection to the open ocean with significant content of water, which is influenced by a certain seasonal fluctuation. Includes marsh, reed bed, peatbog, etc.	1	0.005%
Softwood forest	Type of vegetation mostly composed of trees, including shrub and bush understoreys, where coniferous species predominate and represent more than 75% of the pattern.	3857	17.79%
Hardwood forest	Type of vegetation mostly composed of trees, including shrub and bush understoreys, where broadleaf species predominate and represent more than 75% of the pattern.	8463	39.03%

	Habitat definition	Surface area	Percentage (%) of the whole area
Mixed forest	Vegetation formation composed principally of trees, including shrub and bush understoreys, where neither broadleaved nor coniferous species predominate. The share of coniferous or broad-leaved species does not exceed 75% in the canopy closure.	151	0.70%
Forestry	Planted forest that can be softwood or hardwood trees used for business purposes.	1	0.005%
Cultivated areas	Arable Land is land under a rotation system used for annually harvested plants and fallow lands. The land is permanently or not irrigated. It includes cereals, oil seed plants, vegetables, beets, fodder and flooded crops such as rice and other inundated croplands. Includes orchards, vineyard and all permanent crops.	2914	13.44%
Greenways	Walking and cycling path	166	0.76%
Maintained grassland	Golf, camping, sports field, parks, playgrounds	169	0.78%
Urban discontinuity	Discontinuous presence of buildings and houses intertwined by vegetal areas and components.	301	1.39%
Urban continuum	Structured urban area with continuous buildings and houses. Low presence of vegetal areas.	1481	6.83%
Local road	Maintained by local government, <5 000 vehicles per day.	23	0.11%
County road	Maintained by the sub-regional government (French department), > 5 000 vehicles per day.	123	0.57%

3.4 Threats and barriers

For terrestrial fauna, main factors of poor connectivity between ecological infrastructures in the South of Lake Annecy are urban sprawling, downgrading of natural lands into urban ones on local urban planning, fences, the presence of roads and its intensity of traffic.

Urban areas (continuum, discontinuities) and roads (county, local) have been considered with low permeability and a high resistance value in our model because of the risks they put to the fauna of death, collision, getting lost, urban traps, exposure to predators (higher natural predator exposure, meeting with humans, dogs, etc..).

Fences are also a threat considered to be present mostly in:

- Urban discontinuity
- Urban continuum
- Maintained grassland (which gathers camping, golf, soccer and tennis fields, etc.)

For aquatic fauna, the loss of connectivity is due to barriers fragmentation, riverbank adjustments, dams, weir, canal, piped river, etc…

3.5 Land use permeability identification

We sorted natural habitats into three main categories: Forest habitats and Open lands habitats for green infrastructures and blue infrastructures as one unique category, as classified on the land cover map (cf figure 8). It represents main habitats that fauna will seek to pass through when moving from one place to another. An anthropic land use qualification gathers all the potential obstacles of continuity (urban areas, fences, roads).

Each of these categories were given a grade of permeability which represent an ease (1) to a difficulty (100) to pass through the land cover from one place to another. We based that permeability matrix in a study previously done by Asters CEN 74 in 2009 for the SCOT of Grand Annecy (cf Annex 1, Bal B. et al., 2009) and updated data to our categories.

To characterize a bit more fauna species representative of each habitat, we first consider that corridor analysis excludes flying animals such as birds, bats or butterflies that can by-pass most of the land barriers. We will therefore focus our attention on terrestrial animals from green infrastructures such as:

- Species from the **forest habitat** can include Red deer (*Cervus elaphus*), Pine marten (*Martes martes*), Lynx (*Lynx lynx*), Wolf (*Canis lupus*), etc.
- Species from the **open land habitats** can include grasshoppers, snakes, small mammals, Mole (*Talpa europaea*), etc.

All **blue infrastructures**' species will be gathered under the same type of habitats (wetlands and river) and can include amphibians, fishes, European beaver (*Castor fiber*), Eurasian otter (*Lutra lutra*), White-clawed crayfish (*Austropotamobius pallipes*), etc.

Value of the grades used: 100 = Repellent; 60 = Low permeability; 30 = Mid-permeability; 5 = propitious passing; 1 = easiest way

Table 5: Permeability matrix based on land use

Habitat	Open land	Blue infrastructures	Forest
Lake	100	1	30
River	5	1	5
Pond	100	1	30
Wetland	5	1	5
Maintained grassland	30	30	30
Cultivated areas	5	100	30
Permanent meadow	1	60	5
Temporary meadow	1	30	5

Habitat	Open land	Blue infrastructures	Forest
Bare rocks	1	100	5
Mixed forest	60	30	1
Softwoods	60	30	1
Hardwoods	60	30	1
Forestry	60	30	1
Discontinuous urban area	100	100	60
Continuous urban area	100	100	100
County road	100	100	100
Local road	60	60	60
Green way	30	50	30

To most categories, urban areas and county roads represent a repellent path to take (100).

Local roads with their low traffic are downgraded compared to county roads (60), and greenways are even more downgraded because of their soft mobility and absence of vehicles (50 to 30).

Although species from the forest habitat can move easily on open lands (5), the contrary is not equal for species from open lands on closed habitats (60).

Bare rocks and cultivated areas can be repellent natural habitats for blue infrastructure species (100), whereas for the open land species it is pond and lake that are considered as repellent (100).

We added to blue infrastructures the list of obstacles inventory in each river and gave it a repellent value (100). Barrier fragmentations can take the form of riverbank adjustments, dams, piped river, canal, weir, etc… Adding obstacles enables the model to first analyse it as a barrier for the functionality of the corridor and then the model takes into account the land use permeability (avoid at first the weir and cross a forest for example).

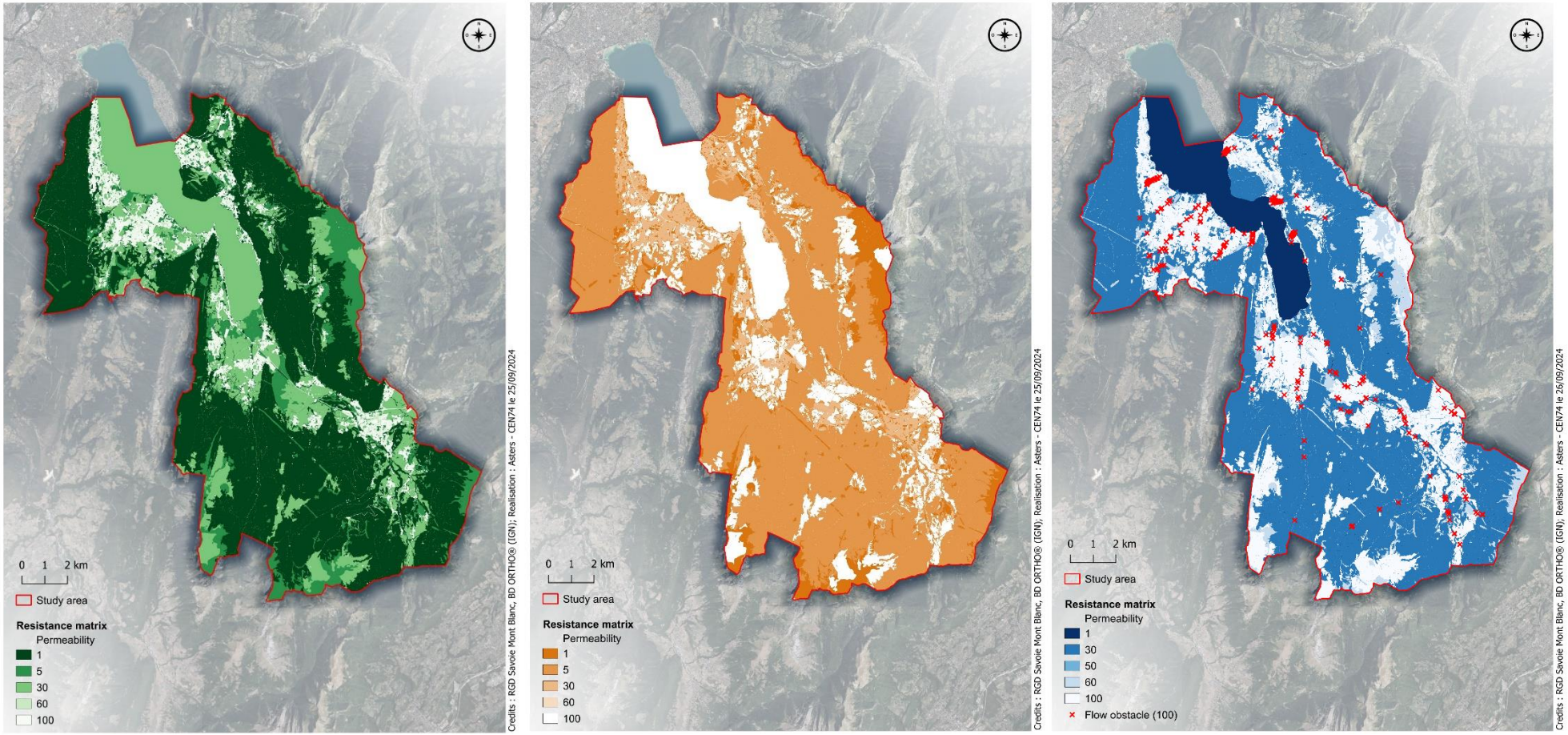


Figure 11: Permeability map of habitats, from the left to the right : Forest habitat, Open land habitat and Blue infrastructures

4 Results

4.1 The least-cost path results

The least cost path allows us to identify main corridors and places of continuity's disruption from a reservoir to another.

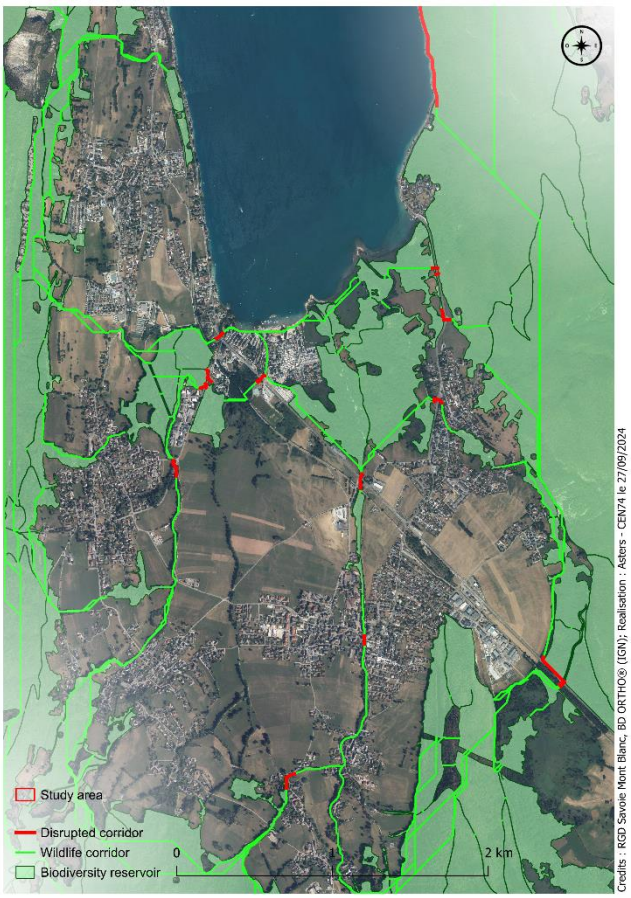


Figure 13: Forest corridors and disrupted location near the tip of Lake Annecy

We can see for example in this zoom of the South of the lake, 4 main corridors whose continuity are disrupted by the county road.

This type of map could be interesting to use as a guideline before going to the field to assess where there is a potential disruption of corridor functionalities.

It would also be a tool for decision makers and planners to identify more precisely places where corridors are located and what are potential issues of their functioning in the territory.

In comparison to B. Bal study, corridors are located within the same areas, which seems coherent. However, the outlines of our model were more precise, probably due to an enhancement of the software (Graphab compared to SAGA-GIS) and of the use of a better raster resolution (1m compared to a 20m in B. Bal study).

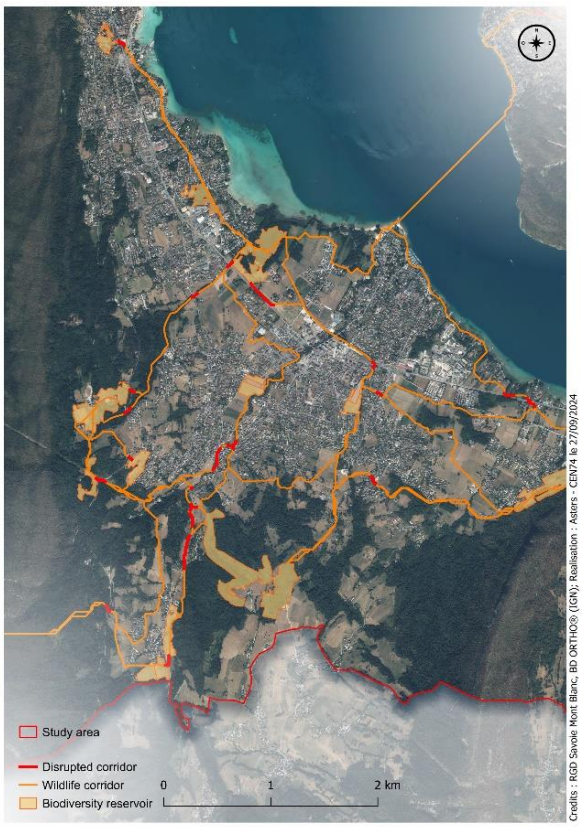
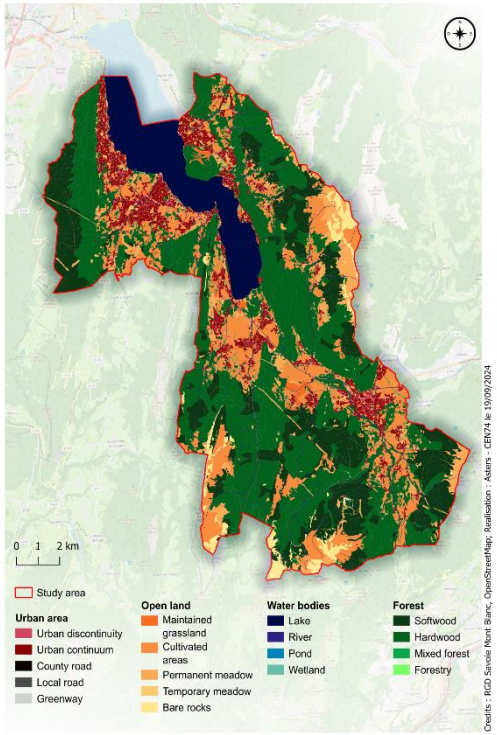
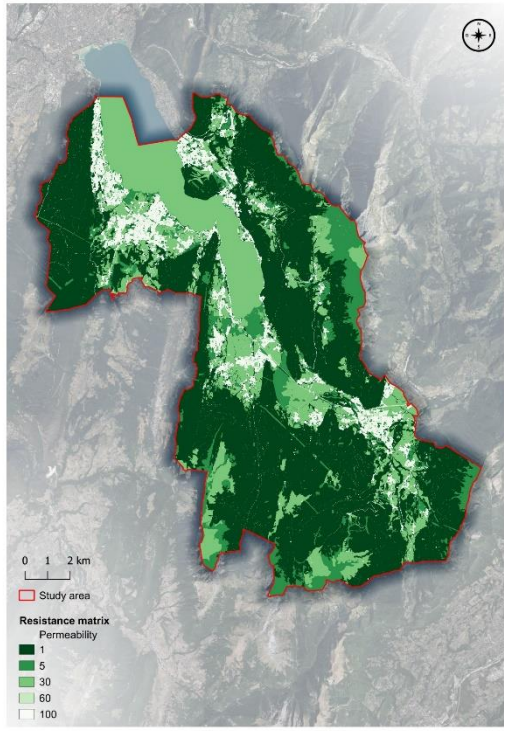


Figure 12: Open land corridors and disrupted location at the West of Lake Annecy

Land cover map



Permeability map



Least cost path map

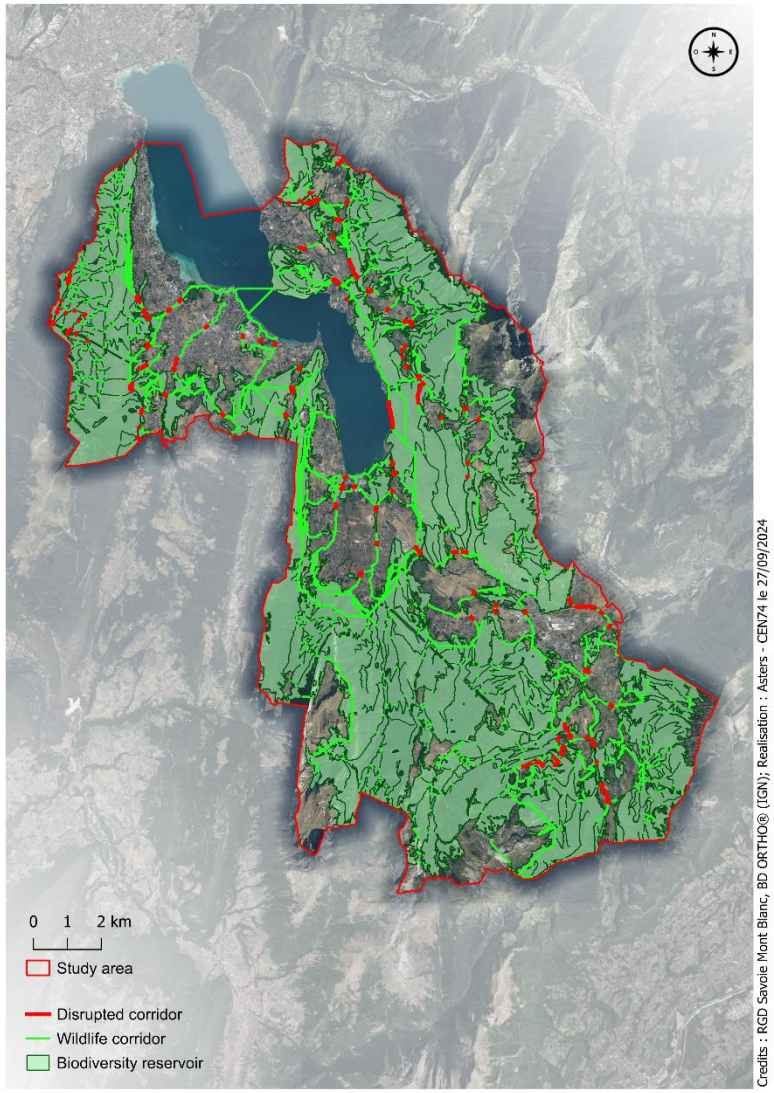


Figure 14: Least cost path results for forest habitats based on the land cover map and the permeability map

Land cover map → **Permeability map** → **Least cost path map**

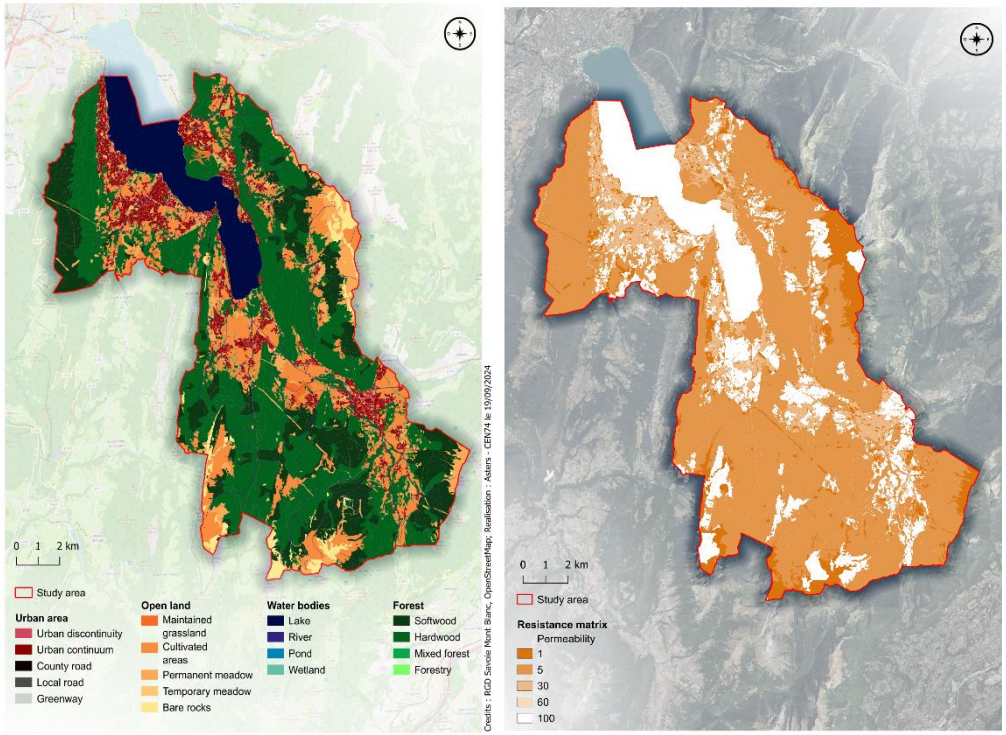
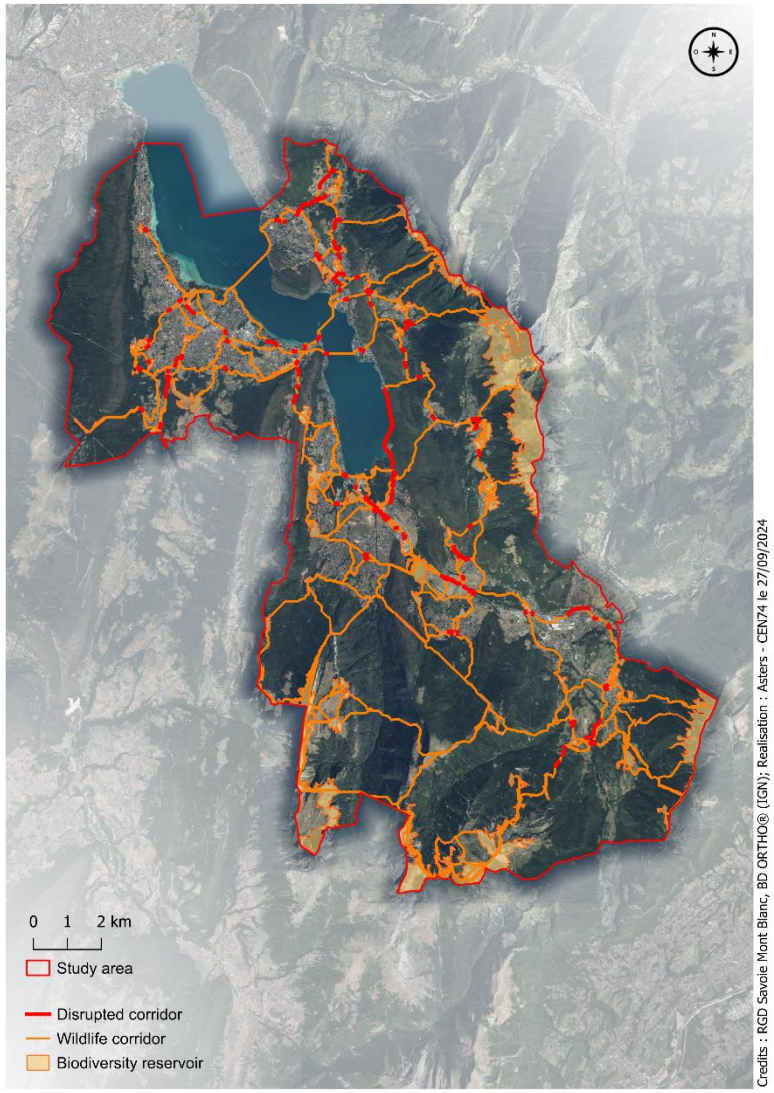
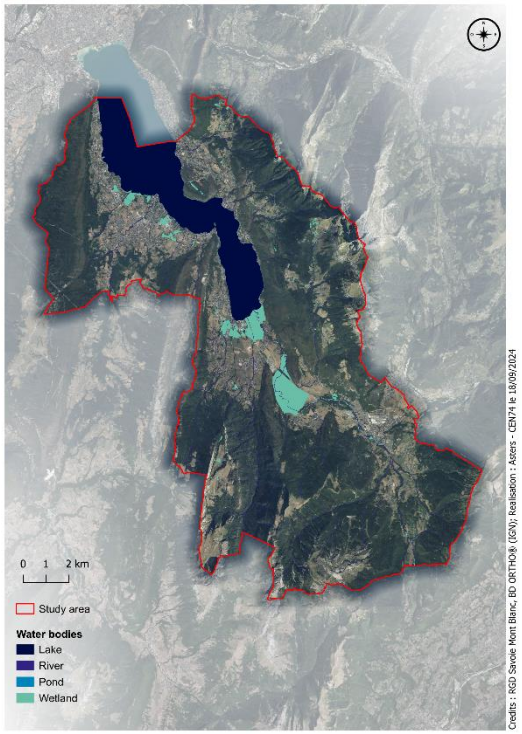


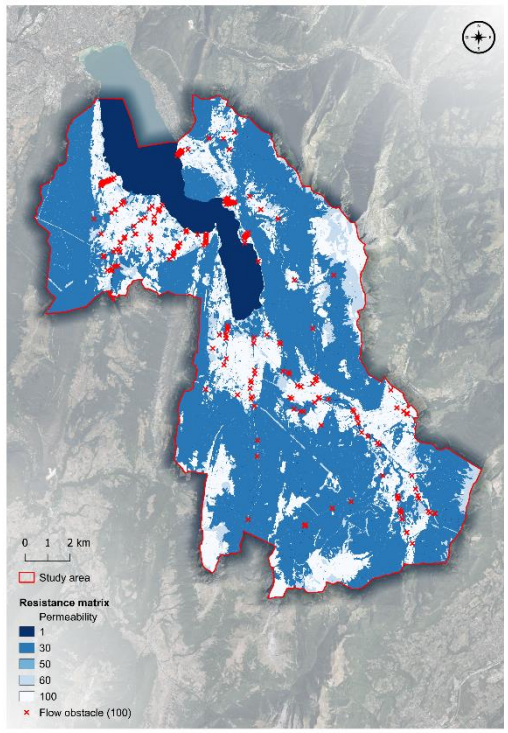
Figure 15: Least cost path results for open land habitats based on the land cover map and the permeability map



Land cover map



Permeability map



Least cost path map

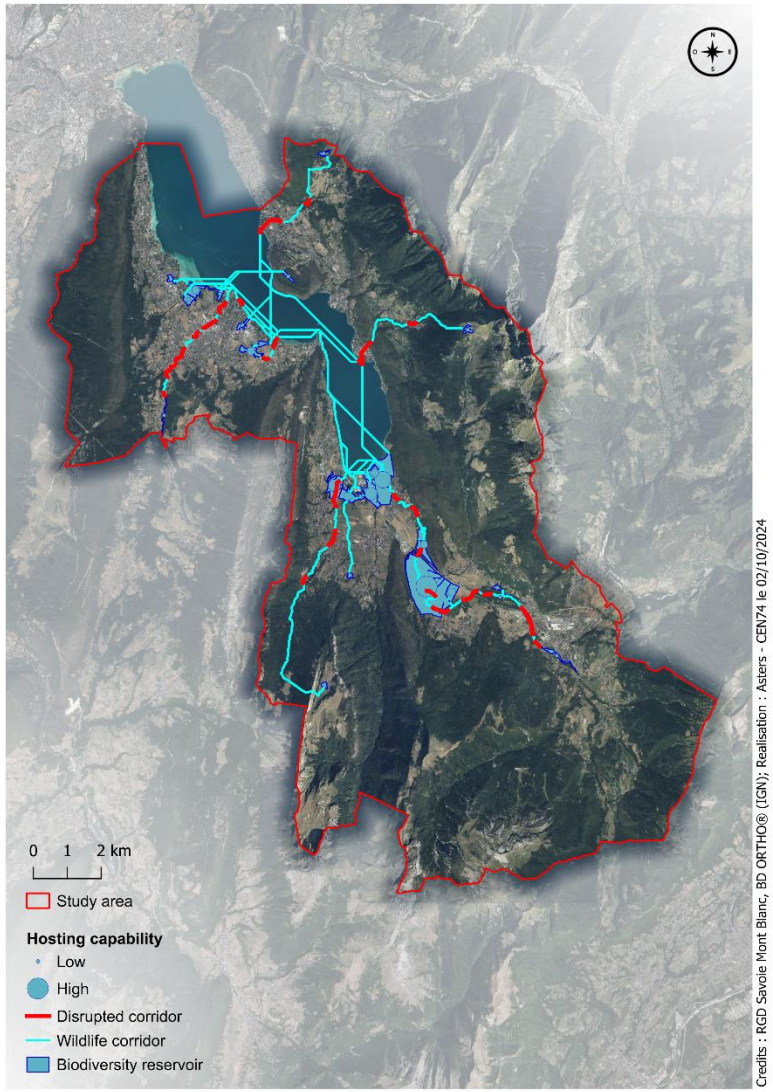


Figure 16: Least cost path results for blue infrastructure habitats based on the land cover map and the permeability map

4.2 Circuitscape results

Unfortunately, we were not able to run the model and have usable results.

We did not manage to use Circuitscape with the programming language Julia. Few explanations are available online on how to use the software and give it shape, which did not allow us to have results based on this method.

Also the free software QGIS does not have the same functionalities as ArcGIS, so some alternatives of Circuitscape were not usable such as the tool “Linkage mapper” that has possibilities to make what they call “linkage priority” or “pinch point mapper”.

4.3 Prioritisation of corridors

Based on Graphab results, we created a map combining all the disrupted corridors (figure 17). Depending on the number of corridors that were disrupted in the same area, a grade was given, grade 3 being corridors to prioritise the most. This map could be used to orientate political decisions towards areas most disrupted.

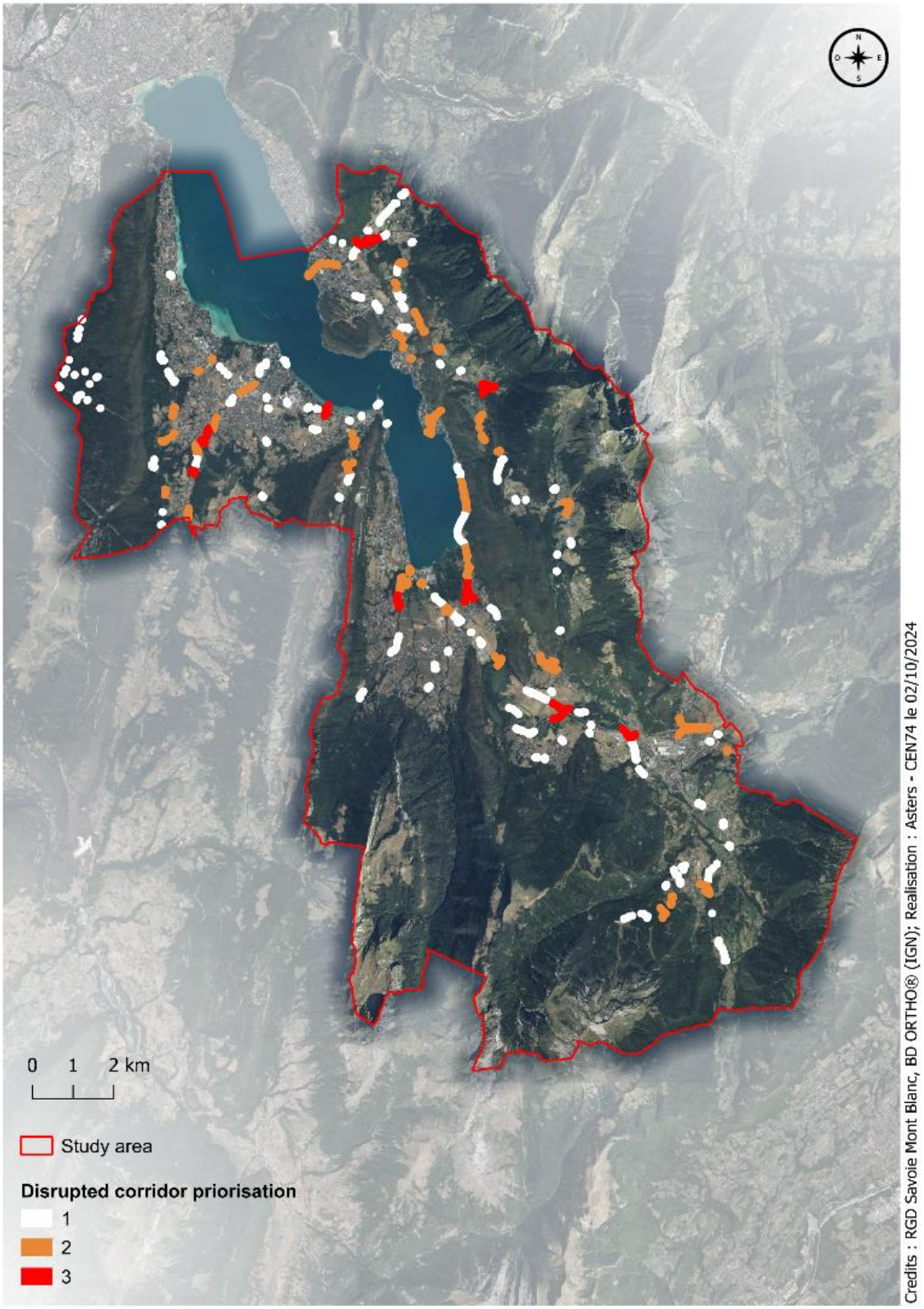


Figure 17: Prioritisation of disrupted corridors

5 Limitations and recommendations

5.1 Fields analysis

The model is only usable at a broad scale but is not enough accurate to be directly used for local actions. Disrupted corridors need to be surveyed in the field to assess if the identification of connectivity issues in an area are as real on the map as on the field.

Lack of small land barriers

Some small land barriers are not taken into account in the model due to a lack of accurate data at a local scale. A field work would allow to have more precise data of fences located in cultivated areas, for example, that would restrain or debilitate the corridor functioning.

The nature of fences need also to be defined depending on their permeability and which type of species is targeted. Both parameters can differ depending if the fence is a wire fence, a chicken wire, a low wall, a ditch, etc.

Figure 18 : Three different type of wire fences, with different permeability from low to high permeability

In the figure 19 below, a field work in this important corridor for the Natural Reserve allowed us to assess that the disruption of continuity was due to several elements in addition to the road identified by the model. There were issues with a low wall, some fences, high predator/human exposure by a lack of hedges and threats of urban sprawling.

<u>The field work is therefore a mandatory step</u> to interpret our model before suggesting some restauration measures to decision makers.

Figure 19 : Low wall near the road that restrained passing through the right to the left towards the Natural Reserve of Roc de Chère

Land use misrepresentation

The land use had some troubles of representation and was either not enough or too accurate depending on the places, which confirmed the necessity to make field analysis.

For example, the open land map identifies a disrupted corridor because of the presence of a road 20m from it but it considers that species should use cycling path. The issue is that the cycling path is highly tarmacked and does not have any natural area where open land species could pass by. It was not identified as such in the model, which shows that a fieldwork is necessary to interpret the results.

Figure 20: Tarmacked cycling path identified as corridor

On the other hand, a too accurate land cover can also lead to wrong corridor identification. In figure 11, the corridor is passing through forested areas which seems coherent for the model.

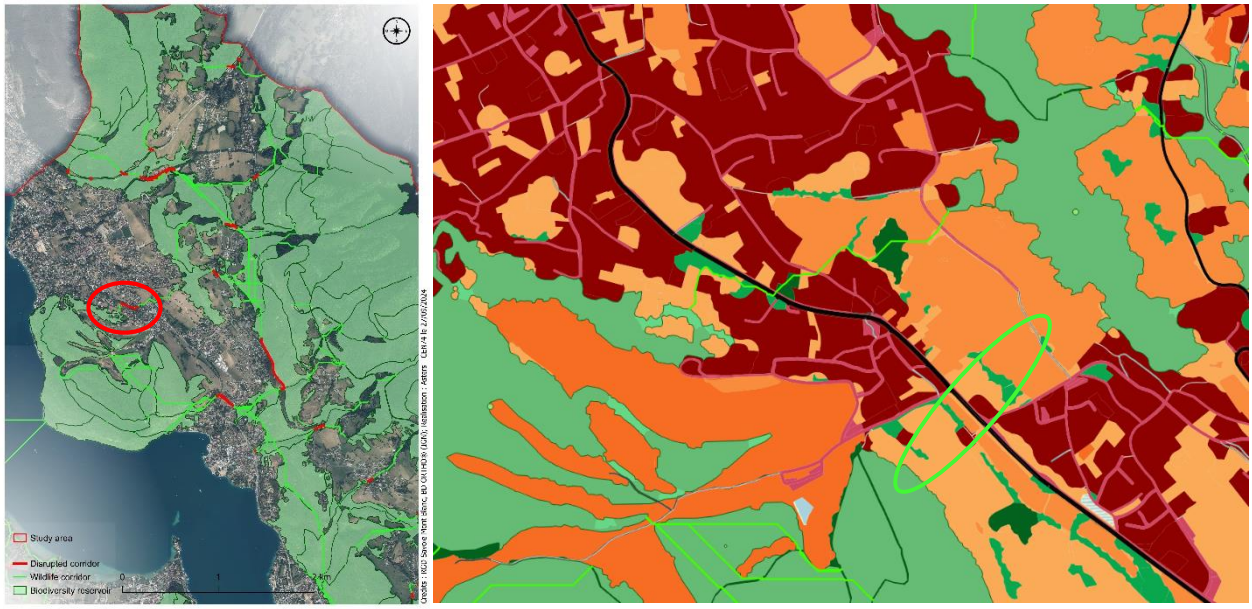


Figure 21: Land use over-accuracy on a corridor not functional on the field

Unfortunatly, by looking at the satellite images, forested areas are trees within gardens and should be part of the urban discontinuum in the land use classification.

Figure 22: Satellite image of the wrong corridor identification

If the land cover had more specified categories of habitat, these patches of forest would have been considered as urban areas and the corridor would take another path, most probably through the connection that is at the East, circled in green on the map, which has been recognized as a real corridor on the field.

To avoid this bias, categorization of land use could be done more precisely by taking into account the surroundings of a land cover entity. For example, in our land cover, a forest in an urban area has the same permeability value as a forest in a natural area. If we take into account the surroundings, the permeability would have lowered the grade in the urban area and the path identified by the model would have changed. By adding more information to the land cover, results could be more precise and it would limit bias. It is also mostly true for cultivated areas that were hard to categorise in the model and could be implemented in further studies by both a field work analysis and a more precise land cover categorisation.

5.2 Species analysis and functional connectivity

The model could be implemented with species analysis by taking into account 3 categories of terrestrial fauna considered as focal species (Ducarme *et al.*, 2013). We would recommend to sort them by size (small, medium, large fauna) or home range (small, medium, extended). They could be representative of either green or blue infrastructures from the South of lake Annecy. Species from the NAP could be part of the focal species since their protection is a key purpose at a national scale and they are present in the pilot area.

This approach would give more accurate results on each species constrains and needs for the functionality of corridors and it would help to have insights on different conflicting areas depending on the species specificities. It would also enable local authorities to improve corridor management for their land-use policy and propose restoration, enhancement or mitigation measures oriented into these species.

For example, the wildlife crossing located at the East of the Natural Reserve of the Tip of the Lake is efficient for amphibians and small mammals but is not calibrated for medium and large fauna that are still confronted to a disrupted corridor. Species oriented analysis could highlight these lacks of corridor's functionalities.

Figure 23: The corridor is disrupted for medium and large fauna, but not for small fauna thanks to the wildlife

5.3 Model limitations

Least-cost path model

Several researches point out that there is limits to Graphab at identifying only a single path. First, alternative paths with comparable costs might exist and are not shown by the model. Then it considers that species would always know where the least-cost path is and make the best decisions to pass through it. In reality animals wander and can take different paths before reaching the desired area (Dickson *et al*., 2019).

The idea to use Circuitscape was to compare it to Graphab and resolve that bias by taking into account all the potential paths taken. It means that the map we created with Graphab is a partial representation of the reality and should be tested by field work analysis.

Study boundaries

The analyse is constrained by an area of study that is based on administrative boundaries. It is not representative of the reality as we know that fauna and flora dispersions can spread wider than our pilot project area.

Corridors identified near administrative borders of our study might therefore not be the sole place where terrestrial or aquatic animals would pass by, since we excluded analysis of elements outside our boundaries.

5.4 Computing constraints

Several computing constraints did not allow us to have a functional Circuitscape model. We did not manage to use Circuitscape with the programming language Julia. Few explanations were available online on how to use the software and give it shape, which did not allow us to have results based on this method.
We tried it on smaller sample zone and it was still too long to process for our computer (5 hours for just one habitat and 10% of the total area). We « only » have 72 Gb of RAM in the computer whereas, according to discussion groups, people mostly used the software on computers with more than 200 Gb of RAM.

Also the software QGIS does not have the same functionalities as ArcGIS, so some software alternatives of Circuitscape were not usable such as the tool “Linkage mapper” that has possibilities to make what they call “linkage priority” or “pinch point mapper”. We were therefore also limited by licence accessibility.

6 References

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- SRADDET, 2020
- Naturalia Environnement, SCOT du bassin annécien, Diagnostic, mars 2023

ANNEXES

Annex 1

Libellé RGD	RGD niv4	CLC niv3	BBA	MAH	ZTS
Urbain continu dense	1110	111	100	100	30
Habitat autre	1121	112	100	100	30
Emprises industrielles et commerciales	1211	121	100	100	30
Friches industrielles et commerciales	1212	121	100	100	30
Axes routiers principaux et espaces associés	1221	122	100	100	5 (100)
Axes ferroviaires principaux et espaces associés	1222	122	100	100	5 (100)
Infrastructures portuaires	1230	123	100	100	30
Aéroports, aérodromes	1240	124	100	100	30
Carrières	1310	131	30	100	30
Carrières massives	1312	131	30	100	30
Décharges	1321	132	30	100	30
Zones de stockages	1322	132	30	100	30
Chantiers	1330	133	30	100	30
Espaces verts urbains et périurbains	1411	142	30	30	30
Golfs	1421	142	30	30	30
Stades, équipements sportifs et de loisirs	1422	142	30	30	30
Campings caravanings	1423	142	30	30	30
Cultures annuelles	2111	211	30	100	100
Maraîchages, serres	2112	211	30	100	100
Espaces en friche	2113	231	30 (5)	100 (30)	100 (5)
Vergers et petits fruits	2221	222	5	30	5
Vignes	2222	221	5 (30)	100	5 (100)
Prairies diverses	2310	231	5	30	5
Forêts de feuillus	3111	311	0	30	5
Peupleraies	3112	311	0	30	5
Forêts de conifères	3120	312	0	30	5
Prairies sèches		321	5	100	0
Boisements 0,5 à 3 ha		322	5	100	5
Affleurements rocheux, falaises	3331	332	5 (100)	100	1 (100)
Tabliers d'éboulis non végétalisés	3332	332	5 (100)	100	1 (100)
Bancs de sables et graviers	3333	331	5	0	1 (5)
Marais intérieurs	4110	411	5	0	5
Cours d'eau et voies d'eau	5110	511	5	1 (0)	5
Plans d'eau	5120	512	30	0 (5)	100

Coefficients de résistance aux déplacements de la faune appliqués pour chaque classe d'occupation du sol et chaque type de continuum.

Figure 24: Permeability grade table from Bal B., 2009 applied to each habitats (BBA = Forest habitats, MAH = Blue infrastructures, ZTS = Open land habitats)

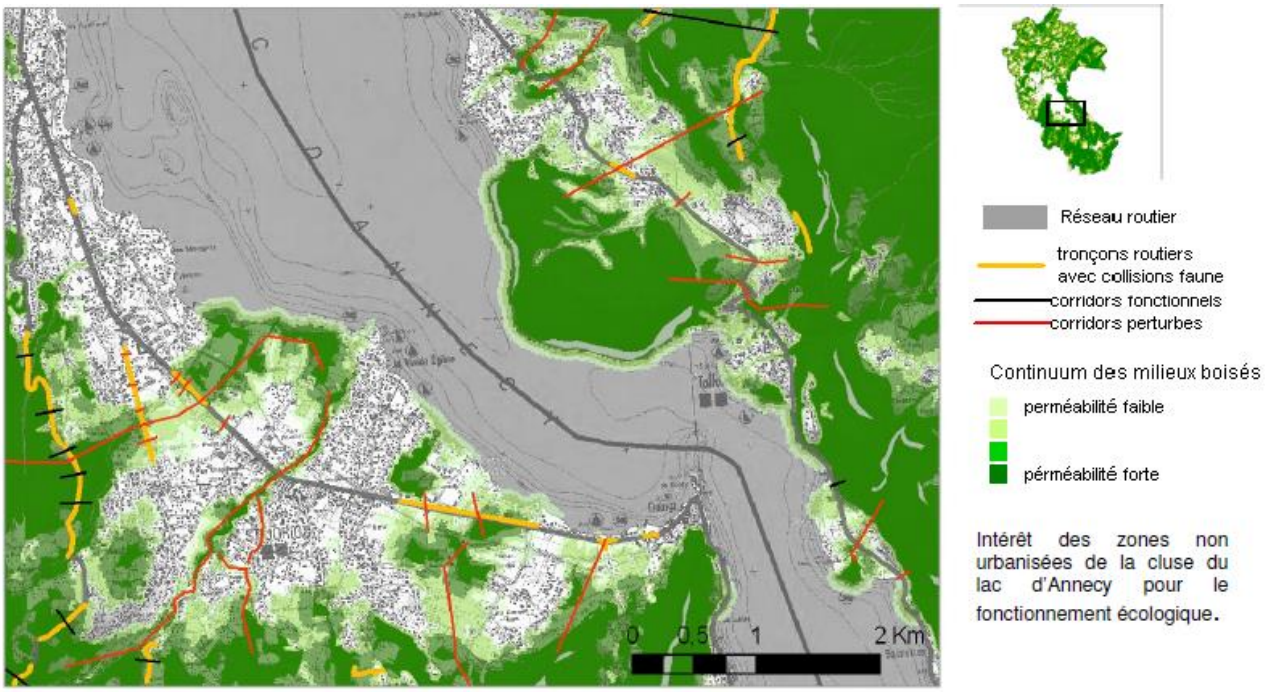

Figure 25: Forest habitats in the South of lake Annecy, Functionality map of corridors from Bal B., 2009

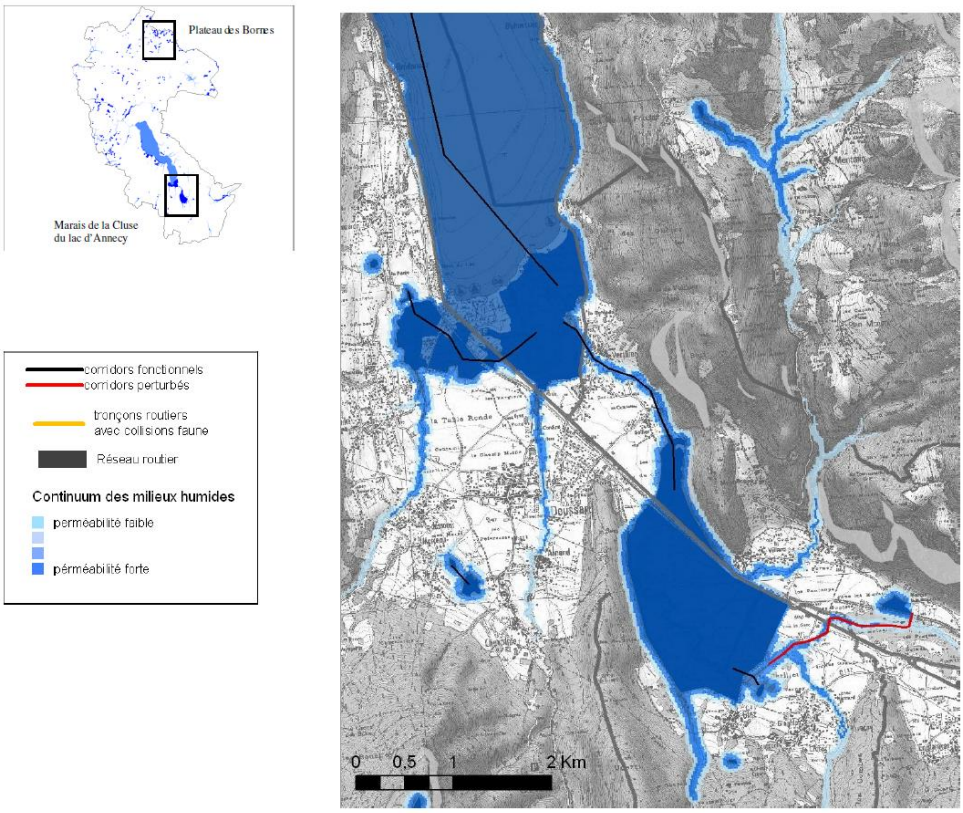

Figure 26: Blue infrastructures in the South of lake Annecy, Functionality map of corridors from Bal B., 2009

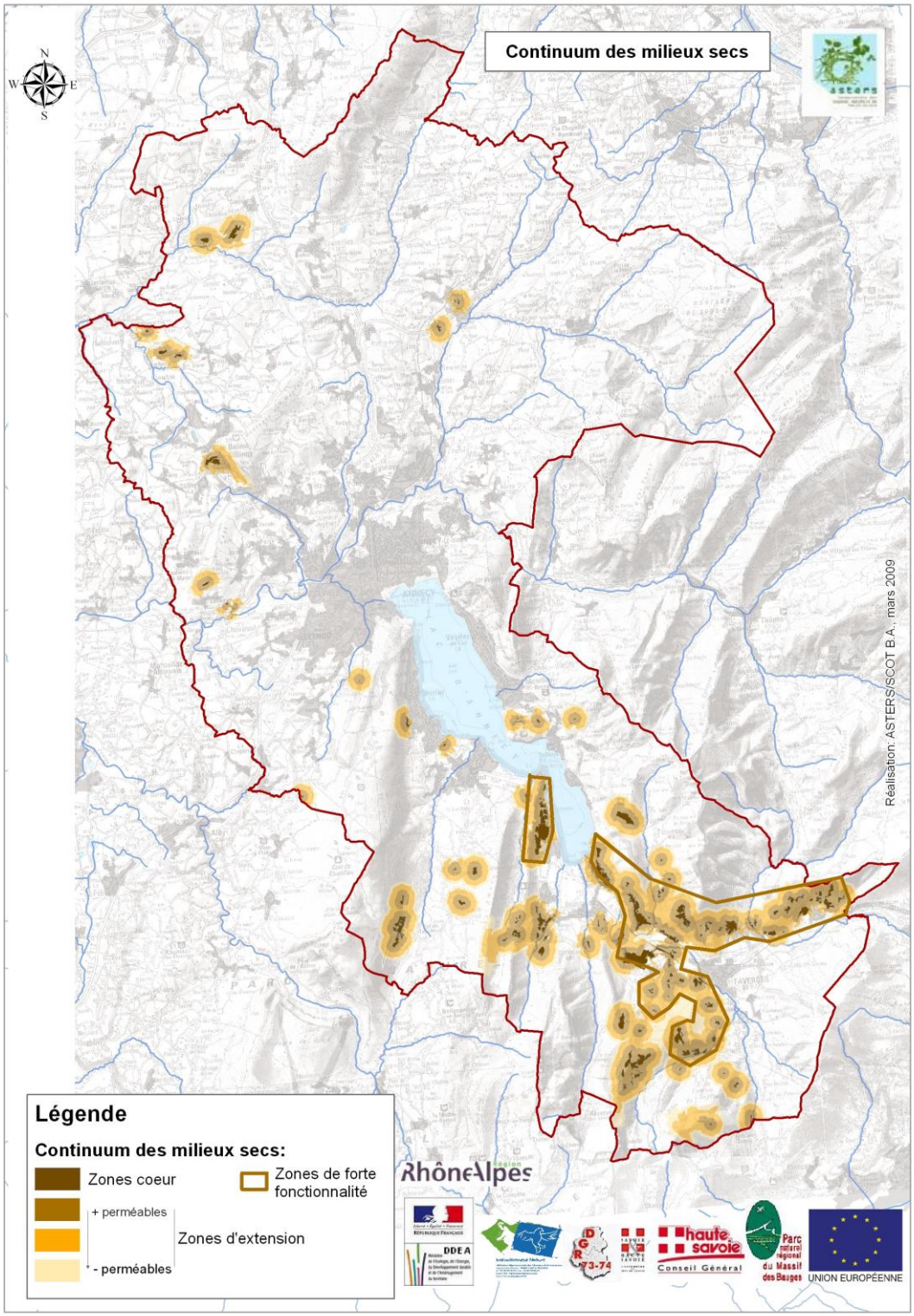

Figure 27: Open land habitats in the South of lake Annecy, Functionality map of corridors from Bal B., 2009

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Ecological connectivity analysis in the South of lake Annecy

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Veneto Region (IT)
ALPARC – the Network of Alpine Protected Areas (FR)
Asters CEN74, organisation for the conservation of natural areas in Upper Savoy (FR)
Eurac Research (IT)
ifuplan - Institute for Environmental Planning and Spatial Development (DE)
University of Würzburg (DE)
Salzburg Institute for Regional Planning and Housing (AT)
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