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Connectivity conservation in rehabilitated lands: Improving and connecting forest habitats in the Rhenish lignite mining area

Submitted by

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Declaration of academic honesty

I hereby certify that I have prepared the attached paper independently and have not used any resources other than those indicated. Any statement that has been taken either verbatim or in a general sense from published or unpublished writings has been cited as such. The work has not been submitted in the same or similar form or as an excerpt during the course of another examination. I certify that the submitted electronic version is fully equivalent to the print version submitted.

Cologne, December 6th, 2021

(Anna Jo Merk)

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Table of Content

Table of Figures

Table of Tables

Table of Equations

Glossary and acronyms

Natural forest rejuvenation	A forest management strategy, where the new generation of trees is not brought in by planting but through natural reproduction.
Sheep wire fence	A special type of wildlife fence, often used for sheep flocks. The meshes of the fence results knotted wire. Wildcats can get stuck in these knots with their claws, unable to escape.
BAST	Bundesanstalt für Straßenwesen
BBergG	Federal Mining Act (Bundesberggesetz)
BMUB	Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit)
BNatSchG	Federal Act on Nature Conservation (Bundesnaturschutzgesetz)
BUND	Friends of the Earth Germany (Bund für Umwelt und Naturschutz)
CBD	Convention on Biological Diversity
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
LANUV	State Office for Nature, Environment and Consumer Protection North Rhine-Westphalia (Landesamt für Nature, Environment und Verbraucherschutz Nordrhein-Westfahlen)
LNatSchG	State Act on Nature Conservation North Rhine-Westphalia (Landesnaturschutzgesetz NRW)
MKULNV	Ministry for Climate protection, Environment, Agriculture, Nature conservation and Consumer protection North Rhine-Westphalia (Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz Nordrhein-Westfahlen)
NRW	North Rhine-Westphalia
Nabu	Nature and Biodiversity Conservation Union Germany (Naturschutzbund Deutschland)
RLMA	Rhenish lignite mining area
Southern district	First lignite mining site in the RLMA which's rehabilitation resulted in the development of the Ville Forest
Wildlife underpassess	All constructions enabling safe crossing underneath a street that were especially designed for the usage by wildlife

1 Abstract

Aim

The restoration of post-mining areas and subsequent reconnection of such fragmented restoration areas represent promising tools to counteract the loss of biodiversity. Rehabilitation efforts taken in the Rhenish lignite mining area (RLMA) for the past 100 have been very successful regarding the diversity of species that has settled or resettled in the rehabilitated landscapes by now. Especially the rehabilitated forest areas show a high level of biodiversity. However, in the RLMA, the conservation of biodiversity through connection of separated areas has not been addressed yet. Therefore, the main objective of this study was to identify factors causing fragmentation of the rehabilitated forest areas in the RLMA and to propose a concept for the connection of these rehabilitated forest areas. In addition to detailed measures to counteract the fragmentation of rehabilitated forest habitats this concept includes measures to further increase the habitat quality within the forest patches. With its need for wide home ranges and diversely structured habitats, the European wildcat (*Felis silvestris silvestris,* Schreber 1777; in the following referred to as wildcat), a commonly used species to enhance forest ecosystem connectivity and natural forest development, was chosen as target species for this concept. The proposed concept follows a holistic approach by not only considering the ecological conditions in the study area but also aspects influencing the implementation of proposed measures. Furthermore, commonly used wildcat conservation measures were investigated closer with regard to their ecological effectiveness and practicability.

Location

The RLMA in the Federal state of North Rhine-Westphalia (NRW), Germany

Methods

In order to identify the path of least restrain for the connection of rehabilitated forest areas a least cost path analysis was conducted. Alongside the ecological needs of the wildcat (represented by a habitat model), factors influencing the actual implementation of conservation measures within the rehabilitated forest areas were taken into account, such as the ownership of land parcels and the distribution of protected areas. Obstacles that potentially hindered wildcat migration as well as potentially wildcat movement motivating green infrastructure such wildlife overpasses identified during the analysis were explored in detail through on-site inspections. An additional action plan to increase habitat quality within the forest patches was worked out. For that purpose, expert interviews were conducted to evaluate the ecological status-quo of the rehabilitated forest areas regarding the needs of the wildcat. Relevant characteristics were food availability, disturbance through anthropogenic use, availability of breeding structures and availability of daytime resting spots. Additionally, commonly used wildcat conservation measures were assessed for their practicability by forestry experts and their effectiveness by wildcat experts. The wildcat experts also rated the effectiveness and implementability of road-related wildcat conservation measures.

Results

In the study area 13 separated forest core areas were identified as potential wildcat habitats and interconnected via a least cost path analysis. Along the resulting path, 17 out of 18 obstacles identified were roads. The longest distance between two core areas was 6.5 km. The habitat quality of the core areas was overall good. Improvable factors were the availability of low-disturbance areas and breeding structures for wildcats. Most resulting forest management-related conservation measures showed a good balance between their practicability and effectiveness while the most effective road-related measures were at the same time the least implementable ones.

Main Conclusions

The analysis showed that the main factor causing fragmentation of rehabilitated forest ecosystems in the RLMA were roads and highways. Consequently, the key to counteract fragmentation in the study area is the installation of green infrastructure that enables wildcats to overcome obstacles. As the subsequent introduction of green infrastructure is highly cost-intensive, the installation of green infrastructure is more likely to be integrated in future road maintenance projects. Therefore, upgrading existing structures, which may enable a safe crossing of roads for wildlife and the installation of guiding structures to these safe crossing points are essential interim-solutions to increase the connectivity in the study area in the near future. Furthermore, claiming and securing land parcels for conservation purposes in order to conserve and enhance the connections between the rehabilitated forest areas is an important step that needs to be taken as soon as possible to increase connectivity in the rehabilitated lands and thus contribute to biodiversity conservation in the RLMA.

2 Introduction

2.1 Biodiversity loss – a tremendous challenge

Some services that mankind depends on in its daily life, such as food, energy, clean water and air, can only be provided by an intact environment in the long run (Hooper et al., 2005; Millennium Ecosystem Assessment, 2005). Many of these so-called ecosystem services are based on the existence of a wide variety of species, ecosystems and genes (Hooper et al., 2005; Millennium Ecosystem Assessment, 2005) – also called biodiversity (Campbell & Reece, 2009). One very popular ecosystem service, due to the recent media attention given to insect mortality, is the pollination of crops by insects. 35 % of global crop production depend on the pollination via pollinators (Klein et al., 2007). The diversity of food available to us is therefore directly related to the diversity of insects that can pollinate crop plants. Another important example for an ecosystem service that is closely linked to biodiversity are medications. About 47 % of cancer medications are directly won or inspired from natural products (Newman & Cragg, 2007). There are countless more ecosystem services that are dependent on the diversity of genes, species, and ecosystems, although the linkage might not always be as obvious as in the previously mentioned cases. Further examples are fibre production, climate regulation, pest control, biomass production and nutrient cycling (Diaz et al., 2006). In total, the loss of biodiversity costs 10 % of the annual gross product (IPBES, 2018).

What could be called the "official global commitment to the importance of biodiversity" and the need to combat its loss was made in 1992, when 168 countries signed the Convention on Biological Diversity (CBD). The main goals of the convention were the conservation and sustainable use of biodiversity and its components as well as the fair sharing of benefits resulting from the use of genetic resources. On December 29th 1993 the convention came into force. Today the CBD counts 193 parties (CBD Secretariat, 2021b).

Nearly 30 years later the situation has not improved. The ever-increasing impact of humans on the environment is threatening biodiversity more than ever (IPBES, 2019). Today 28 % of all known plants and animals are threatened by extinction (IUCN, n.d.). Pimm estimated extinction rates in 1995 to be 100 to 1000 times higher than in pre-human times (Pimm et al., 1995) and still estimated a 1000 times higher rate of extinction 19 years later (Pimm et al., 2014). Furthermore, nearly all biodiversity indicators still showed decreasing trends while factors indicating additional pressure on biodiversity increased (Butchart et al., 2010).

The main factor causing the loss of biodiversity to this unprecedented extend is global land-use change and the resulting degradation of land (IPBES, 2018, 2019; Newbold et al., 2015; Pimm et al., 2014; Wilcove et al., 1998; Wilson, 1989), caused by rapid increase in human population. Since 1970 global human population has more than doubled and is expected to reach 8.5 billion by 2030 (United Nations, 2017). Anthropogenic activities are the direct drivers of 60 % of global land change (Song et al., 2018). In the year 2000 some 55 % of the lands surface have already been significantly altered by humans of which 39 % have been tuned into - and additional 37 % were embedded between - settlements and agricultural land (Ellis et al., 2010). Other factors contributing to land degradation and thus to the loss of biodiversity are the expansion of infrastructure as well as extractive actions (IPBES, 2018).

The demand of land for anthropogenic uses, especially the expansion of infrastructure, does not only lead to the direct loss of habitat but also to habitat fragmentation. Although an on-going debate has recently arisen in the literature about whether or not habitat fragmentation has a negative effect on biodiversity (Fahrig, 2017, 2018). The long-established evidence of a negative effect of fragmentation currently outweighs the arguments that challenge this point of view (Fletcher et al., 2018). Firstly, habitat fragmentation leads to reduced connectivity and thus to decreased genetic exchange between the emerging subpopulations (Campbell & Reece, 2009; EEA, 2011).For example, Dixon et al. (2007) found significant genetic variations between geographically close but by fragmentation separated Florida black bear (*Ursus americanus floridanus*, Pallas 1780*)* subpopulations. This lack of genetic exchange makes local populations more vulnerable to disturbance and can lead to local extinction (Campbell & Reece, 2009). Secondly, the edge effect significantly reduces the quality of the remaining habitat (Haddad et al., 2015; Laurance et al., 2011; Pfeifer et al., 2017). Although the transition areas between two ecosystems are often real biodiversity hotspots due to their high variation of biotic and abiotic factors, these conditions only have a positive effect on so-called generalists, which are adapted to rapidly changing environmental conditions. Specialists, on the other hand, are dependent on the constant environmental conditions of their habitats and are much more often listed as endangered species than generalists (Pfeifer et al., 2017). Thirdly, if fragmentation is caused by roads, the resulting traffic alone poses a high mortality risk to wildlife. For some species, such as the wildcat, vehicle collision rates are so high that road mortality is a population-determining factor (Hermann & Mathews, 2007; Mölich & Klaus, 2003). Finally, it cannot be denied that species which depend on large contiguous habitats are at risk if such habitats of sufficed size are no longer available due to habitat fragmentation. This is especially true for medium to large carnivorous mammals (Crooks, 2002; Noss et al., 1996). Consequently, the restoration and connectivity of ecosystems continues to be perceived as the most effective measures against biodiversity loss (Dixon et al., 2007; EEA, 2011; IPBES, 2018, 2019; Millennium Ecosystem Assessment, 2005).

2.2 The embedment of restauration and connectivity conservation in international and German law

Due to their importance, these two instruments have become increasingly explicit in the CBD's and other strategies' objectives. In the CBD's strategic plan for 2011 - 2020, the prevention of further ecosystem degradation and fragmentation and implementing well-connected ecosystems were recorded in the Aichi targets number 5 and 11 (CBD Secretariat, 2020). The official strategic plan for 2030 by the CBD has not yet been released, as their 15th conference of parties (COP15) was postponed due to the Covid-19 pandemic. Nevertheless, an initial draft of the strategy sets a target of increasing the area devoted to ecosystem connectivity by 5 % by 2030 and by 15 % by 2050 (CBD Secretariat, 2021a).

On the European level, the Flora Fauna Habitat Directive (FFH) was adopted in 1992 as response to the CBD. The core of this directive is the establishment of a Europe-wide network of protected areas, Natura2000 (Council Directive 92/43/EEC, 1992). In 2020 the protection of 30 % of the land and sea area as well as the integration of ecological corridors and the introduction of a EU-Restoration plan were set as key commitments of the European strategy for biodiversity for 2030 (European Commission, 2020).

The national strategy for the protection of biodiversity of Germany was released in 2007 (BMUB (Ed.), 2015). In addition, §20f of the Federal Nature Conservation Act (BNatSchG) calls for the creation of a network of interconnected biotopes on at least 10 % of the area of the federal states for the permanent protection of wildlife and a functioning ecological exchange. However, locally more detailed targets were set in the federal countries' strategies. The biodiversity strategy of NRW states that 15 % of the federal state's area are to be reserved for the connection of ecosystems. Furthermore, the degradation and fragmentation of ecosystems is to be reduced by the implementation of green infrastructure (MKULNV, 2015). Furthermore, § 8 of the Nature Conservation Act of NRW (LNatSchG NRW) prescribes the preparation of a technical report for nature conservation and landscape planning in which guiding principles and recommendations for biodiversity conservation and information on a connectivity concept are included.

The explicit prescription of ecosystem restoration and connectivity as key measures against further biodiversity loss at all policy levels underline the importance of these tools and suggests that these two tools will actually have to be applied for effective biodiversity conservation in the near future. Therefore, the practical implementation of both tools is explained in more detail below.

2.3 Approaches to counteract biodiversity loss caused by fragmentation: restoration, connectivity conservation and surrogate species

Actions to reduce and reverse land degradation can be diverse. They are often closely interlinked, complement or build up on each other. Sometimes a strict separation between different actions is difficult especially because the concepts and terms are often assigned to similar actions. The clear differentiation of the various concepts is also made difficult by linguistic differences. The same expressions in different languages can have different emphasis, while for other concepts there are no adequate translations at all (Brux et al., 2001). Therefore, defining the meaning of different terms is essential for efficient communication. The definition used most for restoration and to which also the CBD and the IUCN (International Union for Conservation of Nature) refer to was set by the Society for Ecological Restoration International Science & Policy Working Group (SER). According to the SER, ecological restoration is a process that supports degraded, damaged or destroyed ecosystems in its recovery (SER, 2004). One of the most important features of restoration that distinguishes it from other related conservation methods is the fundamental goal of bringing the ecosystem back to its original state and often requires continuous management. Measures are therefore based on the state of the ecosystem at pre-disturbance times. Other conservation methods that also seek to improve the ecological state of degraded ecosystems might not aim to reintroduce historic conditions and can be absolved after a shorter period of time (SER, 2004). The term rehabilitation refers to the reintroduction of a self-sustaining ecosystem with the pre-disturbance state as reference. But it focuses on the re-establishment of the ecosystem's processes, functions and services while restoration also aims to bring back the flora and fauna of historic conditions. Consequently, rehabilitation might in most cases be a component of successful restoration. Reclamation describes the return of degraded land into a useful state, usually in relation to mining areas. Actions taken in the frame of reclamation include the aesthetic improvement of the area, assurance of public safety, revegetation, and the stabilisation of land (SER, 2004). Rehabilitation and reclamation efforts can be based on ecological goals and thus in the end also lead to rehabilitation or restoration of the post-mining areas (SER, 2004). The definitions of the terms restoration, rehabilitation and rehabilitation will be used in the context of this work as induced by the SER. In the German language the term "Rekultivierung" is an important expression in the broad subject of restoration. It describes the return post-mining areas to a productive cultural landscape (Pflug, 1998). In comparison to reclamation, the landscape is not only turned into a usable state and prepared for subsequent use, but the new cultural landscape is fully established. Furthermore, the ecological aspects are also increasingly emphasised today, as the aim of “Rekultivierung” is also described as the re-creation of an ecologically valuable cultural landscape that can be reintroduced into the economic and natural circle (Drebenstedt & Kuyumcu, 2014) and is also determined as a compensation measure under the BNatschG. The actual meaning of the term “Rekultivierung” probably lies somewhere between the definitions of reclamation and rehabilitation. However, reviewing the definitions by the SER, “rehabilitation” represents the German term "Rekultivierung" best although it lacks the direct reference to post-mining areas. Therefore, rehabilitation is used in this paper as a translation of the German term “Rekultivierung”.

The fragmentation of natural landscapes is one of the major concerns of nature conservation. Thus, actions that increase the connectivity, that is the exchange of species between habitat parcels, are important tools for conservationists (Crooks & Sanjayan, 2006). For this exchange to be possible, landscapes need to be permeable or migratable for species. To increase the permeability of a landscape, different measures can be taken, depending on the obstacle that causes the fragmentation. The probably most popular measure for connectivity is the introduction of corridors which are linear habitat structures, connecting two or more habitat patches across a dissimilar matrix. Corridors are implemented for conservation purposes as they increase or maintain the viability of populations in the habitat patches (Beier & Noss, 1998). Stepping stones have the same function as corridors but instead of one continuous linear structure, they are characterised by multiple small habitat patches, distributed across a landscape to connect larger habitat patches (Campbell & Reece, 2009). Not only landscapes but also anthropogenic infrastructure like roads can cause fragmentation. Measures to reduce the fragmentation effect of roads can be the installation of green infrastructure like wildife bridges or wildlife underpasses (Campbell & Reece, 2009), which are designed to meet the needs of wildlife to enable them to cross the roads and therefore reduce wildlife-vehicle collisions and connect the habitats on both sides of the roads. Increased connectivity can also bring risks. For example, the faster spread of pests or alien species and the greater range of disturbances as well as high economic costs (Simberloff & Cox, 1987). The debate can perhaps be summed up by saying that connected habitats are always preferable to fragmented habitats. Nevertheless, connectivity conservation measures such as corridors are not a panacea and their benefits must always be weighed against the costs on a situation-specific basis (Beier & Noss, 1998; Crooks & Sanjayan, 2006). Therefore, the probably most important thing about connectivity for its practical implementation is that it consists of two parts. Firstly, the structural part which describes a landscape's spatial composition of habitat types or structure elements and secondly the behavioural reaction of individuals, species or ecological processes to the characteristics of the landscape (Crooks & Sanjayan, 2006). Due to the second component the same landscape can result in sufficient connectivity for one and insufficient connectivity for another species (Taylor et al., 2006). In order to derive and implement meaningful connectivity concepts, the purpose of the network must be precisely defined. Consequently, the selection of the species for which a landscape is to be made migratable is essential for connectivity conservation concepts (Beier & Noss, 1998; Crooks & Sanjayan, 2006).

A method commonly used to delineate the best course for a corridor between two or more separated habitat patches is the least cost path analysis (LCP) (also see chapter 3.4). For the conduction of a LCP, cost values are assigned to different landscape features, representing favourable (low costs) and unfavourable (high costs) conditions for species' movement. The path resulting from the LCP is the "cheapest" and thus most favourable connective path between the habitat patches (Adriaensen et al., 2003; Graham, 2001; Guzmán Wolfhard & Raedig, 2019; Nikolakaki, 2004; Schadt, Knauer, et al., 2002; Walker & Craighead, 1997).

Not only for connectivity conservation concepts but for conservation actions in general the definition of a specific conservation goal is important to derive appropriate measures. Thereby it is not possible to develop an individual conservation plan for every species occurring in the respective area. Hence, in nature conservation practice, the focus lies on single species, whose protection promises the greatest possible benefits also for other species. A collective term for this species is surrogate species. These species obtain characteristics that can help to attain conservation objectives (Caro, 2010). Similar to actions taken to reverse land degradation, there are also different, partly overlapping concepts for the selection of these species and their designation. The most often used concepts are shown with a definition below.

Table 1: Characteristics of different types of surrogate species after Caro (2010).

Umbrella species	Species that have high demands on their environment and thus represent the needs of many other species.
Keystone species	Species with an essential role in the ecosystem
Flagship species	Popular species with which many people sympathise so that they can raise awareness, public engagement and funding
Indicator species	Species that are very sensitive to the change of biotic or abiotic factors and reflect these changes.

Some species can fit into multiple categories. Such species are in the following referred to as target species.

2.4 Rehabilitation of post-mining areas in the Rhenish lignite mining area

One region that is particularly affected by fragmentation and ecosystem degradation is located in the federal state of NRW in western Germany. NRW has the highest population density of the federal states in Germany and is with 23 % sealed surface area also the most heavily fragmented federal state of Germany (MKULNV, 2015). Also, it is home to the largest lignite mining area in Europe: the RLMA. The RLMA is located between the cities of Aachen, Bonn and Cologne and still habits three active open-cast mines today (Figure2). Approximately 50 % of the lignite produced in Germany comes from the RLMA. In 2018, 12 % of the electricity generated in Germany was produced from lignite from the RLMA (Perner et al., 2019). Operator of the open-cast mines is the RWE Power AG, a subsidiary of the energy company RWE AG (RWE, n.d.). For better understanding, RWE Power AG and RWE AG will be both referred to as RWE in the following.

Lignite mining in the RLMA began around 1700 in the so-called “southern district” between Brühl and Erftstadt (Figure 2), where the lignite was close to the surface so that it could be mined without need for large technical equipment. The mining area was then expanded successively along the Ville ridge towards the north (Figure 3). Here the lignite lay deeper, and mining was associated with the handling of much more overburden. Through technical progress and the resulting use of large-scale equipment in the 1950s, the commercially extraction of these deep lignite seams became feasible. Today, lignite seams up to a depth of 350 m are extracted in the three remaining open-cast mines of the RLMA (Eßer et al., 2017; Knauff, 1998).

Lignite mining has always been accompanied by disturbances of nature and landscape in the RLMA. The rehabilitation of the landscape and the compensation of the disturbance are prescribed in Germany by §4 of the Federal Mining Act (Bundesberggesetz, in the following BBergG) and §§13ff of the Federal Nature Conservation Act (Bundes Naturschutzgesetzt, in the following BNatSchG) and must be provided by the polluter. As a result, the responsibility for rehabilitating post-mining sites in the RLMA lies with RWE.

While lignite is still extracted in the north of the RLMA, rehabilitation has already been completed in the southern district, where rehabilitation efforts began in 1920 (Schölmerich, 1998). Through the rehabilitation, the post-mining areas of the southern district developed into the Ville Forest, which's oldest stands are about 80 years old today (Eßer et al., 2017).

Within the company RWE, the Rehabilitation Research Centre (Forschungsstelle Rekultivierung, in the following RRC) is responsible for rehabilitation efforts in the RLMA. Within the rehabilitation areas, the RRC implements measures that go beyond the legal requirements for rehabilitation. Special attention is paid to the promotion of biodiversity. Rehabilitation has created mainly agricultural and forest areas in the RLMA but to increase biodiversity, numerous special biotopes such as particularly wet, dry, or nutrient-poor sites were integrated in the rehabilitated landscape. As a result, valuable biotopes have been created in the RLMA (Eßer et al., 2017). The high quality of the rehabilitation by RWE is confirmed by many rare animal and plant species that have (re-)settled in the area (Albrecht et al., 2005) and by the IUCN (International Union of Conservation of Nature), which describes the rehabilitation in the RLMA as one of the best in the world (Imboden & Moczek, 2015). A good example of RWE's rehabilitation work is the Sophienhöhe, a 1500 ha big outside dump north of the open-cast mine Hambach, which continues to grow. In the course of rehabilitation, the Sophienhöhe was mainly rehabilitated as forest habitat, but various special biotopes were established as well.

Thanks to an implemented deadwood concept, many species that normally just occur in old-grown forests can already be found in the young (oldest stands are about 40 years old) rehabilitation of the Sophienhöhe (Eßer et al., 2017). On the advice of the IUCN, RWE's already successful rehabilitation practices were strategically recorded in an biodiversity strategy especially developed for the RLMA (BioDiS) (RWE Power AG, 2018). This strategy was based on the objectives of other biodiversity conservation strategies, such as that of NRW. Therefore, in addition to objectives such as the promotion of natural development of forests, rivers and lakes, the creation of species-rich agricultural landscapes and the support of target species, the creation of a functioning biotope network is also defined in the RLMA as a key objective in the BioDiS (RWE Power AG, 2018). While the other objectives mentioned were actively pursued through the practical work of the RRC even before the introduction of BioDiS, the promotion of biodiversity in the RLMA through a well-connected biotope network has not been addressed by the RRC yet. Therefore, within the framework of the presented study, a detailed connectivity conservation plan for the rehabilitated forest areas of the RLMA was developed in cooperation with the RRC. To ensure that the concept complements and not repeats the findings of already existing connectivity plans the status quo of existing concepts was examined first.

Meanwhile, many of the rehabilitated forest areas have already been returned by RWE to their original or new owners, which is why, the management of many rehabilitated forest areas is no longer the responsibility of RWE (Eßer et al., 2017). The new owners can be, as in the case of the Ville Forest, the state or other public corporations, but also private persons or companies. Therefore, the implementation of connectivity conservation measures in the RLMA is not only the responsibility of RWE but of many different stakeholders.

2.5 Status quo of connectivity conservation concepts in the Rhenish lignite mining area

In 2007, the NABU presented a concept for connectivity paths for five different target species throughout Germany. For NRW, the planned network structures for the wildcat and the red deer (*Cervus elaphus,* Linnaeus, 1758) were of particular importance. However, these identified connectivity paths were exclusively located in the Eifel (Hermann et al., 2007a). Consequently, potential paths to connect the rehabilitation areas of the RLMA were probably not introduced in this concept due to the scale of the concept, as the aim was to identify the most important connectivity paths throughout all of Germany. No concrete measures for the implementation of the connectivity paths were proposed within this concept, but it was pointed out that this would have to be done by the federal states and municipalities. Within this concept the NABU also identified the 125 most important sites for the construction of green bridges, of which six were located in NRW, but none in the RLMA (Hermann et al., 2007a).

The BUND (Bund für Umwelt und Naturschutz) released a connectivity plan for forest biotopes in Germany for the conservation of wildcats in 2007 (BUND, n.d.-a). In individual plans for the federal states, connectivity axes were derived at a more local level. The network concepts were all based on a wildcat habitat model, which was based on telemetry studies in the Eifel. By applying this model to a least cost path analyses, the most suitable connectivity paths for wildcats were identified (Klar, 2009b; Klar et al., 2008). Although the Ville and the Sophienhöhe were identified as suitable wildcat habitats in the RLMA, they were not selected as target points for the corridors in the plan for NRW (Klar, 2009b), which is why the BUND's network plan for the wildcat does not include the rehabilitated post-mining areas in the RLMA.

The most detailed connectivity plan was published by the LANUV (Ministry for Nature, Environment and Consumer Protection NRW) in 2019 in form of the technical report for nature conservation and landscape planning in compliance with §8 LNatschG NRW (Fröse et al., 2019a). According to this plan, a connectivity axis for forested areas is to be implemented along the rehabilitated forest areas of the RLMA. Target species were a bat species (*Pipistrellus nathusii*, Keyserling & Blasius 1839) and the agile frog (*Rana dalmatina*, Fitzinger 1839). Although both species are suitable target species for natural forest management, neither is suitable as a target species for a wide range connectivity concept. Consequently, only measures to improve the habitat quality for these species within the individual forest patches were proposed in the connectivity concept, but none to connect these fragmented habitats (Fröse et al., 2019b). Along with the written document, geodata was published (LANUV, 2021), in which areas for the creation of a connected biotope network were pictured. A distinction was made between areas of "outstanding importance", which include areas already protected and worthy of protection and "areas of special importance", which were areas intended to facilitate the exchange of neighbouring populations. Although all rehabilitated forest areas of the RLMA were marked here as areas of the biotope network, only some parts of the Ville Forest and the Sophienhöhe belong to the category of "outstanding importance", so that it becomes clear that the other areas are not yet sufficiently secured for nature conservation (Fröse et al., 2019a). As the landownership was not considered in this concept (personal communication Fröse, 2021), it is questionable whether it is even possible to secure all these areas. Unfortunately, it is also not clear from the data set whether steps have already been taken to secure some of the marked areas. The technical report provides a good overview of the areas that could be used to create a biotope network but lacks a detailed description of measures to connect the areas, derived from a target species that is suitable for a wide-ranging biotope network.

All in all, two concepts with the wildcat as target species for connectivity paths were released that worked on such large scales that the RLMA was not considered and no detailed action plans to achieve connectivity along these identified paths were provided (Hermann et al., 2007a; Klar, 2009b). The plan that worked on a local level however proposed for only a few measures for the management of single rehabilitated forest areas but non for their connection (Fröse et al., 2019b). Consequently, to increase connectivity in the RLMA a detailed action plan to counteract the fragmentation of the rehabilitated forest patches is needed. As demonstrated by the connectivity conservation concepts of the NABU and the BUND, the wildcat is a suitable target species for the connection of forest habitats (Hermann et al., 2007a; Klar, 2009b). Therefore, the wildcat was also considered as target species for the connectivity concept for the rehabilitated forest areas of the RLMA.

2.6 The European Wildcat (Felis silvestris silvestris, Schreber 1777)

The latest investigations about the phylogeny of cats sorts the family of Felidae in eight lineages: panthera, bay cat line, caracal lineage, ocelot lineage, lynx lineage, puma lineage, leopard lineage and domestic cat lineage. The species wildcat (*Felis silvestris*), belongs to the domestic cat linage (O'Brien et al., 2008). It splits into five wild living subspecies: the European wildcat (*Felis silvestris silvestris*), the Near Eastern wildcat (*Felis silvestris lybica*, Forster 1780), the Central Asian wildcat (*Felis silvestris ornata*, Gey 1830), the Southern African wildcat (*Felis silvestris cafra*, Desmarest 1822) and the Chinese desert cat (*Felis silvestris* bieti, Edwards 1892). Domesticated cats (*Felis silvestris catus*, Linnaeus 1758) developed from the domestication of *F.s. lybica* in the Near East (Driscoll et al., 2007).

The European wildcat (in the following addressed as wildcat) was once native to all Europe, except for Ireland, Scandinavia and north-eastern Europe, but became nearly extinct due to intensive hunting actions and habitat loss until the middle of the last century (Piechocki, 1990). Fortunately, some smaller but fragmented populations managed to survive in some regions in Europe with Luxembourg, France, Belgium and Germany hosting the most important populations (Trinzen, 2006). In Germany, wildcats have found a refuge in the Eifel, Taunus, Hunsrück, Palatine Forest, Harz and Sollig from where they are slowly migrating into other forested landscapes again (Birlenbach & Klar, 2009) since the hunting ban in 1935 (Piechocki, 1990). The return to near-natural forest management has also contributed to the recolonisation of forests by wildcats in many parts of Germany over the last decade (Trinzen, 2006). According to estimates, the population in Germany is between 5,000 and 7,000 individuals (BUND, n.d.-b), of which about 1,000 live in the Eifel (BUND, n.d.-c; Trinzen, 2006).

Nevertheless, the conservation status of the wildcat remains critical. It is listed under Appendix IV of the European Habitat Directive (Council Directive 92/43/EEC, 1992) and categorized as endangered on the red list of Germany and NRW. Due to the present populations, both Germany and NRW are highly responsible for the conservation of the species (Meinig et al., 2020).

The spatial requirements of wildcats range from 200 to 800 ha for females and 379 to 300 ha for males, whereas the home range of a male wildcat often overlaps with those of a few females. Overlaps between wildcats of the same sex are rare, but do occur (Birlenbach & Klar, 2009; Hupe, 2002; Hupe et al., 2004; Mölich & Klaus, 2003). A small group of wildcats therefore requires 1000 to 3000 ha of sufficient and unfragmented habitat (Trinzen & Klar, 2010). For a long time wildcats were described as forest dependent species (Piechocki, 1990). By now, it is assumed that although the forest often still is the core habitat of the wildcat, it also includes more partly unsheltered landscapes in its home ranges. The general consensus is that forests are still an important refugee area for wildcats but that it is not necessarily the forest itself, but the shelter is the decisive factor, so that more attention is also paid towards richly structured agricultural landscapes as potential wildcat habitat (Hermann et al., 2007b; Jerosch et al., 2017, 2018; Trinzen, 2006). Nevertheless, the wildcat is dependent on structures that typically occur in older forest stands, as it needs sheltered breeding sites to raise its cubs. These can often be found in hollow trunks, under root plates, in piles of deadwood and in windthrow areas (Dietz et al., 2016; Hermann et al., 2007b). Wildcats also need sheltered daytime hiding places. Windthrow areas, stands with a dense shrubs and herbs layer, hedge structures but also abandoned perches or agricultural areas during the vegetation phase are particularly suitable for this purpose (Dietz et al., 2016; Hermann et al., 2007b; Jerosch 2015; Trinzen, 2006). The main food source of wildcats are still mice (Piechocki, 1990). Hence, they often hunt in meadows or windthrow areas (Dietz et al., 2016; Trinzen, 2006). Du to their need for typical structures of aged forests as well as areas with a high dynamic in their habitat, wildcats count as umbrella species for many forest-dependent species such as the black stork (*Ciconia nigra,* Linnaeus 1758), pine marten (*Martes martes*, Linnaeus 1758), Bechtstein's bat (*Myotis bechsteinii*, Kuhl 1817) and red deer (*Cervus elaphus*). Wildcats are also a flagship species due to its great popularity among the society and are therefore well suited to mobilise many different stakeholders for the implementation of measures (Scholz, et al., 2016).

The main mating season of wildcats are the months February and March. On average three to four cubs are born per bred between April and June. If that one is lost, a second breeding event can occur in autumn (Piechocki, 1990). During their daily strolls and in their migration and search for new home ranges, wildcats mainly move within structures that provide shelter while uncovered land tends to be avoided (Hermann et al., 2007b; Jerosch et al., 2018). They often follow the course of linear landscape elements such as hedges or streams (Dietz et al., 2016; Jerosch et al., 2018; Jerosch & Götz, 2015; Klar et al., 2008).

Wildcats are easily confused with wildcat-coloured domestic cats. Although there are a some phenotypical characteristics of wildcats like the flesh-coloured nose leather, the much more diffuse fur pattern and the longer cylindrical tail with two to three black rings at the distal end sometimes allow a solid assessment (Piechocki, 1990; Stefen, 2007), an unmistakable identification can only be retrieved on the dead individual or via a genetic analysis (Hille et al., 2000; Pierpaoli et al., 2003). Furthermore, wildcats are predominantly active at dawn and night and very reclusive animals what makes monitoring very challenging (Piechocki, 1990). A non-destructive method to monitor wildcats is to collect their hair using lure sticks. Here, sticks sprinkled with valerian essence are installed in the study area. Wildcats, attracted by the odour rub themselves against the sticks, leaving hair which can be used for a genetic analysis (Hupe & Simon, 2007).

The main factor for the wildcats' critical conservation status in Germany is ecosystem fragmentation. Settlements, roads and other anthropogenic infrastructure represent critical barriers for wildcats and hinder their migration (Hermann & Mathews, 2007; Klar et al., 2008). Roads pose a particular risk to wildcats. Up to one third of the local populations dies in vehicle collisions (Klar et al., 2009). Consequently, these mid-sized carnivores hardly find connected habitats that meet their special requirements. A viable population in general consist of at least 500 individuals (Trinzen, 2006), unfragmented landscapes that can host so many wildcats are barely present in Germany. Hence, numerous experts claim that connectivity conservation is the only way to sustain wildcat populations in Germany (Birlenbach & Klar, 2009; Hermann & Mathews, 2007; Klar et al., 2008, 2009; Trinzen, 2006).

Within the RLMA the Ville Forest and the Sophienhöhe but also smaller rehabilitated forest patches along the Ville ridge were identified as suitable wildcat habitats (Klar, 2009b). Wildcats have already migrated into the rehabilitated forest areas of the former southern district (Thiel-Bender, 2020). From there, a spread towards the northern rehabilitated forest areas could take place. With regard to the termination of the extraction activities of the open-cast mine Hambach, the suitable habitat for wildcats at the Sophienhöhe will expand even more. The Sophienhöhe is already connected to many old beech forests, the so-called Erbwälder, via shrub structures along the edge of the open-cast mine. The implementation of a connection between the Sophienhöhe and the Ville via the other rehabilitated forest areas is therefore also desirable with regard to the further spread of the wildcat.

In conclusion, the wildcat is perfectly suitable as target species for the connectivity concept for the rehabilitated forest habitats in the RLMA (in the following addresses as connectivity concept RLMA) as it represents the ecological requirements of many other species, is able to mobilise various stakeholders, is especially prone to ecosystem fragmentation and has already settled in the south of the RLMA.

2.7 Connectivity conservation concept for the rehabilitated forest areas of the Rhenish lignite mining area

A functional connection of the rehabilitated forest areas in the RLMA serves the achievement of the targets set in the BioDiS of RWE and those of the biodiversity strategy of NRW. So far, concepts for connectivity paths for wildcats in Germany have been launched that do not incorporate the rehabilitated forest areas of the RLMA and a concept that addresses these areas but lacks concrete measures to connect the fragmented rehabilitated forest patches derived from the habits of a suitable target species, such as the wildcat. In feasibility study for RWE Dr. Thiel-Bender investigated the possibility of a connective path for wildcats between the Sophienhöhe and the Ville. She concluded that such a connection would be associated with some effort, that a detailed investigation of the obstacles along the path would be required and measured to prepare the rehabilitated forest areas for the migration of the wildcat needed to be taken (Thiel-Bender, 2020). For the realisation of a connected biotope network in the RLMA, it is therefore necessary to develop a detailed concept of measures at the local level, so that proposed measures have a direct local reference and can be implemented.

Therefore, the main objective of the present study is to develop a connectivity conservation concept for the rehabilitated forest areas in the Rhenish lignite mining area. By utilizing an interdisciplinary approach, two specific objectives are addressed: to improve connectivity in the RLMA and to boost habitat quality within the rehabilitated forest areas. Figure 1 shows an overview of the methods applied to answer the research questions and how the respective results add to these specific objectives. To ensure that the resulting connectivity concept is ecologically effective and at the same time actually feasible, the action plans were developed in an interdisciplinary approach by including ecological and implementation-controlling factors in the LCP and consulting experts of different disciplines in interviews on the effectivity and practicability of various wildcat conservation measures.

Respectively the following research questions are answered for the development of the connectivity conservation concept:

1. What is the path of least restrain for the connection of rehabilitated forest areas in the RLMA when ecological and implementation aspects are considered?
2. What are the main obstacles along that path?
3. What road-related wildcat conservation measures show the best balance between ecological effectiveness and implementability?
4. What actions have to be taken to counteract the fragmentation effect of the identified obstacles?
5. What is the status quo of the habitat quality within the rehabilitated forest areas regarding the habits and needs of the wildcat?

6. Which forest management-related wildcat conservation measures show the best balance between ecological effectiveness and practicability?
7. What measures can be taken to increase the habitat quality of the rehabilitated forest areas?

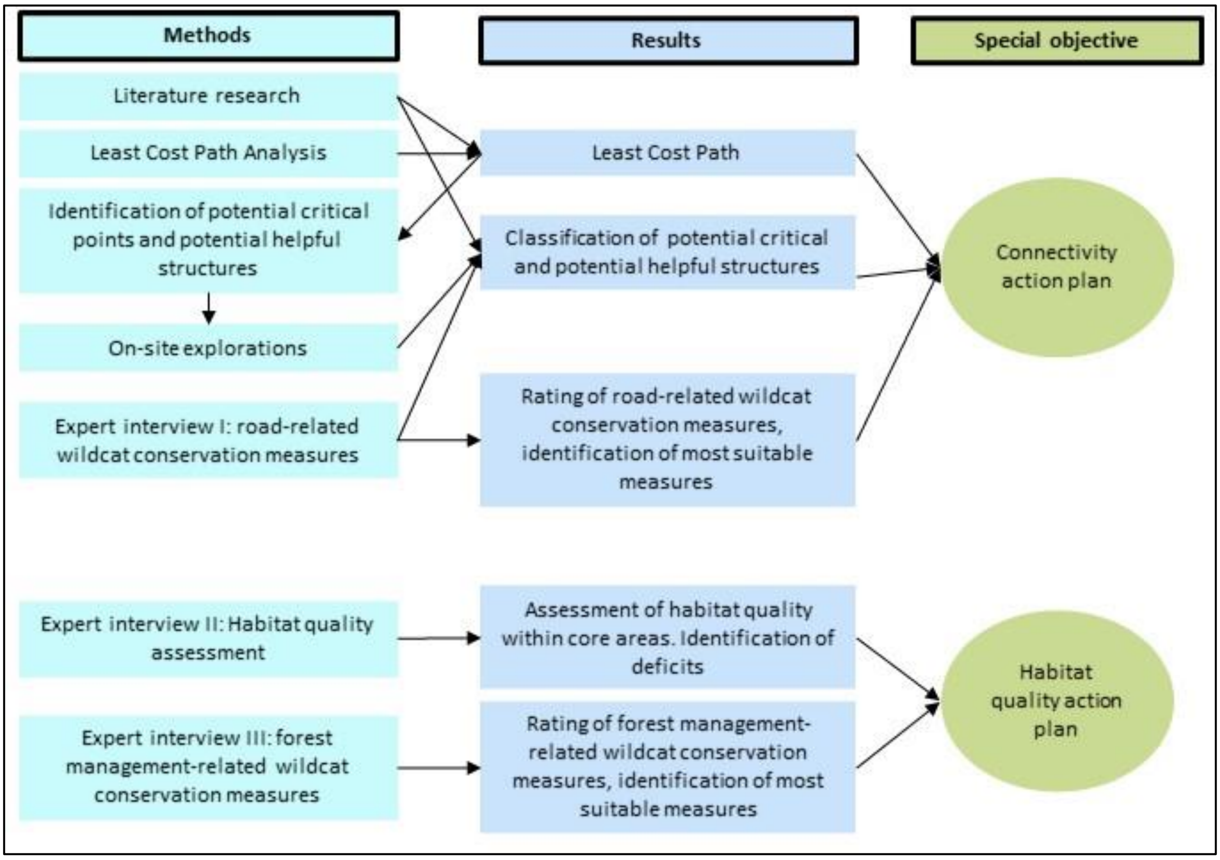

Figure 1: Visualisation of the study's methodological concept.

3 Material and Methods

3.1 Study Region

3.1.1 The Rhenish lignite mining area

The RLMA is located between the cities of Cologne, Bonn, Aachen and Mönchengladbach in the federal state of NRW in western Germany (Figure 2). It expands across an area of 2500 km^2 (Dworschak & Rose, 2014) and contains 55 billion tons of lignite, making it the biggest lignite deposit in Europe (DEBRIV., n.d.). Biogeographically the RLMA can be assigned to the Altantic region of the Lower Rhine Embayment (LRE). This biogeographical unit stretches across an area of about 3450 km^2 and can be subdivided into the Zülpicher Börde ("Börde" describes areas with very fertile soils), the Jülicher Börde, the Ville and the Cologne-Bonn Rhine Plane (Figure 2). Elevations lie predominantly between altitudes of 60 m to 200 m above sea level with the higher elevations being located in the Ville which creates a natural border between the Zülpicher and Jülicher Börde and the Cologne-Bonn Rhine Plane in the LRE (LANUV, n.d.). Exceptions are the Sophienhöhe and the Drachenfels with altitudes around 260 m above sea level (Landesbetrieb Wald und Holz NRW, n.d.). Regions west of the Ville are dominated by agriculture while regions east of the Ville are dominated by anthropogenic infrastructure like settlements, roads and highways. The Ville itself shows a high density of forested land and lakes (LANUV, 2019). With an average annual precipitation of 550 to 800 mm and an annual mean temperature of 9 ° C - 11 ° C (Landesbetrieb Wald und Holz NRW, n.d.), the LRE has a temperate (Cfb) climate (Peel et al., 2007). Industrial lignite mining began in the 18th century in the southern Ville. Further mining areas were developed from there towards the north (LANUV, n.d.). Today, there are three active open-cast mines in the RLMA: Inden, Hambach and Garzweiler. But although these active open-cast mines have a strong influence on the region, the RLMA is shaped even more by the landscape that resulted from the rehabilitation of the former lignite mining areas (Figure 3). For lignite extraction so far about 200 km^2 of land have been claimed by RWE. Of that 290 km have been rehabilitated: about 77 km^2 forest rehabilitation, 103 km^2agricultural rehabilitation and 20 km^2 watercourses, lakes and other landscapes (RWE AG, n.d.).

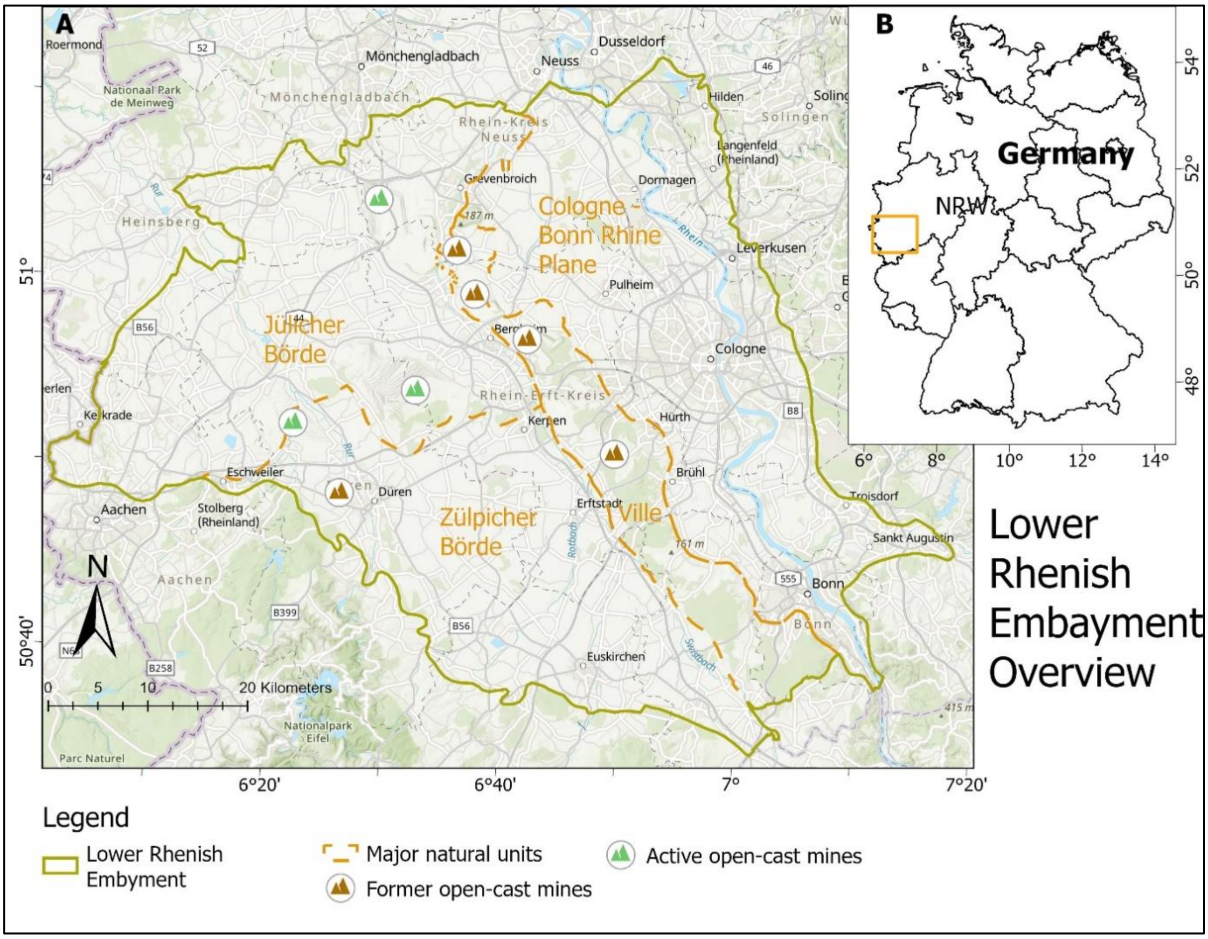

Figure 2: Lower Rhenish Embayment overview.
***A**: Lower Rhenish Embayment Overview (Source Basemap: Esri, EsriNL, Rijkswaterstaat, NASA, NGA, USGS, Land NRW, LVermGeo RP, Kadaster, Esri, HERE, Garmin, FAO, METI/NASA, USGS; Deliniation LRE and Major natural units: data retrieved via Geoportal NRW, © Land NRW, Bundesamt für Kartographie und Geodäsie 2021). **B**: Reference map: Location of the LRE in Germany with the borders of the federal states (Data Source for borders: Verwaltungsgebiete 1:250 000 mit Einwohnerzahlen (Ebenen), Stand 31.12. (VG250-EW 31.12.) © GeoBasis-DE / BKG (2021)).*

3.1.2 Delineation of the study area

The main objective of this study was the development of a connectivity conservation concept for the rehabilitated forest areas in the RLMA. These areas are concentrated in the region between the Ville and the active open-cast mine of Hambach. Therefore, the study area did not expand across the entire RLMA but was reduced to a rectangle that incorporated all forest areas that resulted from rehabilitation efforts by RWE (Figure 3). This study area included approximately 1644 km^2. As the study area incorporated rural as well as urban regions, both the human population and road densities showed high variances. Population densities varied between 99 inhabitants per km^2 in the municipality Hürtgenwald and 2679 inhabitants per km^2 in the city of Cologne. With an average of 670 inhabitants per km^2, the study area had an intermediate population density which accounts for an overall town or suburb character

(Dijkstra & Poelman, n.d.; European Commission, n.d.). The highest road densities were found in the east due to the connection to the city of Cologne, while the western part showed a more rural character. The average density of roads with a traffic volume of more than 2500 motor vehicles per day in the study area was 2 km/km^2. Some 12 % of the study area were forested, and two rivers, the Erft and the Rur, pass through it, fed by some smaller tributaries.

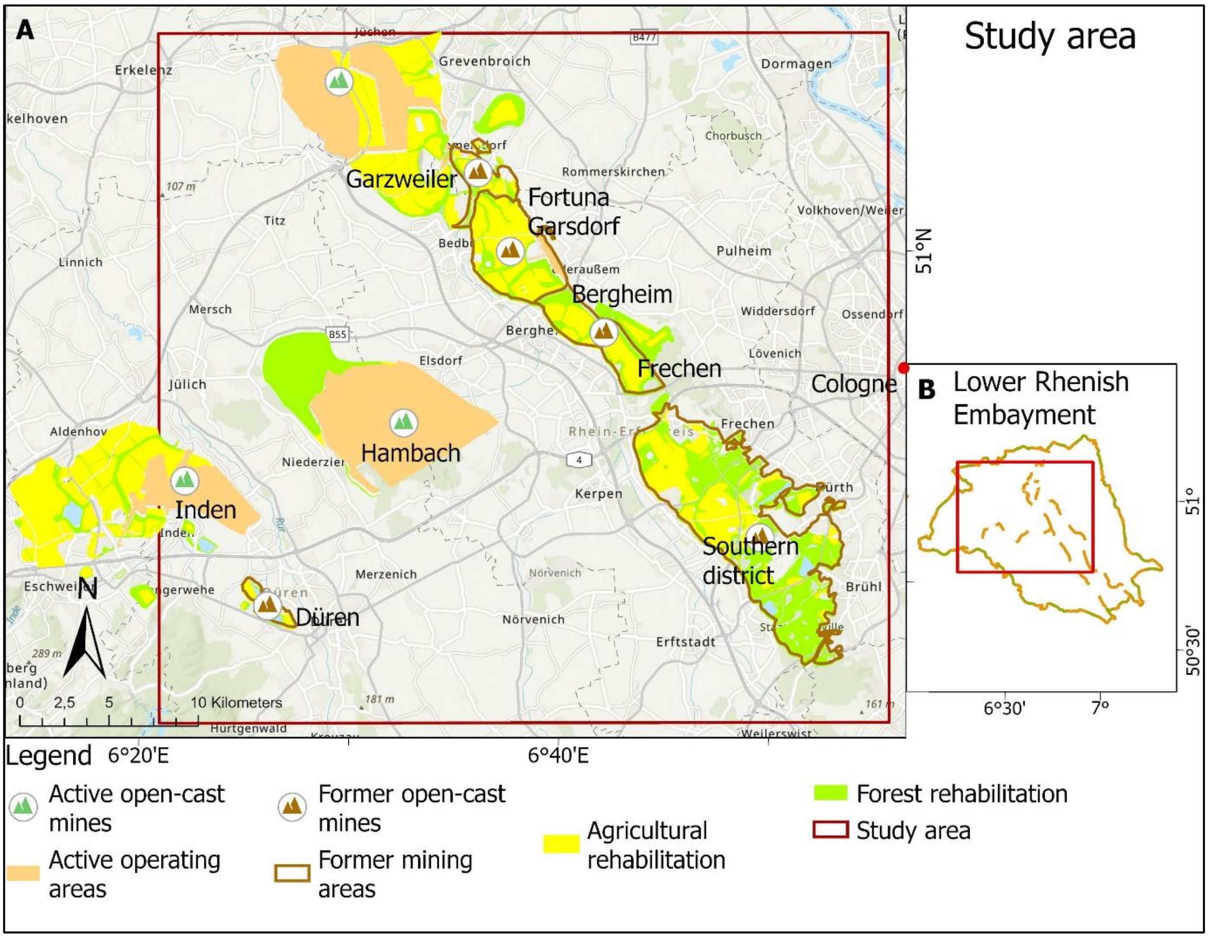

Figure 3: Study area.
***A**: Expenses of the study area within the Rhenish lignite mining area (Source Basemap: Esri, EsriNL, Rijkswaterstaat, NASA, NGA, USGS, Land NRW, LVermGeo RP, Kadaster, Esri, HERE, Garmin, FAO, METI/NASA, USGS). **B**: Reference map: Location of the study area within the Lower Rhenish Embayment (Data source: delineation LRE and Major natural units: data retrieved via Geoportal NRW, © Land NRW, Bundesamt für Kartographie und Geodäsie 2021).*

3.2 General information on the expert interviews

The expert interviews contributed to the development of two action plans to increase habitat quality within the core areas and for better interconnection between them.

The three main objectives of the experts' interviews were:

1. the assessment of habitat quality within wooded areas along the connectivity path

2. the assessment of practicability and effectivity of forest management-related wildcat conservation measures
3. the assessment of effectivity and implementability of road-related wildcat conservation measures

Three different types of experts were interviewed: Forestry experts, RLMA experts and wildcat experts. The interviews with the wildcat experts contributed to the second and third objective, whereas the interviews with the RLMA experts served the investigation of the first objective. RLMA experts with detailed knowledge about some of the forest areas in the study area rated the structural richness of these sections. Forestry experts were asked about habitat quality and the practicability of wildcat conservation measures. All experts qualified due to their long years of professional experience. Short personal descriptions can be found in Appendix 2 (Table 13). During the interviews various valuable information were retrieved from the experts, which were frequently used for the sake of the following analysis. The information gained through the interviews that were conducted in the frame of this study and can be verified via the audio files provided, will be referred to the following as "(Interview [last name of the Expert], 2021)". All in all, 10 experts were interviewed. The interviews took place either in person or online via zoom (Zoom Video Communications, n.d.)(Table 2).

Table 2: Overview Expert interviews. Two interviews were conducted with Dr. Thiel-Bender. As methods changed during the working progress, the rating of the wildcat conservation measures had to be repeated. The introductory questions were not asked again, hence the audio file with the first interview is also handed in. The interview with Michael Stoffels is divided in two audio files as an additional question was added after the official end of the first interview.

Name	Expertise	Date	Interview type	File name
Eßer, Gregor	RLMA	24.09.2021	in person	Interv_Eßer.mp3
Jüssen, Lukas	Forestry	23.09.2021	Zoom	Interv_Juessen.mp3
Dr. Klar, Nina	Wildcat	07.09.2021	Zoom	Interv_Klar.mp3
Pechtheyden, Frank	Forestry	15.09.2021	in person	Interv_Pechtheyden.mp3
Roland, Günther	Forestry	16.09.2021	in person	Interv_Roland.mp3
Dr. Rose,	RLMA	20.09.2021	Zoom	Interv_Rose.mp3
Schmaus, Hermann	RLMA	07.10.2021	in person	Interv_Schmaus.mp3
Stoffels, Michael	Forestry	16.09.2021	in person	Interv_Stoffels1.mp3 Interv_Stoffels2.mp3
Dr. Thiel-Bender, Christine	Wildcat	30.08.2021 06.09.2021	Zoom	Interv_TB1.mp3 Interv_TB2.mp3
Trinzen, Manfred	Wildcat	14.09.2021	Zoom	Interv_Trinzen.mp3
Walther, Henning	RLMA	24.09.2021	in person	Interv_Walther.mp3

The interviews were held in German language. With consent of the experts, all interviews were recorded and the mp3 files were submitted with this thesis. Decisive questions and answers were translated into English for the evaluation. In a preliminary briefing, which took place immediately before the interview, the purpose of the interview, the subject and the aim of the present master's thesis were explained to the experts, as well as the evaluation scales that were used in the interviews. The interview questions were defined in guidelines prior to the interviews. The formulation of the questions during the interviews was very close to the one in the prescribed wording but did not always follow it word for word. The guidelines for the interviews can be viewed in Appendix 3. The interviews with the first experts for an objective resulted in some additional questions for the interviews with the following experts for the same objective. Additional questions put to the experts are also listed in Appendix 2.

3.3 Compilation of information on the migratory behaviour of wildcats from various data sources as basis for the following analyses

For the development of the action plans, background information on wildcats' migration behaviour was collated to derive thresholds for following analyses and to assess the suitability of crossing structures. The information was gathered throughout the whole working process through literature research and the consultation with experts. However, as the information gathered on the behaviour of wildcats was used at many different points on the way to develop the action plans, the ones used for the analysis of the study area and the development of the action plan are presented in the following in a systematic approach. For example: it is known that roads build obstacles to wildcat movement, but at which traffic density is a road considered an obstacle? The information compiled was mainly used to assess obstacles and barriers, but also possibly useful structures such as potential crossings structures for roads, corridors and stepping stones in the study area. In the following it will be distinguished between barriers and obstacles: while barriers are landscape features that are not permeable for wildcats, obstacles are landscape features with unfavourable conditions or even risks for wildcats' migration but can generally be crossed by them.

3.3.1 Traffic

Traffic is one of the greatest mortality risks for wildcats. However, studies showed that rail traffic has no effect or such a small effect that it is negligible. Therefore, rail traffic was not considered as an obstacle in the following analyses (Kautz 2005 in Hermann & Mathews, 2007;

Westekemper et al., 2021). Klar et al. (2009) found that wildcats rarely cross roads with a traffic density of more than 2500 motor vehicles per day (mv/d) while roads with only a few hundred mv/d (Klar et al., 2009) as well as country roads are negligible (Westekemper et al., 2021). Hermann and Mathews (2007) suggested to investigate the fragmentation effect of roads with traffic density of 4000 mv/d more closely. However, not only the traffic density but also the density of roads in the area increases the fragmentation effect (Westekemper et al., 2021). As the study area showed a high road density, the lower value of 2500 mv/d was selected as threshold to classify roads of all classes as obstacles. As the road mortality increases with higher traffic volumes, speed and the road width and was also proven to be higher at highways compared to other road classes (Hermann & Mathews, 2007; Klar et al., 2009), highways were rated as more severe obstacles. Nevertheless, highways can be crossed by wildcats unless they are fenced properly (Klar et al., 2009), therefore highways were in general classified as obstacles, not as barriers.

3.3.2 Settlements

Wildcats generally do not enter settlements or similar anthropogenic structures like industrial areas (Hermann & Mathews, 2007; Klar et al., 2008). Hence, settlements were considered as barriers. Klar et al. (2008) also found that wildcats keep a distance of 900 m to villages and 200 m to single houses. These thresholds were applied for the conducted Least Cost Path Analysis within this study, to keep close to the method used by Klar et al. (2012). However, other studies also showed higher tolerances of wildcats regarding the proximity to human settlements where they were located in 500 m distance to settlements next to a highly frequented pedestrian path (Simon, 2010). Schievenhövel et al. (2010) found a wildcat using a road underpass at about 200 m distance from a village and Hermann et al. (2007b) found wildcats using corridor structures in distances of 220 m to 450 m of settlements. For this reason, connectivity options that did not adhere to the originally observed thresholds of Klar et al. (2008) were also considered in the connectivity action plan.

3.3.3 Crossing structures

Green bridges specially designed for wildlife are well accepted by wildcats (BAST, 2014; Trinzen, 2013) and viaducts were also used for crossing without hesitation (Klar et al., 2009). The Road and Traffic Research Society (Forschungsgesellschaft für Straßen-und Verkehrswesen) specifies a minimum width for newly constructed wildcat under- and overpasses of 50 m (Forschungsgesellschaft für Straßen-und Verkehrswersen, 2008) making the connection of habitats for wildcats very costly and challenging. However, many other structures that were not specifically designed for wildlife are also used by wildcats and other wildlife. Therefore, such structures were also considered as potential crossing structures in the connectivity action plan. As road underpasses for normal motor traffic can pose a risk for crossing wildcats themselves (Klar et al., 2009), they were not classified as potential crossing structures. Railway underpasses, on the other hand, were classified as potential crossing structures due to the low mortality risk for wildcats and because one exemplary railway underpass was also rated as potentially useable for wildcats by Dr. Thiel-Bender (personal communication, 2021) (pictures see Appendix 4). Many authors have demonstrated the use of service road underpasses (for example constructed for forest or agricultural vehicles) by wildcats (Hupe et al., 2004; Schievenhövel et al., 2010; Simon, 2010). During an excursion, Dr. Thiel Bender (personal communication, 2021) also rated a service way underpass under a highway to be suitable. Underpasses that were of similar structure as this underpass (for pictures see Appendix 4) were therefore classified as potentially usable crossing structures. Dr. Thiel-Bender (personal communication, 2021) explained that although the asphalt surface does not prevent wildcats from using the underpass in principle, the removal of the asphalt can make the crossing structure more convenient for wildcats and other species to use. This recommendation was also made by Simon (2010) and Hermann and Mathews (2007). Although the probability of usage of crossing structures by wildlife in general increases with the height and width of the structures (Schievenhövel et al., 2010), the use of much smaller underpasses than those of service roads has also been observed. So, the regular use of a 1.60 m high and 1.30 m wide underpasses by wildcats and even lynx was documented (Deutsche Wildtier Stiftung, n.d.). Wildcats even passed through culverts of 1 m x 0.5 m, whereas the use of culverts corelated negatively with their length (Yanes et al., 1995). Dr. Thiel Bender explained during a fieldtrip that the visibility of the end of the underpass was probably the most important factor (personal communication, 2021). Therefore, all underpasses exceeding the measures of 1 x 0.5 m were classified as potential crossing structures. The underpasses of river or creeks can also work as crossing structures for wildcats if they are equipped with a dry riparian strip (personal communication Thiel-Bender, 2021). Pedestrians and service overpasses with paved ground and without visual protection towards the traffic were not at all or only exceptionally used by wildcats (Hupe et al., 2004; Klar et al., 2009). Similar structures were therefore not considered potential crossing structures in the connectivity action plan.

Of course, the observations of other authors only give hints as to which structures might be used by wildcats. The situations on site are usually too specific that to make general assessments. In addition, the wildcats differ in their character (personal communication Thiel-Bender, 2021). Nevertheless, structures that met the above criteria were classified in the context of this connectivity concept as structures that reduce the fragmentation effect of roads.

3.3.4 Wildcat secure fences

Fencing of roads can be an effective measure to avoid wildlife-vehicle collisions, a measure threat for wildcat migration. Since wildcats are very capable of climbing, only special wildcat secure fences can hinder them from crossing streets. One wildcat secure type of fence was introduced and tested by Klar et al. (2009). The introduced fence was very effective as it reduced wildcat road kills by 83 % (Klar et al., 2009). Nevertheless, the installation of wildcat secure fences along critical roads does not describe the all-round-solution for road-related problems. The positive effect of the prevention of vehicle collisions with wildlife always has to be outweighed against the increased barrier effect (Hermann & Mathews, 2007). Unless suitable crossing structures are installed along with the fence, a wildcat secure fence further increases the fragmentation effect of roads, not only for wildcats but probably all flightless species that do not fit through the meshes. Therefore, the installation of suitable crossing structures every 1.5 km to 2.5 km is recommended. Wildcats show the willingness to make detours of about one kilometre to reach a favoured safe crossing point (Klar et al., 2009). Still, in practice, the installation of a wildcat secure fence along with the crossing structure along all roads that are identified as obstacles is unrealistic due to the costs and also practical conflicts for example with the accessibility of service roads. The wildcat experts also rated the chances of the subsequent installation of wildcat conservation measures, like underpasses along already constructed roads in general as very low. Such measures are often only implemented in connection with other road construction measures or directly included in the planning of newly constructed roads (Interview Thiel-Bender, 2021). Therefore, the wildcat experts were asked for the effectiveness of suitable crossing structures along roads without a fence that prevents wildcats from crossing the road on the roadway. Two of the three experts started, that structures such as hedges or streams have a guiding effect on wildcats and can thus contribute to the use of crossing structures (Interview Thiel-Bender, 2021; Interview Trinzen, 2021). The guiding function of such structures has also been demonstrated in studies (Jerosch et al., 2017, 2018; Klar et al., 2008). Guidance could also be supported by creating poor conditions at unfavourable crossing points, such as the removal of cover structures (Interview Trinzen, 2021). The other expert pointed out that the fragmentation effect of roads on wildcats is not caused wildcats shying away from crossing roads but being run over whilst trying. Wildcats could use the crossing structure on one day and run across the roadway the other day (also observed by Hupe et al., 2004). Therefore, only a fence would help to avoid such accidents (Interview Klar, 2021). Since the implementation of construction-related measures on already existing roads that would lead to a sufficient number of crossing structures to compensate for the fragmentation effect of a wildcat secure fence is so unlikely, an installation of such a fence in the frame of the connectivity action plan is only considered for highways. In the context of this connectivity action plan, the focus is therefore on transitional measures aiming at increasing the likelihood of wildlife using existing suitable crossing structures.

3.3.5 Corridors and stepping stones

Wildcats cross distances of 500 m through unsheltered land (Hermann et al., 2007b). Although there is evidence that wildcats also travel longer distances across unsheltered land (Simon, 2010), these seem to be single cases. Therefore, for the connectivity action plan developed here, unsheltered areas of more than 500 m are rated as obstacles. Stepping stone structures like hedges and woody structures of a size between 0.5 ha and 1 ha enable the migration of wildcats over several kilometres (Hermann et al., 2007b). The classification of stepping stones for the connectivity action plan was also based on these sizes. In the framework of the project "Ein Rettungsnetz für die Wildkatze" a 50 m wide corridor was built in Thuringia for the connection of two forest habitats to enable the migration of wildcats between them (Mölich & Vogel, 2007). This dimension is also described by the BUND as the optimal variant for wildcat corridors. Such a corridor consists of an approx. 35 m wide central area with native, site-appropriate tree species, followed on both sides by a 5 m wide shrub structure and a 2 m wide herbaceous area. The minimum requirements for a corridor structure would be a single line of fruit trees (BUND, 2011). The actual use of implemented corridor structures by wildcats has not been documented yet. Assessments of the usability of corridor structures within the study area are therefore based on the best corridor variant proposed by the BUND.

3.4 Methods used to development the connectivity action plan

The following methods contributed to the development of the connectivity conservation plan for the rehabilitated forest areas of the RLMA. To identify the path of least restrain between previously delineated core areas, a least cost path analysis was conducted. Next, potential critical points e.g., obstacles and barriers, as well as potentially usable crossing structures, alternative paths, and potentially usable corridors or stepping stones along the least cost path were identified. The assessment of which structures were obstacles or barriers, or which could be used as potential green infrastructure was based on literature reviews and the consultation of experts. On-site explorations of the identified structures, together with the insights gained through literature and the exchange with experts (presented in 3.3), then allowed an assessment of the critical and potentially helpful structures along the least cost path. Subsequently, various road-related wildcat conservation measures were assessed by wildcat experts with regard to their effectivity and implantability. The results of the least cost path analysis, the literature review, the on-site explorations and expert interviews were then combined to develop an action plan to increase connectivity between the core areas.

3.4.1 Least Cost Path Analysis

Least Cost Path Analyses (in the following LCP) have become a popular analysis tool for conservationists since the 1990's to identify the connective path of least restrain between two or more locations. The calculations are based on so-called cost values, which are assigned to different environmental conditions depending on the ecological preferences of the target species. Landscapes that can easily be migrated by the target species are appended with low cost values, while unfavorable landscapes and obstacles are appended with high cost values. The assignment of cost values results in a raster dataset that quantifies the permeability of the landscape for the target species. In the last step of the LCP the used software identifies the path of least cumulative cost connecting the predominantly defined target areas (Adriaensen et al., 2003; Graham, 2001; Guzmán Wolfhard & Raedig, 2019; Nikolakaki, 2004; Schadt, Knauer, et al., 2002; Walker & Craighead, 1997).

In this LCP the permeability of the landscape was not only based on the environmental conditions (*ecological costs*) and obstacles occurring in the study area but also on factors influencing the implementation of wildcat conservation measures (*implementation costs*) along the resulting path of least restrain. Consequently, three different cost rasters, were generated to quantify the conditions for wildcat connectivity conservation in the study area. These three cost rasters were then joint together into one *total cost raster*, which thereafter built the basis for the identification of the connective path of least restrain within the study area.

Cost values can be founded on experts' estimations or on habitat models (Bourdouxhe et al., 2020). While the *implementation costs* and the *obstacle cost values* of the obstacles were estimated values resulting from literature review and experts' assessments, the *ecological costs* resulted from the application of a wildcat habitat model by Klar *et al.* (2008). This model was chosen for the following reasons. First, through the application of the habitat model cost values are assigned to the raster cells depending on the distance of a raster cell to influential landscape features. This results in a more fluent transition between areas of high and low costs compared to cost rasters where cost values are only defined by a landscape type. On that account the cost values resulting from the habitat model better reflect reality (Bourdouxhe et al., 2020) and thus the natural migration behavior of wildcats. Secondly, the data collection for the habitat model was performed in the Eifel (Klar et al., 2008), which is nearby the examined study area. Therefore, the landscape types tested for their influence on wildcat habitat selection are the same that occur in this project's study area. Third, it is assumed that the source population of wildcats that migrated to the Ville originates from the Eifel (BUND, 2021). The presumed close relations between the populations suggests that not only the environmental conditions in both cases are alike, but also the actual behaviour of the wildcats from the Ville will be analogue to that of the ones from the Eifel. At last, the conceptualisation for the *Wildkatzenwegeplan* (wildcat-corridor-concept) for Germany as well as the detailed concepts for the federal states were based on that habitat model (BUND, 2015; Klar, 2009b, 2009a; Klar et al., 2012). Along these lines, it seemed advantageous to fund this study on a habitat model that was used as a basis for LCP before and was additionally used for the practical implementation of corridor structures (Scholz et al., 2016).

The overall workflow of the LCP was subdivided into six processing steps which are described in the following.

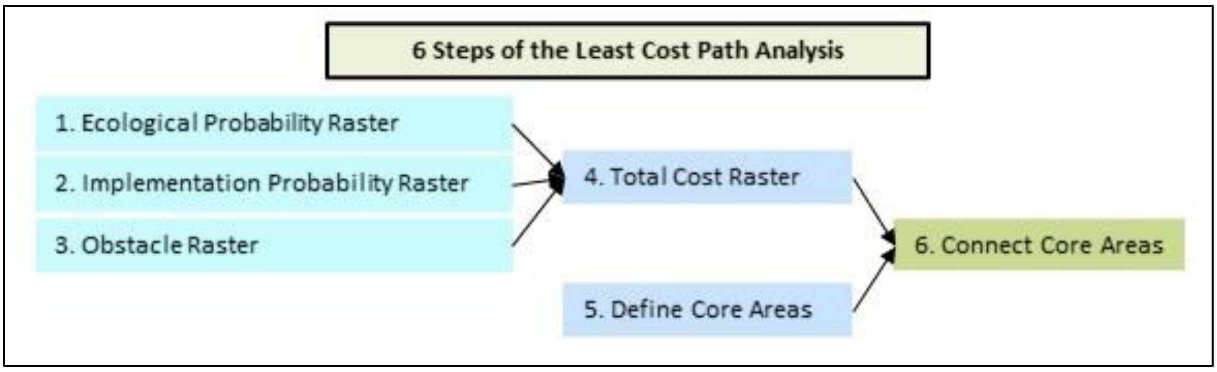

Figure 4: Overview of the 6 steps of the Least Cost Path Analysis.

All analysis steps were conducted in ArcGIS Pro (ESRI, n.d.). The exact functions and tools applied in ArcGIS Pro to conduct the LPC can be taken from Appendix 1. The geological data used for the LCP were retrieved from various sources. In order to simplify the readability of the methodological performance, all geological data were listed with their sources and simplified trivial names which were used for the methodological description in Table 3.

Table 3: Geodata used for LCP.

Trivial Name	Official Data Name	Retrieved via	Data Source	Date downloaded/retrieved	Further Information
DLM	Digitales Basis-Landschafts-modell (NAS) 50 NW	Open Data retrieved via Geoportal NRW	www.geoportal.nrw	23.06.2021	Editor: Geobasis NRW; Stand 30.03.2021
CLC	Corine Land Cover 5 ha	via https://gdz.bkg.bund.de/index.php/default/corine-land-cover-5-ha-stand-2018-clc5-2018.html	© GeoBasis-DE / **BKG** (2021)	23.06.2021	Resolution: 5 ha Stand: 19.07.2019
Street Network	Straßennetz Landesbetrieb Straßenbau NRW	Open Data retrieved via Geoportal NRW	www.geoportal.nrw	15.06.2021	Editor: Landesbetrieb Straßenbau NRW; Stand: 19.03.2018
Nature Conservation Areas	Kartenlayer Naturschutzgebiete NRW	Open Data retrieved via Geoportal NRW	www.geoportal.nrw	21.07.2021	Editor: Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen; Stand

					21.07.2021 (data are updated daily)
Landscape Protection Areas	Kartenlayer Landschaftsschutzgebiete NRW	Open Data retrieved via Geoportal NRW	www.geoportal.nrw	21.07.2021	Editor: Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen; Stand 21.07.2021 (data are updated daily)
Nature Parks	Kartenlayer Naturparke NRW	Open Data retrieved via Geoportal NRW	www.geoportal.nrw	21.07.2021	Editor: Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen; Stand 21.07.2021 (data are updated daily)
FFH	Kartenlayer FFH-Gebiete NRW	Open Data retrieved via Geoportal NRW	www.geoportal.nrw	21.07.2021	Editor: Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen; Stand 21.07.2021 (data are updated daily)
Compensation Areas, Erftverband, Public Areas	-	on request	Amt für Liegen-schafts-kataster und Geoinformation Abt. 62/1 – Liegen-schafts-kataster Team 62/12 – Liegenschafts-kataster II Rhein-Erft-Kreis, Der Landrat Willy-Brandt-Platz 1 50126 Bergheim	08.07.2021	Stand: 08.07.2021
RWE, RWE Bat, RWE Rehabilitation	-	on request	Forschungs-stelle Rekultivierung Burggasse 50126 Bergheim	07.06.2021	Stand: 07.06.02021

3.3.1.1 LCP in ArcGIS Pro - Step 1: Ecological Probability Raster

The basis for the ecological cost values was an *ecological probability raster* generated through the application of the wildcat habitat model by Klar *et al.* (2008). The usage of the model allows the quantification of habitat suitability, expressed as a function of the distance from the raster cells to the following landscape variables: forests, meadows, water courses, roads, settlements and single houses (Klar et al., 2008).

Equation 1: Equation for the calculation of logit (P) (Klar et al., 2008)

$$logit\ (P) = 1.1479 - 0.0125 * Distance\ Forest - 0.0011 * Distance\ Meadow - 0.0014 * Diestance\ Water + 0.0024 * (Distance\ Settlements - 900) + 0.0019 * (Distance\ Streets - 200) + 0.0044 * (Distance\ Single\ Houses - 200)$$

These probability values can be transferred into cost values which in turn can be used for an LCP (Klar et al., 2012). Geological data for the calculation of probability values in the study area were retrieved from the Basis DLM, CLC, Street Network and RWE Bat. In the wildcat habitat model forests are described as the most important factor for wildcats' habitat selection (Klar et al., 2008). Nevertheless, more recent studies suggest that it is not the forest itself, but the shelter in general that is the decisive factor in habitat selection (Jerosch et al., 2017, 2018; Streif et al., 2016). Therefore, the factor forest was replaced by the factor shelter in the formula. The shelter layer included all forests and woodland structures larger than 0.5 hectare in the study area as 0.5 hectare is the minimum size of sheltering structures used as stepping stones by wildcats (Hermann, 2007b). In a more detailed review of the data, it became apparent that in some cases the surface areas of roads or highways that intersected with shelter areas were included in the polygon areas of the shelter structures. The roadside greenery of a road, for example, was not separated into two polygons at each side of the road but displayed as continuous shelter polygon including the entire width of the road. In order to avoid an artificial enlargement of the shelter areas, the roads (*Kreisstraßen, Landstraßen, Bundestraßen*) and highways were cut out of the shelter structures before the size selection. For that purpose, all roads were buffered by an extend of 12 m and all highways by an extend of 31 m which represent average road and highway widths in Germany (BAST, 2015; Wikimedia, 2019). RWE bat protection areas were also included in the shelter layer. These areas are reforested by RWE for bat conservation purposes and although they might not be declared as forested land in the DLM by now they will offer shelter in the near future. In the DLM, settlement data also includes mining areas. However, mining areas were expected to pose a smaller hindrance to wildcat migration than actual settlements as anthropogenic activity at night as well as noise and light pollution are reduced compared to those of settlements. Additionally, mining areas are surrounded by vegetative structures so that the distance of 900 m wildcats keep from settlements (Klar et al., 2008) might not account for mining areas. Therefore, these areas were excluded from the settlement geodata for the probability value calculation. Another adaptation to the formula presented by Klar et al. (2008) had to be made due to a lack of data. As single houses could not be extracted from the accessible geological data, this factor was excluded from the calculation and single houses were treated as settlements.

These adaptations led to the usage of the following formula:

Equation 2 : Adapted Equation for the calculation of logit (P) (modified after Klar et al., 2008)

$$\begin{aligned} logit\ (P) = 1.1479 - 0.0125 * Distance\ Shelter - 0.0011 * Distance\ Meadow \\ - 0.0014 * Diestance\ Rivers + 0.0024 \\ * (Distance\ Settlements\ without\ Mining\ Areas - 900) + 0.0019 \\ * (Distance\ Roads - 200) \end{aligned}$$

Prior to the application of Formula 2, the available vector data had to be transferred into *distance rasters*. A resolution of 10 m * 10 m was picked for the raster cells. The output created by the utilisation of Formula 2 was processed further through the usage of Formula 3. The result was a raster dataset of the expanses of the study area coding for the probability of raster cells being selected as habitat by wildcats in dependence of the proximity to the landscape variables: shelter, meadows, rivers, settlements and streets in a resolution of 100 m^2. Probability values reached from 0 for least suitable habitats to 0.744 for most suitable habitats in the study area.

Equation 3: Transformation of logit (P) into P (Klar et al., 2008)

$$P = \frac{e^{logit\ (p)}}{1 + (e^{logit(p)})}$$

3.4.1.2 LCP in ArcGIS Pro - Step 2: Implementation Probability Raster

Two factors that influence the implementation of connectivity-increasing measures in the study area were considered in the LCP: the protection status of the areas and the ownership of land. For the LCP, five different categories of protection status were distinguished. Three of them belonged to the protected area categories defined by the Federal Nature Conservation Act (BNatSchG), namely: nature conservation areas, landscape protection areas and nature parks (§§ 22 BNatSchG) while the fourth category were areas protected under the FFH Directive 92/43/EEC. Additionally, compensation areas were considered as sort of protected areas. Compensation areas result from the execution of §15 (2) BNatSchG which declares that unpreventable disturbances of nature have to be compensated by the initiator. However, data of compensation areas were only available for the Rhein-Erft-Kreis. National parks and bird protection areas as well as national nature monuments did not occur in the study area. Furthermore, data for biosphere reserves were not available so that these could not be considered in the analysis. Consequently, the following geodata were used for the analysis of the protection status: *Nature Conservation Areas, Landscape Protection Areas, Nature Parks, FFH and Compensation Areas*.

Categories of land ownership distinguished for the LCP were: *Private landowners, RWE, RWE Bat, Erftverband and Public Areas* (owned by the towns, the federal state or other public bodies) whereas the category private landowners described all land parcels that did not fall into one of the other four categories. Land owned by RWE was subdivided into regular *RWE* areas and *RWE Bat* areas. *RWE Bat* areas are land parcels owned by RWE that are preserved for bat conservation purposes. Therefore, the implementation of further conservation measurements within these areas appeared more likely than on regular RWE areas.

The geodata for conservation statuses and landownership within the study area were converted into raster datasets with a resolution of 10 m * 10 m. Afterwards probability values representing the likelihood that conservation measures could be implemented in the designated areas were assigned to the different protection status and land ownership categories. Thereafter, each raster cell was assigned to a probability value for its protection status and one for its landownership. These two values were added up to an *implementation probability value* for each raster cell. Consequently, unfavorable conditions for the implementation of measurements were assigned to low *implementation probability values* while favorable conditions for the implementation of measurements were assigned to high *implementation probability values*. Since these *implementation probability values* needed to be comparable to the *ecological probability values*, they had to be represented on a numerical range between 0 and 1 (minimum and maximum *ecological probability values* after Klar et al. (2008)). Hence, the probability values of the protection status and land ownership categories had to be chosen in such a way that their sum did not exceed an *implementation probability value* of 1.

Within this analysis the land ownership was considered the more influential factor in comparison to the protection status. That resulted from the assumption that although protection status can set favourable conditions, in the end the landowner decides about the implementation of voluntary conservation measures. On that account probability values for land ownership were coded on a range from 0 – 0.6 while protection status categories were assigned to probability values from 0 – 0.4. The only exception were RWE bat areas. As they were considered the most probable areas for the implementation of conservation measures unbiased by their protection status, these areas were assigned to the value 1. In order to prevent that RWE bat areas that were located in a protected area reached *implementation probability values* higher than 1, these areas were cut out of all protected area polygons before the transformation into raster data.

The same issue had to be solved with all protection status categories. Since different types of protected areas often overlap rather than being sharply separated from each other, it was necessary to prevent the probability values of several overlapping protection categories from adding up in a raster cell. For the analysis, the protection category with the highest probability value was to be used. Therefore, all areas belonging to a protected area category with a higher probability value were cut out from those with a lower probability value. Since the same probability values were assigned to FFH areas and nature conservation areas for these areas it did not matter which were cut out of which. It occurred that some publicly owned areas and compensation areas overlapped with RWE Bat areas. As RWE Bat areas were assigned to the higher probability value these areas were erased from the publicly owned and compensation areas.

Chances for the implementation of wildcat conservation measures were rated as very high due to the fact that this connectivity conservation concept for the RLMA was developed in cooperation with the Rehabilitation Research Centre (RRC) of RWE, which emphasises the interest of the RRC to increase connectivity in the RLMA. This is also manifested in the biodiversity strategy for the RLMA by RWE (RWE Power AG, 2018). The bat areas of RWE were rated with a much higher probability than other RWE land parcels as those are designated to nature protection anyways. Therefore, the implementation of additional wildcat conservation measures should not encounter too many obstacles as long as they are in line with bat conservation. All other RWE land parcels were rated with higher probability values as those of private landowners based on the RWE goals formulated in the BioDiS. Nevertheless, these areas are not designated to nature conservation yet and therefore have to be weighed against other company interests which is why they resulted in lower probability values than publicly owned areas. Within the land ownership categories publicly owned areas were considered second best for the implementation of connectivity increasing measurements. The biodiversity strategy of NRW determines that 15 % of the federal State's area have to be turned into a network for connectivity conservation (MKULNV, 2015). Hence, administrative organs have an interest in counteracting ecosystem fragmentation and therefore an increased willingness to designate land to connectivity conservation compared to private persons or companies. Since it was not possible to derive a reliable assessment of the willingness to contribute to a wildcat connectivity concept of all private persons or companies in the study area other than RWE, privately owned land as well as land owned by companies other than RWE were assigned to the probability value of 0. This valuation was not based on the assumption that the willingness of private landowners or all companies except RWE to contribute to connectivity conservation is in general low but on the fact that every privately or company owned land parcel that is required for the implementation of the concept equals at least one additional stakeholder. These stakeholders first have to be convinced to agree to measures and then to be guided to actually execute the agreed measures. Thus, every additional stakeholder translated into increased effort for the implementation and also to an increased likelihood for hindrances in the implementation process. Although the Erftverband itself is a public law body committed to the common – and environmental well-being, the probability of the introduction of measures on its properties was rated medium as it is already composed of representatives of six different interest groups (Erftverband, n.d.).

The assignment of probability values for the different protection status categories were oriented towards the strictness of the protection requirements imposed by the Federal Nature Conservation Act. Accordingly, more strictly protected areas were assigned higher probability values as the protection of nature has a higher priority in these areas. Hence, nature conservation areas got the highest probability value while landscape protection areas and nature parks were assigned lower probability values. Although compensation areas do not have a legally defined protection status, they must be legally secured by the party causing the intervention and the duration of the compensation measures must not be limited in time. The necessary compensation measures are calculated on the basis of the quality of the biotope disturbed by the intervention. Compensation can be achieved by the qualitative enhancement of another biotope (De Witt & Geismann, 2011). Since the additional implementation of wildcat conservation measures would in principle lead to an increase in the biotope quality of the compensation areas, the probability of their implementation was also considered to be high. As FFH areas are strictly protected under European law and wildcats are listed in Appendix IV of the FFH species (92/43/EEC), they were also assigned to the highest probability value. The assignment of probability values is shown in Table 4.

Table 4: Implementability probability values assigned to the different protection status and land ownership categories.

Factor	Category	Probability value
Protection status	Nature Conservation Area	0.4
	Landscape Protection Area	0.2
	Nature park	0.1
	FFH	0.4
	Compensation Area	0.4
Land ownership	Publicly owned Areas	0.6
	Private Areas	0.0
	RWE	0.3
	RWE bat	1.0
	Erftverband	0.3

The resulting probability rasters were all summed up to one *implementation probability raster*. A side effect of the conversion process from vector to raster data was that the borders of polygons were not shaped as accurately in raster data as coded in vector data. That resulted in the overlapping of rasters in border areas of former adjacent polygons and thus in probability values higher than 1. Therefore, the *implementation probability raster* was received by reclassifying all probability values higher than 1 to 1.

3.4.1.3 LCP in ArcGIS Pro - Step 3: Obstacle Raster

Although the transversion of the habitat model by Klar et al. (2008) into cost values allows the differentiation between preferred and less preferrable conditions for wildcat migration, the clear hindrance of migration or the great risk that can result from some landscape features was not yet considered in the calculations. Hence, environmental conditions that act as a barrier or obstacle for wildcats were assigned to additional cost values. That way a passage across these obstacles was prevented in the connectivity model unless it was absolutely necessary (Klar et al., 2012). In practice obstacles or barriers were transferred into raster data and assigned to different cost values. At last, the different cost rasters were added and thus combined to one *obstacle raster*. Geodata used for that process were: DLM, Street Network and a self-created polygon layer for green bridges. As well as in Klar et al. (2012) settlements and lakes were regarded as barriers and therefore assigned to cost values of 1000. This time mining areas were not excluded from the settlement data. Although wildcats might not keep a certain distance to mining areas as the anthropogenic activity is low during the nights, a passing through them is not possible. Therefore, mining areas were treated as settlements in this context. Rivers were not taken into account in this study as the only rivers in the study area are the Erft and the Rur across which wildcats are able to swim (Dr. Thiel-Bender 2021, personal communication). In contrast to Klar et al. (2012) not only highway junctions but the complete highways were accredited with a cost value of 500. For that purpose, highways were buffered with a width of 50 m and not only 31 m to prevent that roadside greenery of highways was used as main travel axis in the model. Although a crossing of highways is possible for wildcats, traffic is also the greatest danger to the animals and should therefore be avoided if possible (Hermann & Mathews, 2007). The high cost value was not only assigned to the whole length of highways in the study area to prevent unnecessary crossing, but also to promote crossing at the most favorable places if necessary. The study area is equipped with two green bridges that lead over highways. The usage of the existing structures in the LCP was promoted by assigning high cost values along the complete highways except for the green bridges. In practice that was done by creating polygons resembling the green bridges, converting those into raster data and assigning them to cost values of -995. Satellite pictures (Esri et al., 2021) as well as the extend of the buffered highways served as template for the bridge polygons. Through the addition of all obstacle-resembling rasters the green bridges resulted into a cost value of 5. Roads with a traffic density higher than 2500 mv/d are only crossed by wildcats at night or during times of low traffic (Klar et al., 2009). Thus, although a safe crossing of roads with a traffic density of 2500 mv/d is possible, they were assigned to cost values of 300. The buffer zone for roads was increased to 20 m, again to prevent roadside greenery to be weighted too heavily. There is also one additional green bridge leading over a country road with a traffic density of more than 2500 mv/d. The procedure of including this green bridge in the analysis was the same as for the other green bridges except the cost value of the bridge was set to -295 as the road it crosses had a cost value of 300. The investigation of the first LCP output showed that in some cases roundabouts or road crossings created gaps in the Street Network polylines. These resulted in inexact raster data translation as these areas were not assigned to cost values and hence mistakenly recognised as paths of least restrain. To solve this problem, polylines of roads or highway sections where this problem was noticed were corrected manually. Furthermore, the resolution for the road raster was increased to 5 * 5 m. In the 10 * 10 m resolution more curvy sections of the roads were converted into rasters that were only at tangent to each other at one vertex. This is why in some parts the roads' width was only represented by the contact point of two raster vertices. As the path of least restrain created by the LCP was a polyline, these points were mistakenly valued as areas without additional cost values and thus proposed as best crossing points. The correction of the road cost raster resolution and the increase of the buffer zone of the roads to 20 m fixed this problem.

3.4.1.4 LCP in ArcGIS Pro - Step 4: Total Cost Raster

In order to combine the *ecological probability raster* with the *implementation probability raster* the weighted sum of both rasters was calculated. The impact of the ecological equipment of the study area was weighted slightly higher than that of the *implementation probability* as the ecological equipment of the landscape also influences the implementation of a connectivity concept. In an area with favorable conditions for wildcats less measures have to be implemented to enable migration while areas with unfavorable conditions translate into more effort to make them migratable and thus face higher hindrances in implementation. Consequently, the *ecological probability raster* was weighted with 0.6 and the *implementation probability raster* with 0.4. As demonstrated in Klar et al. (2012) the combined probability values were translated into cost values using three different mathematical conversions. Through the usage of the formulas the *ecological probability values* and the *implementation probability values* were converted into *cost values* meaning that unfavorable conditions for wildcat migration or implementation of measures from there on were represented by high cost values while favorable conditions were represented by low cost values. The usage of three different transformation values on the combined probability raster allowed the calculation of the path of least restrains with three different cost rasters with differently weighted valuations of the cost values and hence the output of three possible connectivity paths. These three options were used to identify the most robust version of a connectivity path in a later step (Klar *et al.*, 2012).

Equation 4: First Equation for the conversion of probability values into cost values (modified after Klar et al. 2012)

$$Cost\ 1 = (0.744 - P) * 100$$

Equation 5:Second Equation for the conversion of probability values into cost values (modified after Klar et al. 2012)

$$Cost\ 2 = \sqrt{(0.744 - P) * 100}$$

Equation 6:Third Equation for the conversion of probability values into cost values (modified after Klar et al. 2012)

$$Cost\ 3 = 1 + (ln\ ((0.744 - P) * 100))^2$$

Afterwards the *obstacle cost raster* was added to all three cost rasters resulting in three separate *total cost rasters*.

3.4.1.5 LCP in ArcGIS Pro - Step 5: Define Core Areas

In order to develop a connectivity conservation concept for the rehabilitated forest areas of the RLMA, core areas which were supposed to be connected through the concept had to be defined. Core areas were delineated from each other in that way that within a core area the wildcat's migration was not hindered by any obstacles while the unhindered migration between the core areas was not possible or posed a great risk on the wildcats. Barriers were defined as settlements, highways, roads with a traffic density higher than 2500 motor mv/d as those are rarely crossed by wildcats or the crossing poses great risk upon them and landscapes providing no shelter (Hermann, 2007b; Klar et al., 2008, 2009). Since wildcats migrate distances of at least 500 m through unsheltered landscapes (Hermann et al., 2007b; Simon, 2010), unsheltered areas were only considered as barriers if they created distances of more than 500 m between two shelter structures (at least 0.5 ha). Geodata used for this process were RWE Rehabilitation and DLM. All adjacent rehabilitated forest areas that were not intersected by one of the named obstacles were joint together to one forest area. These areas were expanded by adjacent forest areas or woodland that did not result from rehabilitation efforts until they reached one of the named obstacles. The expansion by non-rehabilitated forest structures is reasonable as wildcats do not know if the areas which they cross were shaped by rehabilitation or not so the decisive factor was the unfragmented character of the forested areas. Wildcats require large unfragmented forest areas for their home ranges (Birlenbach & Klar, 2009). Therefore, it would have not made sense to develop a connectivity concept that considers every small forest or woodland patch to one another. Hence a threshold of 200 ha for core areas was chosen as this is the smallest size of a female wildcat's home range (Birlenbach & Klar, 2009). Smaller forested structures were still considered as connective features between the core areas in the analysis. All in all, 13 core areas were delineated within the study area, whereas the fragmentation of these areas was mainly caused by highly frequented roads (Figure 5).

Figure 5: Core areas overview.
The different core areas were assigned to names for identification. The names refer to nearby villages or landscape features. In order to avoid confusion between villages and core areas, numbers were added to the core areas' names. The numbers visualized in the map correspond to the names of the core areas as follows: 1 = Ville1; 2 = Ville2; 3 = Ville3; 4 = Ville4, 5 = Hürth1, 6 = Berrenrath1; 7 = Kerpen1; 8 = Horrem1; 9 = Bergheim1; 10 = Bergheim2; 11 = Paffendorf1; 12 = Frimmersdorf1; 13 = Sophienhöhe1. Data source base map: Land NRW, LVermGeo RP, Kadaster, Esri, HERE, Garmin, METI/NASA, USGS; Land NRW, Earthstar Geographics. This basemap was used for various other maps created for the purpose of this study and is referred to in the following as: "Esri Imagery Hybrid".

3.4.1.6 LCP in ArcGIS Pro -Step 6: Connect Core Areas

Three cost connectivity analysis were conducted with the three different *total cost rasters* and the *core areas* as input. As output the potential connective networks between the core areas were generated. In order to identify the most robust variant of the three pathways another cost connectivity analysis was conducted with a cost raster that coded lowest cost values for raster cells sections where all three potential paths overlapped, medium costs for raster cells where two paths overlapped, high costs for raster cells that were delineated by single paths only and extraordinary high costs of 1000 for all raster cells that were no part of one of the three derived potential paths. The result was the most robust connectivity pathway with regard to all three mathematical variations of the probability values (Klar et al., 2012) and thus the final connectivity path. The final path also displayed the "cheapest" route through the core areas. However, as wildcats can move freely within the core areas, these parts of the path are irrelevant. Therefore, sections of the connectivity path within core areas were deleted. Instead, the complete expanses of the core areas are regarded as part of the connectivity path (see also Klar, 2009b).

3.4.2 Identification of potentially critical and potentially useful structures along the least cost path

Critical points were defined as those spots along the final connectivity path proposed through the LPC where wildcats would face barriers or obstacles if they would follow that path. According to the results of the literature review and communication with experts (section 3.3) settlements, highways, roads with a traffic density higher than 2500 mv/d and areas without shelter wider than 500 m were considered critical points and potential barriers or obstacles. Consequently, all points where the proposed connectivity path intersected one of those structures were marked as potential obstacles or barriers. Additionally, areas that gave the impression of unfavorable conditions for wildcat migration along the path like sheltered but narrow sections between two barriers were also regarded as potential critical points. The surrounding environment of those critical points was then scanned for potential crossing-, corridor- or steppingstone structures and alternative paths. All these structures were identified by the use of geodata from the LCP and satellite pictures. In cases where the obstacles hindering migration between the core areas were roads or highways, the focus of the problem analysis did not lay on the exact crossing point shown in the LCP result but on the complete section of the road or highway separating the core areas from each other. Within these sections, the satellite pictures were investigated for potential crossing structures like underpasses or bridges in cases of road and highway obstacles or for potential alternative routes for other types of obstacles and barriers. In cases where the potential obstacles or barriers were characterized by unsheltered land, the environment was checked for potential corridor or steppingstone structures. For easier identification all potential obstacles or barriers, crossing-, corridor-, or steppingstone structures and alternative paths were assigned to an identification number. All potential obstacles or barriers were assigned to the letter O and alternative paths to the letter P. Both were then assigned to an individual identification number (e.g., O1 or P1). Potential crossing-, corridor-, or steppingstone structures were assigned to the letters S marked with two numbers: the first one assigning them to the related obstacle and the second for individual identification (e.g., S1.2). Potential crossing structures that were not directly related to an obstacle or barrier were assigned to the number 0 (e.g., S0.2).

3.4.3 On-site explorations

A representative selection of some critical points and potential crossing structures was investigated on site during a field trip accompanied by Dr. Thiel-Bender, Dr. Raedig and Henning Walther on June, 8th 2021. During this excursion Dr. Thiel-Bender was kindly asked to give assessments about the situation at the critical points and possible crossing structures as well as propositions for improvement of the situation in place from a wildcat expert's point of view (some statements were introduced in section 3.3). Structures visited during the excursion were: S0.1, S4.1, S6.1 and P1 (Table 5). The time the excursion was planned the main objective of the study was the concept for a connective path between the Ville Forest and the Sophienhöhe. However, during the process, the main objective changed from the development of a connective path between the Ville Forest and the Sophienhöhe to a connectivity concept for the rehabilitated forest areas of the RLMA. That affected the outcome of the LCP so that five additional spots that were visited during the excursion did not occur in the final connectivity concept.

The remaining critical points, alternative routes and potential crossing structures were explored unaccompanied on further on-site explorations, which took place by car, by bicycle or on foot. The assessments of these locations and structures followed the example of Dr. Thiel-Bender and incorporated the insights gained on the joint excursion.

Table 5: List of structures investigated during the on-site explorations.
Pictures of the on-site explorations are shown in Appendix 4. Pictures were taken on the day of the exploration except for: O4 – pictures taken on 06.06.2021, S.01 – pictures taken on 17.03.2021 and S.4.1 – pictures taken on 06.06.2021. Exploration methods were divided in three categories: on foot, by bicycle and by car. Explorations by car took place on roads that could not be approached by foot or bicycle due to missing infrastructure and high traffic volumes. Here the explorations took place by driving along the road by car and examining the roadside greenery and other possible influential factors as good as possible as well as watching out for structures (like railings) that indicated the existence of underpasses of any kind. In some cases, it was possible to stop by the side of the road to investigate potential under passing more closely. In these cases the exploration method was recorded as "by car with stops".

Structure type	Structure	Explored by	Date of exploration	Exploration method
Obstacles	O1	Merk	12.08.2021	by bicycle
	O2	Merk	12.08.2021	by bicycle
	O3	Merk	17.08.2021	on foot, by car
	O4	Merk, Dr. Raedig, Dr. Thiel-Bender, Walther	08.06.2021	on foot, by car
	O5	Merk	09.09.2021	on foot
	O6	Merk	09.09.2021	on foot
	O7 - O10, O12	Merk	09.09.2021	by car
	O13	Merk	05.09.2021	on foot, by car
	O14	Merk	09.09.2021	by car
	O15, O17, O18	Merk	12.09.2021	by bicycle
	O16	Merk	12.09.2021	by car
alternative Paths	P1	Merk, Dr. Raedig, Dr. Thiel-Bender, Walther	08.06.2021	on foot
	P2	Merk	12.09.2021	by bicycle
Potential crossing structures	S0.1	Merk, Dr. Raedig, Dr. Thiel-Bender, Walther	08.06.2021	on foot
	S0.2	Merk	27.10.2021	on foot
	S0.3	Merk	27.10.2021	by car with stops
	S1.1	Merk	12.08.2021	by bicycle
	S2.1 - S2.2	Merk	12.08.2021	by bicycle
	S3.1 - S3.3	Merk	17.08.2021	on foot
	S4.1	Merk, Dr. Raedig, Dr. Thiel-Bender, Walther	08.06.2021	on foot
	S7.1	Merk, Dr. Raedig, Dr. Thiel-Bender, Walther	08.06.2021	on foot
	S8.1	Merk	27.10.2021	on foot
	S8.2	Merk	09.09.2021	by car with stops
	S9.1 - S9.2	Merk	09.09.2021	on foot
	S14.1 - S14.2	Merk	09.09.2021	on foot
	S15.1, S17.1, S18.1	Merk	12.09.2021	by bicycle
	S16.1	Merk	16.09.2021	by car with stops
	S16.2	Merk	16.09.2021	on foot
	S16.3	Merk	27.10.2021	on foot

3.4.4 Assessment of potentially critical and potentially useful structures along the least cost path

The potentially critical and potentially useful structures along the least cost path were now assessed on the bases of the compiled data introduced in section 3.3, the on-site explorations and the insights gained through the excursion accompanied by Dr. Thiel-Bender. Potential crossing structures, corridors and stepping stone structures were subdivided according to whether or not they were suitable for wildcats' use and whether they really increased connectivity along the least cost path. Structures that could be made usable for wildcats through the implementation of measures were also classified as usable. Critical points along the path were subdivided in barriers, which were structures that were impossible for wildcats to pass and obstacles which hold unfavourable conditions or risks for wildcats' migration but are in general surmountable by wildcats.

3.4.5 Expert interviews I: assessment of road-related wildcat conservation measures

For this assessment, a list of road-related wildcat conservation measures was read out to the experts. In order to increase the comprehensibility, the measures were also visible for the expert either on screen or on handouts. The wildcat experts were asked to rate these measures on two scales. First, to rate how difficult it is to achieve the actual implementation of these measures at already existing roads. Answering options for this assessment were *not at all implementable, not implementable, medium implantability, implementable, very implementable* and *I do not know*. Second, the effectiveness of road- related measures was assessed using the answering options *not effective at all*, *not effective*, *medium effectivity*, *effective, very effective* or *I do not know*. The experts were encouraged to give supplementary explanations to their ratings if they found it necessary.

3.4.5.1 Analysis of the assessment of road-related wildcat measures and ranking of the measures

In order to evaluate the results gained through the expert interview, the answering options of the different rating scales were transferred into numerical rating values for further analysis. Table 6 shows the options of the rating scales with the assigned rating values. In case the experts answered with I do not know, the answer was not assigned to a numerical value and not included in the ongoing analysis process. In some cases, the answers of the experts could not be assessed to one exact answering option of the scale but were in between two different answering options. In these cases, the worse of the two possible rating options was used for further evaluations.

Table 6: Rating values assigned to answering options for the assessment of road-related wildcat conservation measures.

Rating options wildcat conservation measures (road-related)	numerical value
not at all effective / not at all implementable	1
not effective / not implementable	2
medium effectiveness / medium implementability	3
effective / implementable	4
very effective / very implementable	5

For the comparability of the measures among each other, average values of the experts' assessments regarding implementability and effectiveness were calculated. The measures assessed were then assigned to two different conservation purposes: the prevention of wildcat-vehicle-collisions and the provision of safe crossing structures. Based on the mean values, a ranking of the measures was created, indicating which of the measures would preferably be proposed in the subsequent action plan. Measures that were assessed as both effective and implementable were positioned on top of the ranking and generally preferred in the action plan.

3.4.6 Selection of measures for the connectivity action plan

The final step in creating the connectivity action plan was to propose appropriate measures to overcome the identified obstacles and barriers. For this purpose, all collected results from the literature research, the expert interviews, the expertise of Dr. Thiel-Bender and on-site explorations were compiled. The expert interviews and the subsequent ranking of road-related measures served to identify the most effective and at the same time most implementable measures, so that measures to overcome traffic-related obstacles and barriers could be easily derived from the ranking. Although the ranking provided a good impression of which measures suited best for the two purposes in terms of practicability and effectiveness, the actual situation in place played a major role regarding the suitability of the measures. The measure placed first in the ranking was not necessarily the most appropriate measure for all critical points. Therefore, in some situations lower ranked measures were proposed in the connectivity action plan if they were more suitable for the specific situation in place.

3.5 Methods used to develop the habitat quality action plan

To develop the habitat quality action plan, a habitat quality assessment and an assessment of commonly used forest management-related wildcat conservation measures were conducted. The habitat quality assessment served the investigation of the ecological status-quo of the *core areas*. The evaluation of the measures helped to identify the most practicable and effective measures to counteract deficits in the *core areas*. Suitable measures were then assigned to the *core areas* in an action plan.

3.5.1 Expert interview II: Habitat quality assessment

To be able to have the habitat quality rated by experts, the forest areas within the study area needed to be subdivided into structurally similar *habitat areas*. As this delineation of different areas was not based on barriers as it was for the *core areas* but rather on the age structure and applied forest management strategies, detailed knowledge of the forest areas was necessary for the sensible division. Therefore, the delineated *habitat areas* were reviewed and revised in cooperation with the experts Frank Pechtheyden and Michael Stoffels before the interviews were conducted. Forest areas that were smaller than 200 ha but showed off as important connecting fragments between the *core areas* in the LCP were also considered in the delineation process of the *habitat areas*. Furthermore, areas, that were not included in the connectivity concept through the LCP but were in close proximity to *core areas* so that they constituted room for potential alternative connections were included in the habitat quality assessment. The *habitat areas* „Erbwälder, „Lörsfelderbusch and Dickbusch“ and „Parrig and Kerpener Bruch“ were originally not considered for the habitat quality assessment. Nevertheless, they were identified as structurally similar regions and delineated by Günther Roland and assessed by the other experts in order to be able to include those areas in the action plan in case they developed unexpectedly into essential areas for the connectivity concept during the ongoing analysis. Since this did not happen, these results were not discussed in detail but can be seen in Appendix 5. All in all, 14 different habitat areas were delineated (Figure 6).

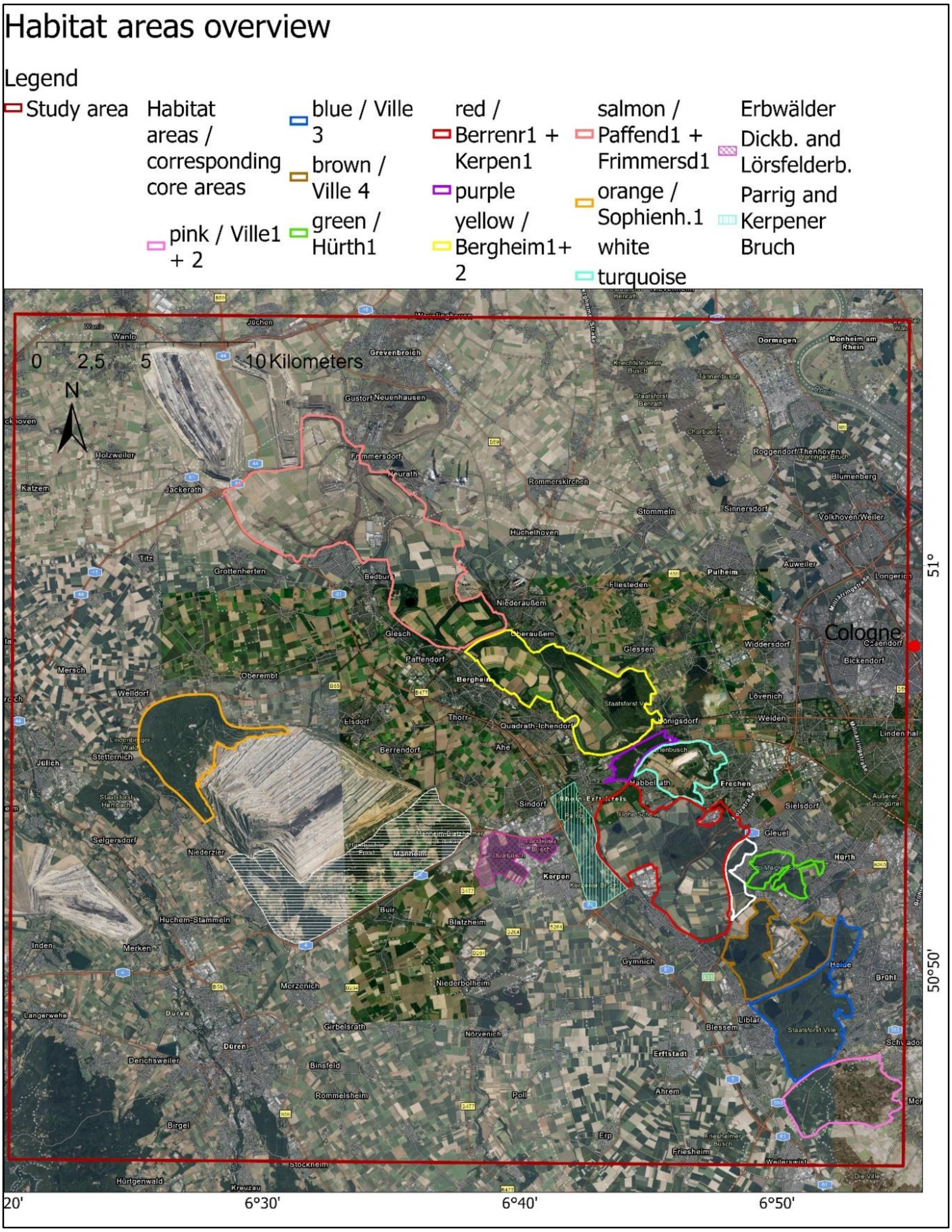

Figure 6: Habitat areas overview.
Coloured lines delineate the different habitat areas. The core areas located within the habitat areas are listed in the legend after the "/". The turquoise and white habitat area did nit incorporate any core areas as well as the habitat areas Dickbusch and Lörsfelderbusch, Erbwälder, and Parrig and Kerpener Bruch. For a better overview the names of "Paffendorf1", "Frimmersdorf1", "Sophienhöhe1", "Dickbusch" and "Lörsfelderbush" were shortened. Base map: Esri Imagery Hybrid.

Experts asked to rate the habitat quality were either forestry experts or RLMA experts. Four different factors influencing the habitat quality with regard to the needs of the wildcat were rated for the habitat quality assessment: structures for breeding, structures for daytime hiding places, food supply and anthropogenic disturbances. The rating scale for the first three factors reached from *rare* [0 – 0.5 structures per hectare] over *medium* [0.5 – 1 structure per hectare] to *high* [> 1 structure per hectare]. The quantification of the scale steps rare, medium and high was developed with and validated by Dr. Thiel-Bender. Since more than one structure per hectare was regarded as high structure abundance by the wildcat expert a further subdivision of the rating scale from a three-point into a five-point scale was regarded not conductive. A further subdivision would have diminished the intervals of the rating scale from 0.5 to 0.25 so that the expert would have had to assess the abundance of structures in units of 0.25 structures per hectare which did not seem applicable. Even the range within the three classes of the scale, was assumed to be hard to apply on the matter. Therefore, it was pointed out to the interviewed experts that the numerical scale was a guide to get an initial idea of how to quantify the rare, medium and high stages, but that the most important thing was that the assessed proportion between the different *habitat areas* was realistic. For the ratification of the fourth factor, a five-point scale was used. The proportion of areas with low anthropogenic disturbances could be assessed with: *very low* [<10 %], *low* [11 – 30 %], *medium* [31 – 50 %], *high* [51 – 70 %] *very high* [> 70 %]. The experts could also answer with "I do not know" at any point of the interview. The experts were also asked to give short explanations for their ratings which resulted in descriptions of the conditions in place. Thereby more specific measures could be proposed in the action plan.

In order to determine which habitat areas each expert knew well enough to be able to assess them according to the four criteria, they were presented a map in the preliminary briefing, showing the different *habitat areas*, which were delineated with different colours. To ease the communication, the habitat areas were named after their borderline colour during the preliminary briefing and the interview. In order to give the experts a more precise idea of how detailed their knowledge of the habitat areas had to be for their assessment, they were given some exemplary structures which are suitable for breeding or as daytime hiding places. Then it was highlighted that the habitat quality assessment was about estimating the abundance of such structures in the habitat areas using the presented scales. Afterwards the experts named the *habitat areas* they knew well enough to rate, and the actual interview started. The map that showed the delineation of the different *habitat areas* was open as reference source for the experts along the whole time of the interview. The definitions of structures that can work as breeding places, structures that work as daytime hiding places, structures that increase food availability and structures with low anthropogenic disturbances were read out to them and could be reviewed by the experts during the complete time of the interview. That was necessary as the experts rating the *habitat areas* had the local knowledge to assess the abundance of structures that create favourable conditions for the wildcat but did not necessarily know which exact structures that were. The definitions were reviewed by Dr. Thiel-Bender before the interviews were conducted. The interviews were organized in such a way that the experts assessed the abundance of one of the four habitat quality determining factors for all habitat areas the expert knew before moving on to the next factor.

3.5.1.1 Analysis habitat quality assessment

For the habitat quality assessment different experts were asked to rate four different factors of habitat quality within previously delineated habitat areas. In contrast to the *core areas*, the focus for the delineation of the *habitat areas* was placed on a similar ecological character within the areas rather than on an unhindered migration of wildlife through the delineated areas. The differentiated division into *habitat areas* was important for the habitat quality assessment. However, in order to provide a better overview in the habitat quality action plan drawn up later, the proposed measures should be clearly based either on the division of *habitat areas* or on the division of *core areas*. The *core areas* were better suited for that purpose as the connectivity action plan was also addressed through the *core areas*. Furthermore, the delineation of both area types showed that in most cases one *core area* could be assigned to exactly one *habitat area* but in some cases one *habitat area* incorporated two *core areas*. Thus, the focus on the *core areas* enabled the discussion of measures on a smaller scale. To increase the traceability for the further course of the connectivity concept, from here on, reference is made to the *core areas* also for the results of the habitat quality assessment. In practice that means that the results of the habitat quality assessment are presented with reference to the expanses of the *core areas* instead of the *habitat areas*. *Core area*s located within the same habitat area thus gained the same results in the habitat quality assessment. The *habitat areas* “turquoise” and “white” did not correspond to any core area and are therefore further on listed under their habitat area names.

Like the results of the interview with the wildcat experts, the results of the habitat quality assessment had to be translated into numerical values in a first step (Table 7).

Table 7: Rating values assigned to answering options for the habitat quality assessment.

Rating options habitat quality assessment	numerical value
rare [0 – 0.5 structures per hectare]	1
medium [0.5 – 1 structure per hectare]	2
high [> 1 structure per hectare]	3
very low [<10 %]	1
low [11 – 30 %]	2
medium [31 – 50 %]	3
high [51 – 70 %]	4
very high [> 70 %]	5

For the further analysis of the habitat quality assessment, the rating values of the three-point and five-point answering scales used for the habitat quality assessment had to be transformed so that all rating values were represented in the same numerical range. Therefore, the rating values of the habitat quality factor “low-disturbance areas” were divided by five and the rating values of the remaining three factors by three. As a result, the ratings for all four habitat quality factors were displayed on a value range from 0 – 1. In a next step mean values of the ratings from the different experts were calculated for each core area and habitat quality factor. In order to evaluate which habitat quality factor was rated best across all core areas, the mean rating values for the same habitat quality factor of all core areas were summed up.

Equation 7: Calculation of total habitat quality factor rating.

$$total\ habitat\ quality\ factor\ \ rating = \sum (Mean\ rating\ value\ of\ \ habitat\ facor\ (x))_{Core\ area\ 1-14}$$

To be able du compare the overall habitat quality of the different *core areas* to one another, the total core area quality was calculated by summing up the mean values of all four *habitat quality factors* for each *core area*.

Equation 8: Calculation of total habitat quality.

$$total\ habitat\ quality\ = \sum \textit{(Mean rating values of all four habitat factors for core area (x))}$$

3.5.2 Expert interview III: assessment of forest management-related wildcat conservation measures

3.5.2.1 Practicability Assessment

For the practicability assessment of the forest management-related conservation measures, the forestry experts were asked to rate wildcat conservation measures for their practicability on a five-point scale with the options *not practicable at all*, *not practical*, *medium practicability*, *practicable* and *very practicable*. The experts could also answer with *I do not know*. Ratification of the conservation measures by the forestry experts took place directly after the habitat quality assessment within the frame of the same interview. The conservation measures originated from a collection of wildcat conservation measures that was provided by Dr. Thiel-Bender (Thiel-Bender, 2020). This collection was based on her own experience and on measures proposed by Trinzen and Behrmann (2015) and Hermann (2005) .During the interview, the measures were read out to the experts but to increase the comprehensibility, the measures were also visible for the expert either on screen or on handouts. The experts were encouraged to give supplementary explanations to their ratings if they found it necessary.

3.5.2.2 Effectivity Assessment

Wildcat experts were asked to rate the same forest management-related wildcat conservation measures as the forest expert but with regard to their effectiveness. The rating scale offered the following options: *not at all effective*, *not effective*, *medium effectiveness*, *effective* and *very effective*. The experts could also answer with *I do not know*.

3.5.2.2 Analysis of the assessment of forest related wildcat measures and ranking of measures

The Forest management-related wildcat conservation measures were rated for their effectivity by three different wildcat experts and for their practicability by four different forestry experts. Analogue to the analysis of the results of the previously introduces expert interviews, the answering options for the assessment of effectivity and practicability were translated into rating values as shown in Table 8. In a next step mean values of the assessments given by the experts for the introduced measures regarding their effectivity and practicability were calculated.

Table 8: Rating values assigned to answering options for the assessment of forest management-related wildcat conservation measures.

Rating options wildcat conservation measures (forest management-related)	numerical value
not at all effective / not at all practicable	1
not effective / not practicable	2
medium effectiveness / medium practicability	3
effective / practicable	4
very effective / very practicable	5

The forest related measure “Remaining and support coppicing as forest management strategy” was only rated by one wildcat expert and two forestry experts. The other experts answered with I do not know. Therefore, this item was not included in the further analysis. For all remaining measures mean values of the ratings given by the different experts were calculated for the effectivity and the practicability. Due to the great similarity of the measures “Remain 5 - 10 % of big windthrow areas and ca. 5 root plates per hectare” and “Remaining parts of windthrow with ground level structures untreated”, they were combined into the measure "Remaining the largest possible parts of windthrow untreated". The rating values for effectivity and practicability for this measure were generated by calculating the mean values for both factors of the original measures. Next the measures were assigned to five different conservation purposes according to the outcome of the different conservation measures (Table 9).

Table 9: Allocation of forest management-related wildcat conservation measures to their conservation purpose. The assignment of the measurements' purposes was taken from Dr. Thiel-Bender's table of measures (Thiel-Bender, 2020; Trinzen & Behrmann 2015; Hermann (2005) and from the interview with Dr. Thiel-Bender.

Measures	Provision of breeding structures	Provision of day-time resting places	Increase of food supply	Reduced anthropogenic disturbances	Successful upbringing of cubs
Remaining biotope trees and deadwood in the stand.	X	X			
Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand.	X	X			
Stockpiling of crown wood	X	X			
Support natural forest rejuvenation, prioritising natural rejuvenation before other rejuvenation strategies		X	X		
Establish richly structured forest edges		X	X		
Remaining meadows through extensive management.			X		
Renunciation on thinning in forests stands younger than 5 years between April and July				X	X
Designate areas suitable for breeding and if possible, postpone intensive management measures between Sep. and Feb.				X	X
Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood.				X	X
Renunciation of rodenticides					X
Controlling wood stacks before removal					X
Controlling root plates before folding them back.					X
Remain the largest possible part of windthrow areas untreated		X	X	X	X

The measures that were assigned to the same purpose were then compared with each other in terms of their effectiveness and efficiency. The aim was to rank the measures in a way that shows which measures are preferably proposed to increase habitat quality in the core areas. If for example three measures serve the purpose to increase daytime resting places these three measures are compared to each other with regard to their effectivity and practicability. The measure with the best balance between these two factors is ranked in first place and consequently preferably proposed in the habitat quality action plan.

3.6 Selection of measures for the habitat quality action plan

In order to present the collected results of the habitat quality assessment and the last interviews in a usable form, they were compiled in an action plan. appropriate measures were. All *habitat quality factors* within a *core area* that gained a mean rating value ≤ 0.5 were identified as *deficits*. Here appropriate measures based on the prescribed ranking were proposed. Measures to increase habitat quality were also proposed for *habitat quality factors* with mean rating values of 0.51 – 0.8 and therefore classified as *improvable*. *Habitat quality factors* within a *core area* with a mean ration value of ≥ 0.8 were classified as *sufficient*. Hence no measures were proposed here. In some cases, specific circumstances within the *core areas* required that, despite their high practicability and effectiveness, not always the best but lower-ranked measures, according to the ranking were proposed. Furthermore, the implementation of the measure "Remaining the largest possible parts of windthrow untreated" was proposed for all *core areas* due to its multiple positive effects and high effectiveness. However, as this measure was only moderately practicable, it is proposed in the most practical way for forest workers, depending on the situation.

4 Results

4.1 Results concerning the connectivity action plan

In the following section all results, that contributed to the development of the connectivity action plan in the RLMA are presented. They are outcomes of the methods described in section 3.4.

4.1.1 Least Cost Path, on-site explorations and classification of potential critical points and potential useful structures

The delineation of the of the *core areas* showed that traffic infrastructure was the main cause for habitat fragmentation in the study area. 11 out of 12 core areas were separated from each other by crossing roads with more than 2500 mv/d. Only Sophienhöhe1 was separated from the other *core areas* by agriculturally dominated landscapes. Accordingly, 17 out of 18 identified obstacles or critical points along the identified l*east cost path* and *alternative paths* were roads with a traffic density of more than 2500 mv/d. The connective path along the *core areas* was subdivided into eight sections, whereas this subdivision did not follow any other guidelines but to depict all parts of the *least cost path* along with the identified critical point and potential crossing structures in a resolution of 1 : 26000 to 1 : 30000. For a more comprehensive presentation of the results, the findings of the LCP and the on-site explorations are described together, following the subdivision of the sections. The on-site explorations confirmed that the previously identified critical points were all obstacles or barriers. The classification of the potential crossing- corridor- and stepping stone structures resulting from the on-site exploration and the information gained from literature and experts are also presented in the following.

4.1.1.1 LCP and on-site explorations – Section 1

The core areas Ville1 and Ville2 were separated by the L194, also called Phantasialandstraße (O1; > 2500 mv/d) along a distance of ≈ 3.6 km (Figure 7). The most suitable crossing point identified through the LCP was located at about two thirds of the way northwards (Figure 7). The underpass of a riding track was identified as potential crossing structure (S1.1) and assessed as suitable for the usage by wildcats, as the proportions are meant to allow the passing by horses. Furthermore, the end of the underpass was clearly visible and light and the ground was covered with sand (pictures see Appendix 4). A cycle path was located along the southern side of the L194 as well as a narrow strip of grass between the cycling path and the street so that wildlife crossing the road from south to north does not walk immediately on the roadway when leaving the shelter. The core areas Ville2 and Ville3 were fragmented by the highway A553 along a distance of 1.8 km (Figure 7). The highway was located slightly higher, compared to the surrounding environment, so that a wooded slope delimited the highway from the core areas Ville2 and Ville3. Two service road underpasses (S2.1 and S2.2) allowed a safe crossing underneath the A553 which were also suitable for wildcats as the expanses of the underpasses were constructed for motor vehicles and humans. The end of the underpasses was bright and clearly visible from both sides. The ground is covered with gravel (pictures see Appendix 4).

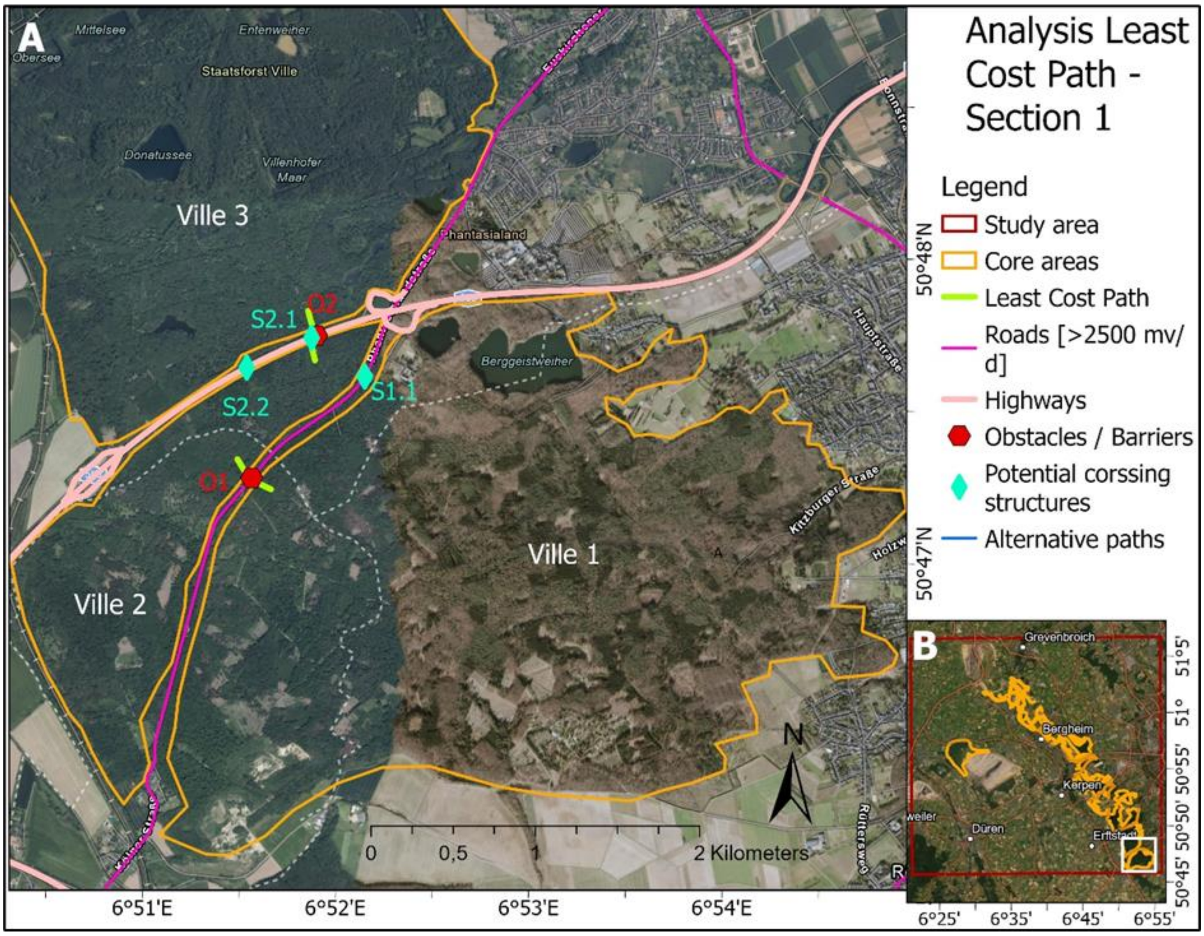

Figure 7: LCP – Section1.
A: *Section 1.* ***B:*** *Reference map showing the location of Section 2 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.2 LCP and on-site explorations – Section 2

One obstacle with three related potential crossing structures was identified in section two hindering the migration between Ville3 and Ville4. The obstacle was the Luxemburgerstraße, B265 (> 2500 mv/d). The road separated the two core areas along a distance of ≈ 4.2 km. The point selected for crossing by the LCP was located at approximately one third (from west to east) of the route (Figure 8). Up to that point the B265 lied a bit elevated compared to the adjacent areas which resulted in a wooded slope separating the road from the *core areas*. Approximately at the marked crossing point of the least cost path, the surrounding areas of Ville3 and Ville4 reached the level of the road. At the same spot a cycle path started to follow the direction of B265 eastwards along with a narrow gras strip, which created a sort of buffer between the shelter structures of Ville 3 and the southern side of the road. The potential crossing structure S3.1 was a service road underpass, suitable for the usage by wildcats (pictures see Appendix 4). A wildlife fence was installed from the proposed crossing point to S3.3 at least on the northern side of the road. The end of the wildlife fence at the southern side of the road could not have been located. This exact type of wildlife fence poses a risk on wildcats as they can get stung with their claws in the wire knots (Dr. Thiel-Bender, 2021, personal communication) (picture see Appendix 4). This exact type of wildlife fence will be referred to as "wire sheep fence" in the following. The other two potential crossing structures were some sort of drainage structures for the B265. With a height of ≈. 1.4 m and a width of ≈ 1.20 m they were big enough for wildcats. The end of the tunnel structures was also visible from the entry point. Nevertheless, the wire sheep fence was installed that way that it prevented the entrance of wildlife to the drainage structures (pictures see Appendix 4). Still, S3.2 and S3.3 were classified as usable crossing structures.

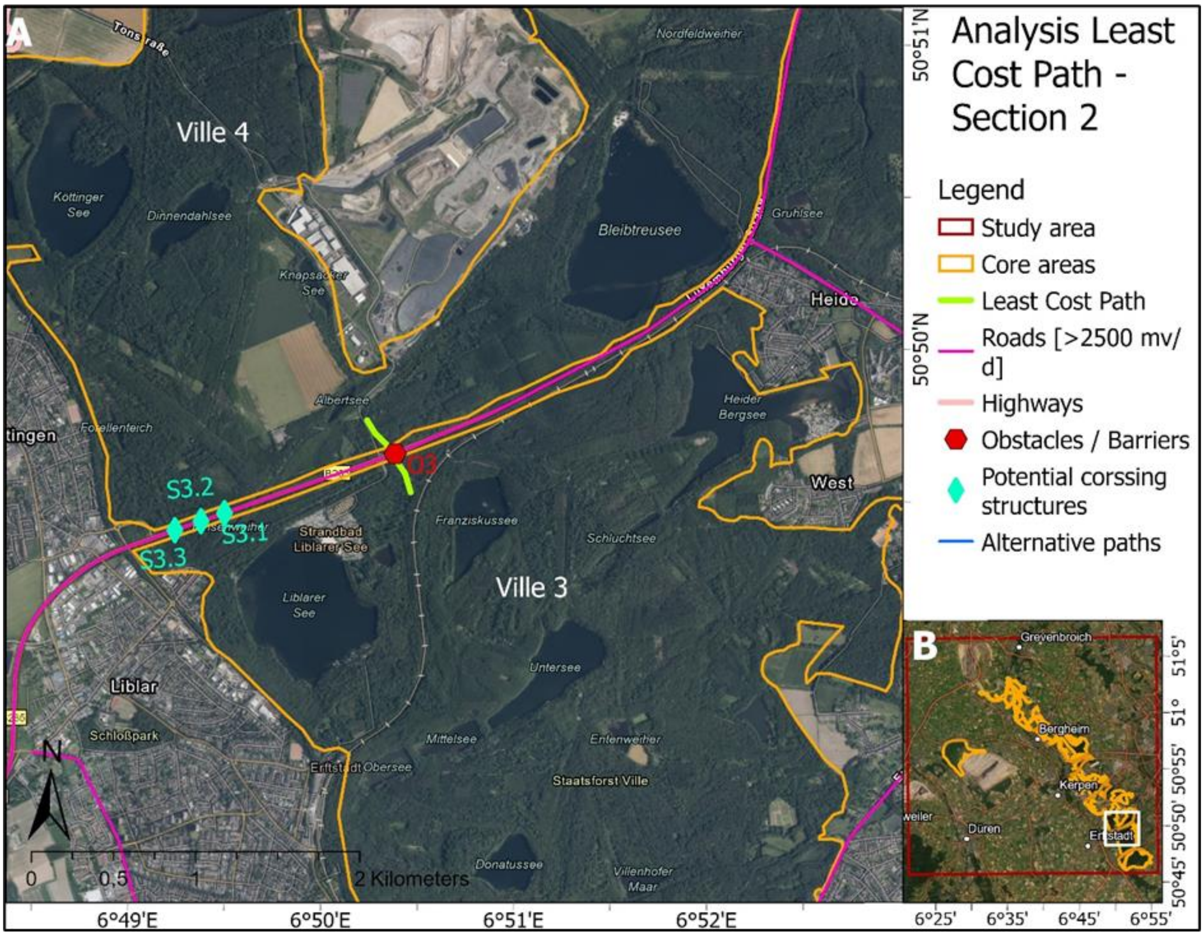

Figure 8: LCP - Section 2.
A: *Section 2.* ***B:*** *Reference map showing the location of Section 2 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.3 LCP and on-site explorations – Section 3

Five obstacles, five potential crossing structures and one alternative path were found in section 3 (Figure 9). The outlined path for the connection of Ville4 and Hürth1 led across a highly frequented road (Berrenratherstraße, >2500 mv/d) and through a wooded ditch (≈ 35 m wide) that was located between the village Berrenrath and the industrial area Knapsack. Both, the Berrenratherstraße and the ditch were identified as critical spots. S4.1 described an abandoned bridge leading over the Berrenratherstraße (Figure 9). The bridge bordered a heaped wooded slope at both sides of the road, stretching out to the marked point of O4. These slopes formed a sort of barrier between the roadside greenery with the adjacent fields and the road. Access to the bridge was only obtained via the slope, so that the bridge was not used by humans. In addition, the vegetation and the steep slope made the access point to the bridge difficult to locate for humans and wildlife. Wildlife would only be guided to that spot if it wandered on top of the slope. Although, the access to the bridge was problematic, the construction itself was suitable for wildcat crossing (Dr. Thiel-Bender, 2021, personal communication).

The vegetation of the roadside greenery stretched from both sides over the bride, providing shelter and leaving only a few meters in the centre of the bridge without shelter and with paved underground.

The ditch between Berrenrath and Knapsack showed dense vegetation which provided shelter as well as a dese shrubs and herbs layer and ground level vegetation structures. The ditch thus offered enough cover to allow a passage of wildcats. However, it is questionable whether the width of 35 m is sufficient to mitigate the anthropogenic effects of the settlement and the industrial area to such an extent that wildcats will actually use that short critical section for migration.

For the migration from Hürth1 to Berrenrath1 the Wendelinusstraße (O6) has to be crossed (> 2500 mv/d) (Figure 9). The Wendelinusstraße bordered fields in the south with only a slim hedge structure (≈ 3m) providing shelter and at the same time bordering gardens of the Village Berrenrath which made it even less suitable for being used as migration structure by wildcats (pictures see Appendix 4). At next, the highway A1 (O7; > 2500 mv/d) had to be crossed to get from Hürth1 to Berrenrath1 (Figure X). Due to the accumulation of three obstacles along the proposed *least cost path* an alternative path, avoiding the unfavourable conditions of O5 and O6 and leading to a suitable crossing structure for a safe migration of the highway A1 (O7) was delineated (Figure 9).

This alternative path (P1) followed the roadside greenery bordering the abandoned bridge (S4.1), then turned northwards, using another strip of densely structures roadside greenery, with adjacent fields in the west and the settlement Berrenrath to the east. This strip of roadside greenery had a minimum width of 30 m and thus suited for wildcat migration (personal communication Thiel Bender, 2021). This strip of wood led to a wider wooded area, which was bordered to the east by a railway dam and to the west by the A1 (Figure 9). Towards the fields, the descried wooded structures showed dense vegetation and levelled edges. Towards the few pathways for pedestrians that led through the area, the vegetation structure was light without ground-level structures (pictures see Appendix 4). The railway dam fulfilled a guiding function here, which might lead wildlife further north to the underpass of the A1 and thus to the potential safe crossing structure of the A1 (Dr. Thiel-Bender, 2021, personal communication). S7.1 was a railway underpass. To both sides of the railway track ran a footpath, which also allowed wildcats and other wildlife a use of the underpass without having to enter the railway tracks. The railway tracks were secured by a fence and the ground was paved. Nevertheless, the underpass can be used by wildcats as they would be able to climb over the fence and do not hesitate to walk across paved ground (Thiel-Bender, 2021, personal communication). A sheep wire fence was installed along the roadside greenery towards the highway.

It would also be possible that wildlife that wanders through Ville4 uses S0.1 for passing the A1. S0.1 was a rather long service way underpass (≈ 70 m) with paved ground but nevertheless suitable for wildcats (Dr. Thiel-Bender, 2021, personal communication). The highway was again elevated compared to the rest of the environment, so wildcats would have to climb up a slope to get to the roadway. From Ville4, a narrow drainage channel ran west to S0. 1. West of the underpass it then bended north after a few meters and led to the Berrenratherstraße. Wildcats that cross the A1 at S0. 1 have to cross the Berrenratherstraße afterwards without supporting structures to get to Berrenrath1. The wooded structures in the *core area* Berrenrath1 led from there on northwards.

A further migration from Berrenrath1 to Kerpen1 was hindered by the Holzstraße, L264 (08; > 2500 mv/d) along a distance of ≈ 3.5 km. This highly frequented road offered two underpasses (Figure 9). The first one was a service path to a small concrete plant (S8.1), which and assessed as usable for wildcats. The underpass led directly to the edge of Kerpen1. The close proximity to the small concrete plant was not considered a hinderance. Because of its small size, it did not cause much disturbance through transporting traffic and, especially at night, it is unlikely to cause any disturbance except for light pollution (pictures see Appendix 4). The second underpass was a railway underpass from the same railway line as S.7.1. This structure was carried by columns to the left and right of the railway tracks, so that in addition to the underpass for the railway traffic there were two other passages, which were suitable for wildcats that did not lead directly along the tracks (pictures see Appendix 4).

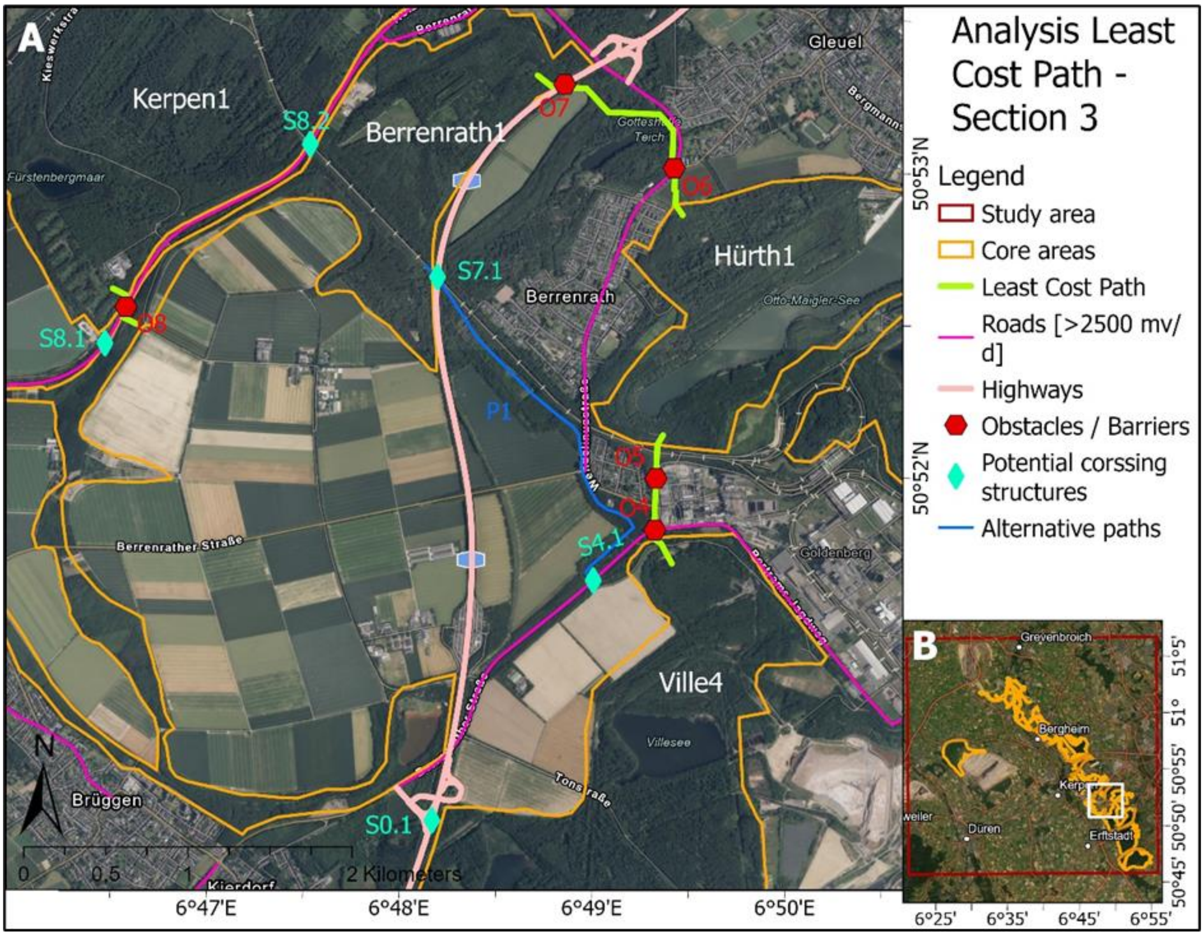

Figure 9: LCP - Section 3.
A: *Section 3.* ***B:*** *Reference map showing the location of Section 3 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.4 LCP and on-site explorations – Section 4

The *core areas* Kerpen1 and Horrem1 were separated by the highway A4 (O9, > 2500 mv/d) and the Dürenerstraße (O10, > 2500 mv/d) (Figure 10). The path resulting from the LCP proposed a crossing of both obstacles right after one another. However, a noise barrier was installed along the entire length of Kerpen1 and Horrem1, along the A4 so that it would not be possible for wildcats or other flightless animals to cross the highway along the boundaries of the two *core areas* without any supportive structures. Hence, the A4 was classified as the only barrier along the least cost path. The suitability of the identified potential crossing structures along the A4 was questionable. The first one was an underpass that was suitable in size but ended in a street of the village Horrem with the nearest house less than a hundred meters away from the underpass (S.9.2). Although passing wildlife could hide in the roadside greenery of the A4 directly after using the underpass and follow it to west in the direction of the Dürenerstraße and Horrem1, the close proximity to the village was clearly recognizable from the underpass at day and at night the street would be illuminated by lanterns so that wildcats might not be interested in exploring the other side of the underpass (pictures see Appendix 4). Therefore, this underpass was not considered a structure that reduced the fragmentation effect of the A4. S9.1 was a pedestrian bridge, leading over the A4. Since the bridge was very narrow (≈ 5 m), did not have a sight protection on the sides and did not offer any shelter (pictures see Appendix 4). Furthermore, the only existing, shelter providing connection of the bridge to Horrem1 was characterised by narrow strip of woodland between a cultivated field and the A4 which was only about 200 meters away from the village of Horrem. Therefore, this bridge was also not considered as structure useful for wildcat crossing. There were no potential crossing structures found along the section of the Dürenerstraße that borders Horrem1. A bicycle path followed the Dürenerstraße at the south side of the road. The roadside greenery was dense at both sides of the road but turned into a grass strip right at the side of the road, so that animals would not step directly out of the cover onto the roadway. As the crossing of O9 and O10 right after one another seemed rather unfavourable an alternative path P3 was delineated. This path incorporated the already rehabilitated areas of a gravel plant and the forested area of the Erlenbusch. Unfortunately, a more detailed inspection of this alternative path through an on-site exploration was not feasible in the scope of this study.

For a better overview the obstacles O11 and O12 are depicted again in the map frame of section 5 and discussed there.

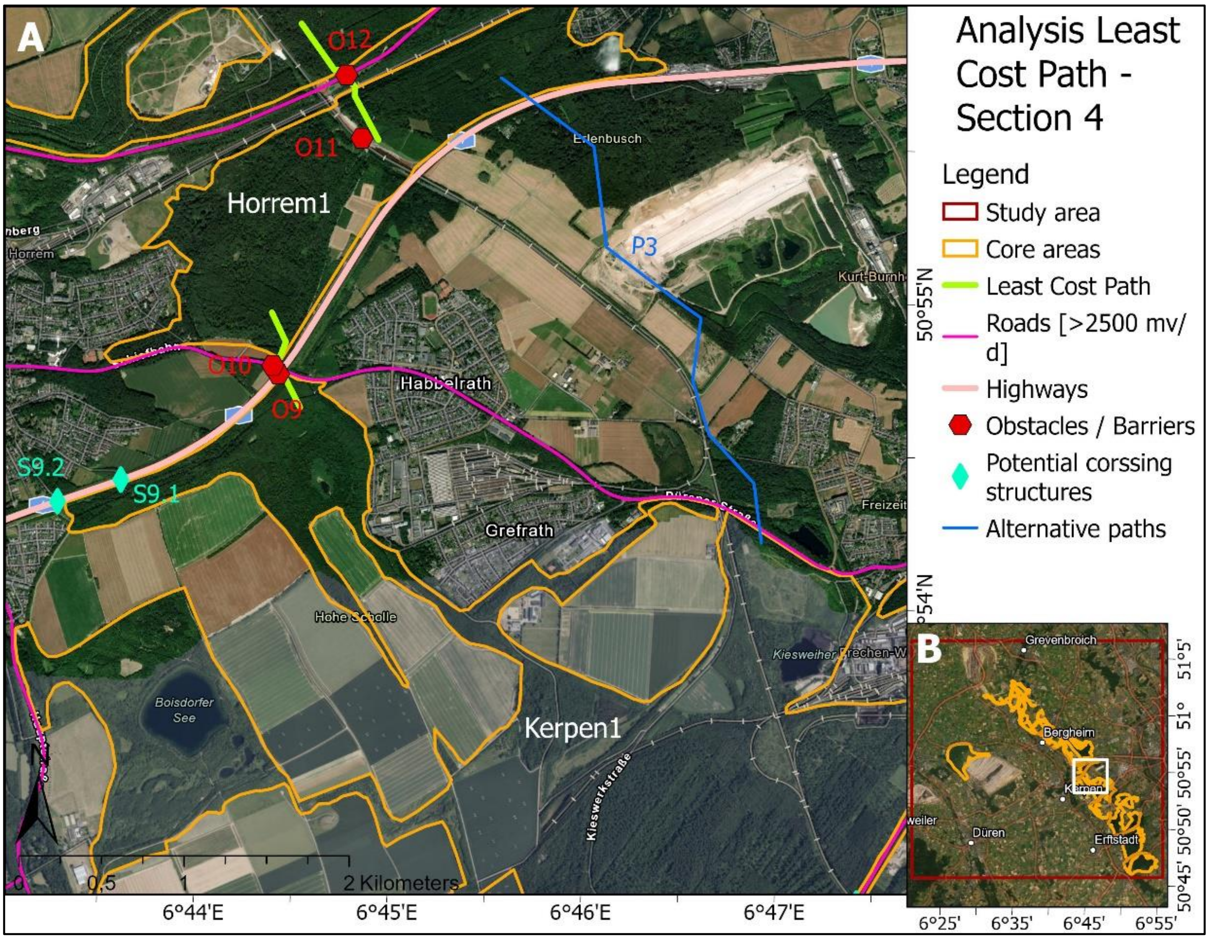

Figure 10: LCP - Section 4.
A: *Section 4.* ***B:*** *Reference map showing the location of Section 4 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.5 LCP and on-site explorations – Section 5

Three obstacles were identified in section five. O12 and O13 represented the Aachenerstraße (L361, > 2500 mv/d) and the Wacholderweg (L93, > 2500 mv/d) (Figure 11). O11, although its construction is not completed jet, represented a connective road from the Aachenerstraße to the A4, which will lead directly through Horrem1, fragmenting the *core area*. Although an underpass for pedestrians and bicycles is planned (Landesbetrieb Straßenbau Nordrhein-Westfalen, n.d.) , which is probably suitable for wildlife crossing, no further information about planned measures for wildlife crossing could be found. There were no potential crossing structures found along the ≈ 3 km long section of the Aachenerstraße that separated Horrem1 from Bergheim1 (Figure 11). In front of the dense roadside greenery was a relatively wide grassy strip to both sides of the Aachenerstraße preventing wildlife from stepping directly out of the cover onto the roadway. The grass was 30 cm to 50 cm high. The Wacholderweg also did not offer any obvious crossing structures along the ≈ 2.6 km long section that fragmented the *core areas* Bergheim1 and Bergheim2. Furthermore, the street was rather curvy decreasing the visibility of traffic. The road was also built into a slope, so that steep rises and falls characterise the roadside greenery. Steep slopes are generally not a problem for the wildcat and would not hinder them at crossing roads. But due to the given local environment, structures that secure the slope were installed along the more southern parts of the road. Due to these structures, the roadside greenery rises straight up to ≈ 2 m above road level in some places. Therefore, a crossing of the road by wildlife at these places is rather unlikely and would therefore be more suitable in the northern part of Bergheim1 and Bergheim2 (pictures see Appendix 4). The roadside greenery was densely structured. At the eastern side of the road, towards Bergheim1 a cycling path acted as a buffer between the roadway and the shelter structures.

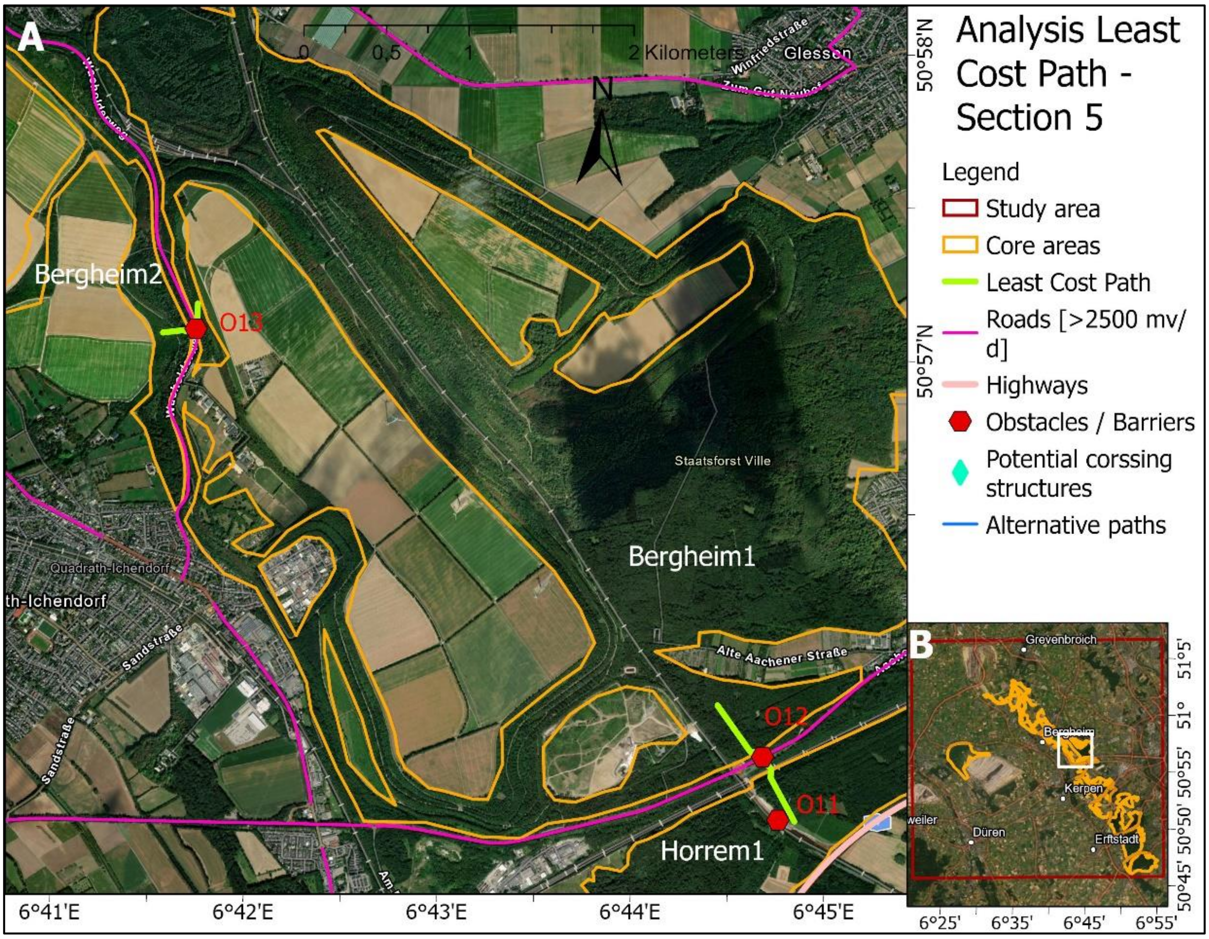

Figure 11: LCP - Section 5.
A: *Section 5.* ***B:*** *Reference map showing the location of Section 5 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.6 LCP and on-site explorations – Section 6

The core areas Bergheim2 and Paffendorf1 were separated by the B477 (O14, >2500 mv/day) along a distance of ≈ 2.2 km(Figure 12). According to the LCP the be best spot for crossing the road was located more to the west of the bordering section of the B477 with Bergheim1 and Paffendorf1. However, at the eastern edge of their intersection, a railway underpass (S14.1) and an underpass belonging to the infrastructure of the former open-cast mine Fortuna Garsdorf (S14.2) offered two safe crossing structures (Figure 12). The railway tracks were located in a dip and the underpass did not offer much space next to the tracks. A safe use of this underpass by wildcats thus would not be possible simultaneously with a train crossing (pictures see Appendix 4). Generally, however, the underpass was suitable as a crossing possibility for wildcats. The railway tracks could possibly even take a guiding function towards this crossing possibility. The underpass S.14.2 was embedded in the rehabilitated forest structures of Bergheim1 and Bergheim2, so that migrating wildlife would even find shelter to both sides of the paved road under the underpass. The road once might have been a service road towards the open-cast mine but was abandoned or at least used very unfrequently by single motor vehicles now and therefore useable for wildcats.

The obstacle O15 and potential crossing structure S15.1 are displayed for better overview in in sections 6, 7 and 8 but addressed later in Section 8 together with O17 and O18.

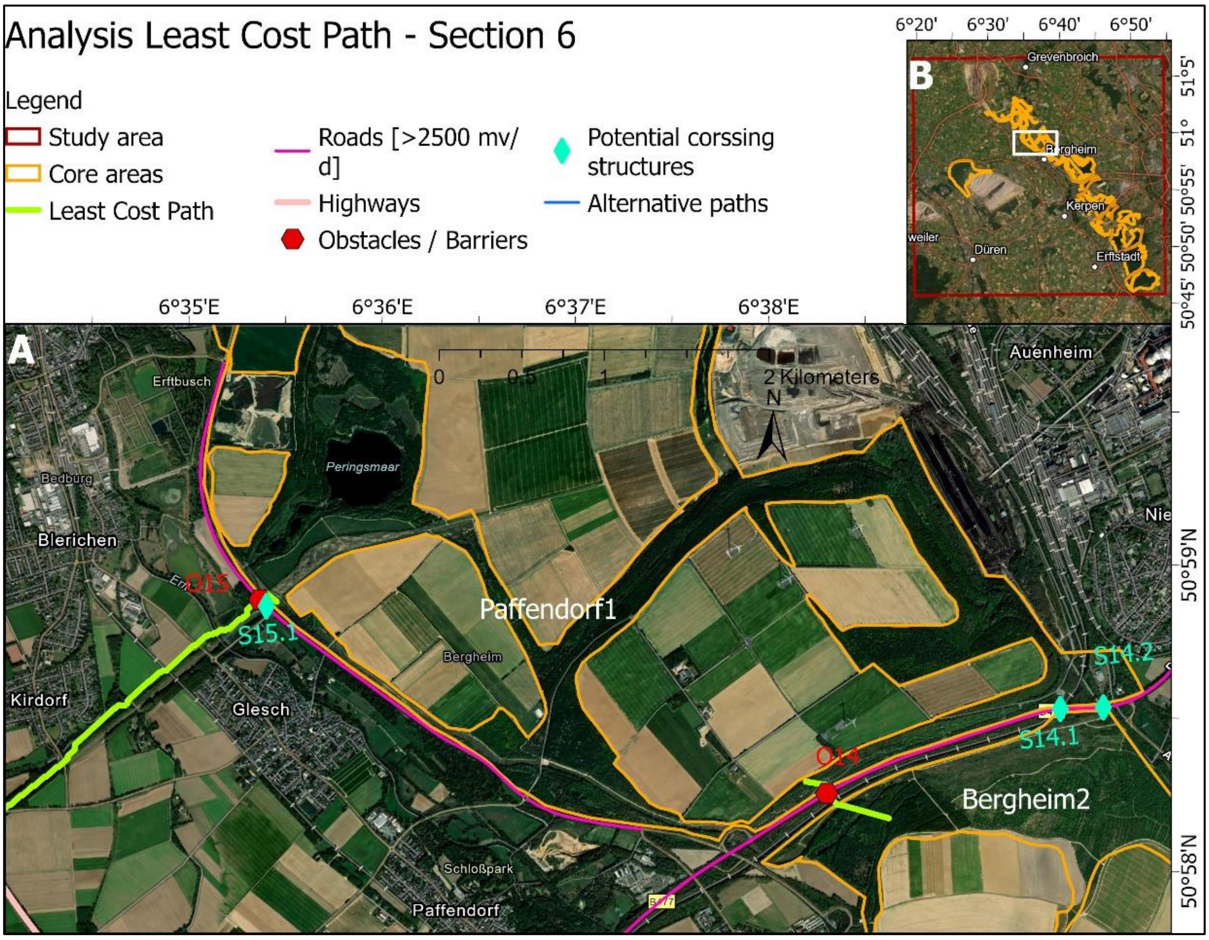

Figure 12: LCP - Section 6.
A: *Section 6.* ***B:*** *Reference map showing the location of Section 6 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.7 LCP and on-site explorations – Section 7

Beside the structures O15 and S15.1 which are discussed in section 8 (Figure 14), section 7 showed one obstacle and two potential crossing structures. S.02 represented an underpass of the river Erft under the road L213 and S0.3 a railway underpass under the same road less than 100 m apart from S0.2. Although the section of the L213 where the proposed *least cost path* crossed it was not marked as a section with more than 2500 mv/day, the adjacent sections of that exact street were marked as such. Therefore, it was questionable if that ≈ 1.7 km wide section of the road is not that highly frequented (Figure 13). Hence the underpasses S0.2 and S0.3 were investigated more closely. The underpass S0.2 was equipped with pedestrian paths to both sides, making it usable for wildcats (pictures see Appendix 4). The railway underpass was also suitable for the usage by wildcats due to its size and wide grass strips leading through the underpass beside the railways (pictures see Appendix 4). O16 was a road (L116) leading to an industrial area and frequented by more than 2500 mv/d (Figure 13). The proposed connection of the LCP linked the rehabilitated forest areas in the north of Paffendorf1 with a 100 m to 200 m wide strip of rehabilitated forest land of Frimmersdorf1 between a golf course and an industrial area. A potentially useful safe crossing structure for the L116 (turns into L213 south of the roundabout that leads to the industrial area) was located about 100 north of the proposed crossing point of the *least cost path*. This introduced structure was an underpass of the Mühlenerft. During the exploration the water level of the Mühlenerft was relatively high, resulting in flooded riparian strips. During times when the Mühlenerft keeps less water the riparian strips might be used by wildcats as safe crossing structure. S16.2 was another underpass of the Mühlenerft. The underpass was usable for wildcats according to its expenses. The underpass of the Mühlenerft was equipped with a pedestrian and cycling path to both sides of the river and hence could be used by wildlife without the needs to swim or cross the river. Although 16.2 led directly into a section of older floodplain forest with a dese shrubs and herbs layer, which could be structurally interesting for the wildcat, before merging with the younger rehabilitated forest areas. It is questionable if wildcats would approach the crossing structures due to their close proximity to the villages Bedburg and Kaster. The only way to that crossing structure leads thorough an only 200 m wide wooded section bordering the village Bedburg and using the underpass ends wildcats in only 150 m distance of the village Kaster. Consequently, S16.2 was not classified as usable crossing structure. S16.3 was located even closer to the villages Bedburg and Kaster. The crossing of the underpass form Paffendorf1 northwards led directly to the ground of a public swimming pool. The only option for wildcats to migrate any further after passing S16.3 would be by using the roadside greenery between the public swimming pool and the L213. In addition, a lot of rubbish, sleeping mats and sleeping bags were found in the underpass, which indicated that it served as a refuge for homeless people. Therefore, the presence of humans could also deter wildcats from using the underpass at night. All in all, this underpass was not considered a useful crossing structure for the purposes of this connectivity concept. The L213 was located on a higher elevation along the complete way to the industrial area, reaching from ≈ 4- 5 m at 16.2 and 16.3 to a minimum of ≈ 1 – 2 m compared to the surrounding environment near the industrial area. Thus, the roadside greenery built a slope between the road and the surrounding environment. Furthermore, the L213 and L116 were equipped with hard shoulders and grass strips to both sides of the road preventing wildcats and other wildlife from stepping directly out of the shelter onto the roadway.

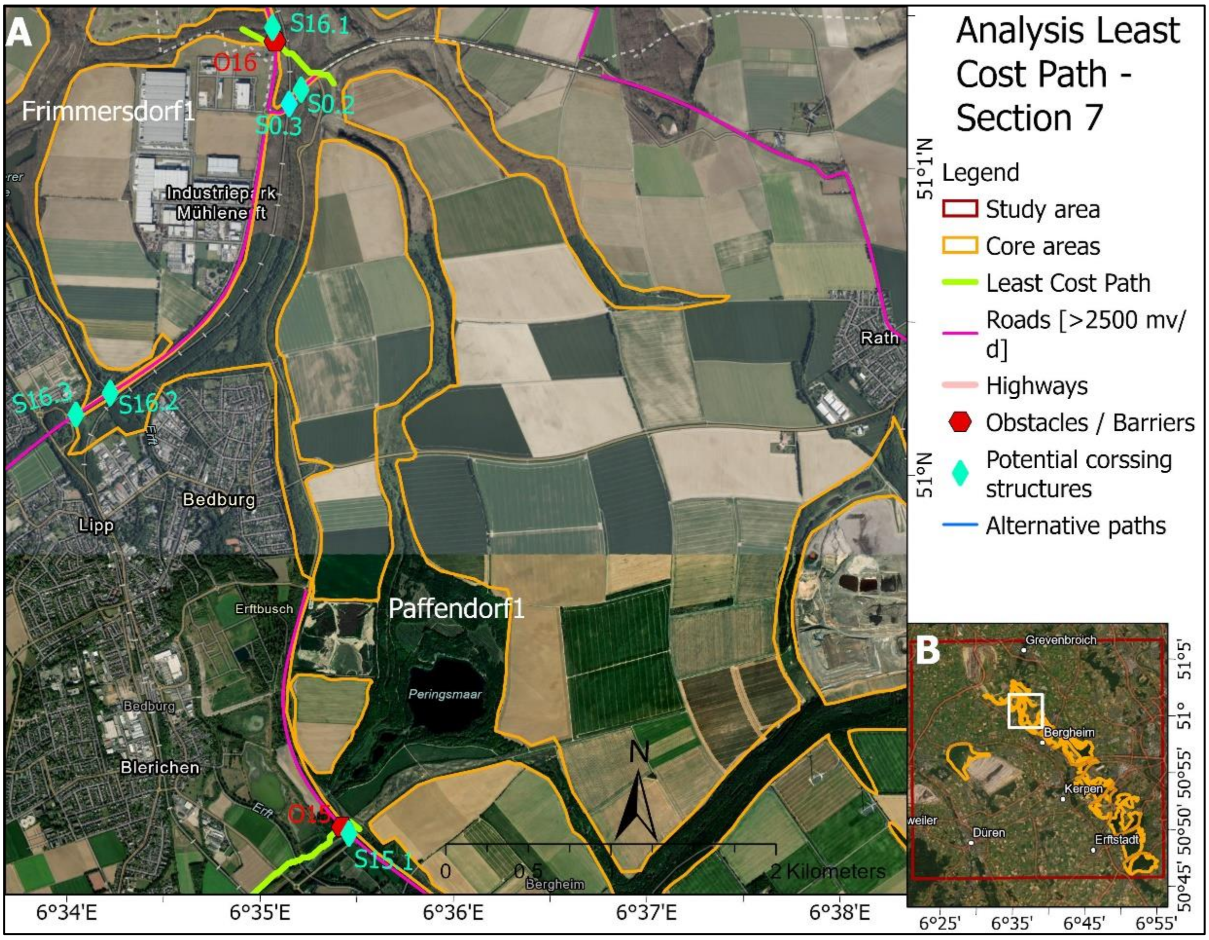

Figure 13: LCP - Section 7.
A: *Section 5.* ***B:*** *Reference map showing the location of Section 7 in the study area. Base map: Esri Imagery Hybrid.*

4.1.1.8 LCP and on-site explorations – Section 8

Section 8 shows the connection of Paffendorf1 to Sophienhöhe1 (Figure 14). The l*east cost path* led along the Terra Nova Speedway, a paved road only open for bicycles, pedestrians and skaters but not for motor vehicles. This speedway leads directly to the eastern edge of the open-cast mine Hambach and hence connects Paffendorf1 to Sophienhöhe1. The recreational trail was framed on both sides by wooded vegetation strips, which were 30 meters wide at the narrowest spots and 50 meters wide at the widest places and thus represents a kind of corridor structure which might be suitable for the use by wildcats. Since the migration along sheltered land is technically possible using the neighboring structures of the Terra Nova Speedway, the agriculturally dominated land between the core areas Paffendorf1 and Sophienhöhe1 was not identified as potential obstacle. Nevertheless, the suitability of the greenery framing the Terra Nova Speedway has to be discussed. The paved road between these vegetation strips was only 5 m wide and although highly frequented by athletes on the weekends, it is most likely not used by humans at night. Including the paved road between them, the vegetation structures reached expanses of 65 m to 130 m. The wood structures were quite dense along the speedway with only a few exceptions, providing migrating animals shelter from the speedway but also from the settlements in close to the speedway. Most of the time the Terra Nova Speedway bordered fields, and hence created interesting epitopes with the levelled wooden structures that separated the Speedway and the adjacent agricultural lands. Another advantage of the Terra Nova speedway was that underpasses for the pedestrians and athletes using the speedway were installed under every intersecting road. Hence, suitable crossing structures for the obstacles O15 (L361, >2500 mv/d), O17 (A61, >2500 mv/d) and O18 (B55, >2500 mv/d) were found directly along the Terra Nova Speedway (Figure 14). S15.1 and S18.1 were underpasses of the Terra Nova Speedway, with wide grass strips to both sides of the paved road of the speedway. They were rather wide but short so that the end of the underpass would be clearly recognizable for wildcats (pictures see Appendix 4). All in all, every underpass along the speedway was found suitable for the migration of wildcats. S17.1 represented a bridge leading the Terra Nova Speedway across the A61. As this bridge was equipped with sight protections towards the A61 and grass strips to both sides of the paved speedway, it would also be likely to be used by wildlife like wildcats. Critical about the location of the Terra Nova Speedway was the close proximity to the villages Kirdorf and Glesch. Using the wood strips opposite the villages would allow wildcats to keep a distance of only ≈ 170 m to Glesch and ≈ 150 m to Kirdorf. Short before the edge of the open-cast mine Hambach, the original *least cost pat*h left the Terra Nova Speedway and led across a 500 m side section of unsheltered field (Figure 14). Although wildcats do cross such distances of unsheltered land are not characterized as obstacles for wildcats, the alternative path P2 was delineated, following the Terra Nova speedway to the edge of the open-cast mine Hambach, from where on wood structures provide shelter towards Sophienhöhe1. The fence securing the open-cast mine of Hambach can be climbed over by wildcats (pictures see Appendix 4). The wood structures that framed the Terra Nova Speedway showed the expanses of the optimum version of a wildcat corridor as proposed by the BUND (BUND, 2011) along half the way if only one side of wooded structure next to the Terra Nova Speedway is considered and along the complete way if both sides are considered as one joint corridor. Nevertheless, the effects of the recreational path between them as well as the close proximity to the did not allow a clear classification of this potential corridor structure by now.

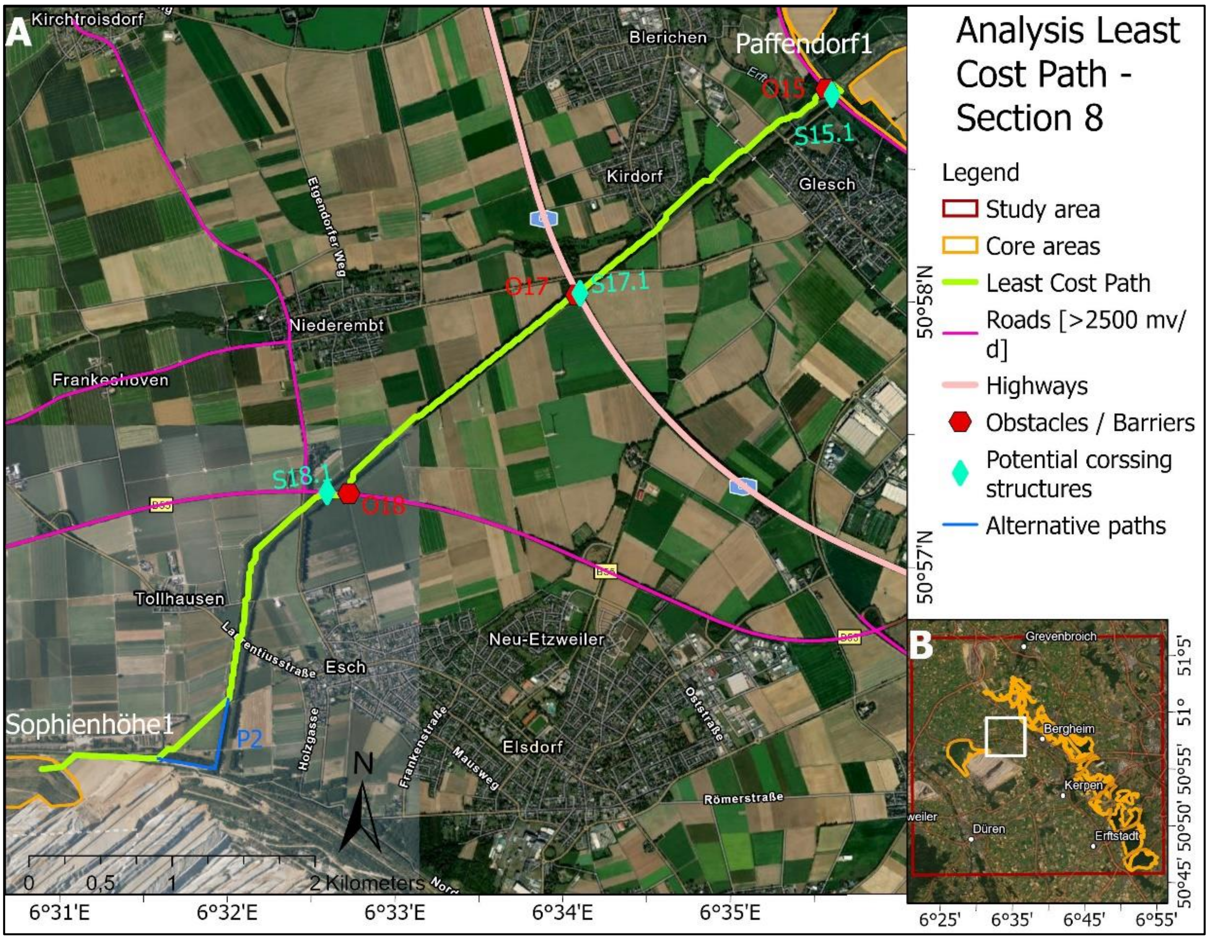

Figure 14: LCP - Section 8.
A: *Section 5.* ***B:*** *Reference map showing the location of Section 8 in the study area. Base map: Esri Imagery Hybrid.*

4.1.2 Effectivity and implementability of road-related wildcat conservation measures

All but one of the road-related measures were rated as more effective than implementable (Figure 15). The ratings always related to the implementation at already existing and not newly constructed roads. The measures could be subdivided into two groups with different conservation intentions. First measures that aim to reduce the accidents with motor vehicles and wildcats. Second measures that intend to introduce save crossing infrastructure (Figure 15).

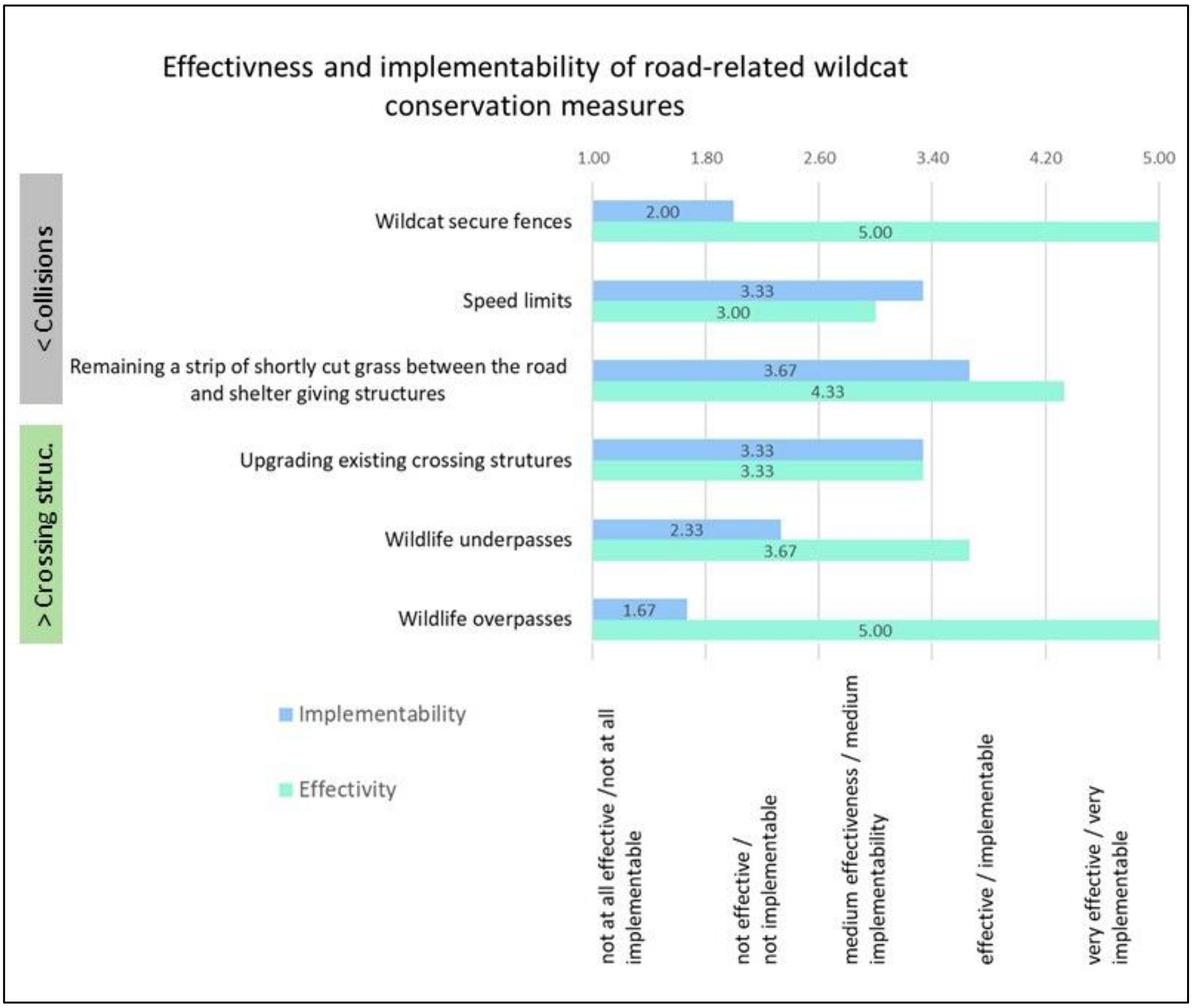

Figure 15: Mean rating values of rated effectivity and implementability of road-related wildcat conservation measures resulting from ratification by different experts. The number of experts rating the effectivity and implementability was 3 for all introduced measures. Coloured bars on the left indicate to which conservation purposes the measures were assigned to. "Crossing struc." Represents the conservation purpose of providing safe crossing structures for wildcats, "< Collisions" represents the conservation purpose of preventing vehicle-wildcat collisions.

For both purposes the most effective measures, wildcat secure fences (mrv effectivity = 5; mrv implementability = 2) and wildlife overpasses (mrv effectivity = 5; mrv implementability = 1.67) were the least implementable ones. Due to the low probability that these measures would be implemented, these two were only taken into account for the connectivity action plan if the other measures were not expected to be successful due to the situation on site. For measures to avoid accidents, "Remaining a strip of short cut grass between the road and shelter structures" preferred compared to the introduction of speed limits due to the better balance of implementability and effectiveness. Both measures can of course also be proposed along with each other. The effect of the short cut grass strip could also be achieved by removing a strip of shelter giving roadside greenery and could was thus also proposed in the connectivity action plan. For the implementation of safe crossing structure, the “Upgrading of existing crossing structures” (mrv effectivity = 3.33; mrv implementability = 3.33) was preferred over the installation of new wildlife underpasses (mrv effectivity = 3.67; mrv implementability = 2.33) due to its higher implementability and only slightly lower effectiveness. Of course, this is only possible if structures exist that can be improved.

Table 10: Ranking of road -related wildcat conservation measures.

Conservation purpose	Measure	# Ranking
Prevent vehicle-wildcat collisions	Remaining a strip of shortly cut grass between the road and shelter giving structures	1
	Speed limits	2
	Wildcat secure fences	3
Provide safe crossing structures	Upgrading existing crossing structures	1
	Wildlife underpasses	2
	Wildlife overpasses	3

4.1.3 Connectivity action plan

The results of the LCP, the on-site explorations, literature research and expert interviews were used to develop an action plan with sufficient measures to increase the connectivity between the rehabilitated forest areas of the RLMA. For the action plan the transition zones between adjacent *core areas* were discussed regarding the obstacles and barriers separating the *core areas* from another. Additionally, measures to counteract the fragmentation effect of the obstacles were proposed. Unfortunately, statistics on wildlife accidents were not available for the roads in the study area.

All of the 17 roads identified as obstacles showed a traffic density higher than 2500 mv/d. The three wildcat conservation measures that would result in bigger construction efforts, namely wildcat secure fences, wildlife underpasses and wildlife overpasses were rated as *not* or *not at all implementable* by the experts. During the interviews all three experts emphazised that the introduction of such measures along existing roads is very unlikely due to high costs and the associated effort. In cases where it has worked in the past, the implementation process took a long time, and in some cases these structures were installed in conjunction with other road work (Interview Thiel-Bender, 2021). Due to the low likelihood of the implementation, these three measures were proposed rarely in the connectivity action plan. The focus lay on the remaining measures like upgrading existing usable crossing structures and the direction of wildlife towards these safe crossing opportunities. Still, it must be highlighted that these measures should be regarded as transitional solutions that can mitigate the fragmentation effect and the risk potential of individual roads. In the long term, however, they are no substitute for the introduction of many more crossing options suitable for wildlife in the study area. A functioning biotope network can only be achieved through the introduction of green infrastructure Therefore, the planning of additional suitable crossing facilities to complement the existing appropriate structures is strongly recommended so that green infrastructure is provided every 1.5 to 2.5 km along the problematic roads described, especially if future road works are considered necessary anyway. A recommendation as to which type of crossing structure is suitable at which location cannot be given at this point due to a lack of expertise.

4.1.3.1 Connection Ville1 and Ville2

The *core areas* Ville1 and Ville2 were separated by the L194 (Phantasialandstraße) along ≈ 3.4 km with only one sufficient crossing structure located towards the northern end of the critical road section. Consequently, there was no sufficient number of crossing structures along the L194. Nevertheless, dense hedge structures that guide wildcats to the underpass should be planted on both sides of the underpass. On the northern side of the road, where there is no cycle path to provide a buffer between the shelter and the roadway, part of the sheltering structures should be removed and replaced with a strip of shortly cut grass to improve visibility of the road. the same could be done on the other side of the road to make crossing the road at locations other than the underpass even less attractive. Since the presence of wildcats is proven for both *core areas*, further investigations on the actual usage of the underpass by wildcats should be conducted.

4.1.3.2 Connection Ville2 and Ville3

The highway A553 separated the *core areas* Ville2 and Ville3 along a distance of 1.8 km. This section of the highway was equipped with two sufficient crossing structures within a distance of ≈ 450m. Consequently, this section of the A553 featured enough crossing structures. Furthermore, the highway laid elevated compared to the *core areas* Ville2 and Ville3 which created a sort of guiding structure towards the underpasses. This slope as well as the pedestrian paths could have a guiding function on wildcats towards the crossing structures. Due to the two existing crossing structures, it would even be possible to install a wildcat secure fence here if it becomes apparent that this area is prone to accidents with wildlife. The sheep-wire fences around the hedge structures of S2.2 should be replaced by another sort of wildlife fence. Since the presence of wildcats in both *core areas* has already been proven, it should be investigated to what extend the underpasses are used by wildcats or other wildlife.

4.1.3.3 Connection Ville3 and Ville4

The B265, separating Ville3 and Ville4 showed three usable crossing structures across ≈ 4.2 km. Although this amount of crossing structures would be sufficient for that distance, the three crossing structures were accumulated along the first 700 m of the western end of the intersecting road section. Thus, there were not enough crossing structures situated at the B265, to compensate its fragmenting effect. Furthermore, two of the crossing structures were not usable yet, as sheep wire fences block their entrances. Thus, those fences have to be removed. If the drainage structures are made accessible, wildlife cameras should be installed in order to investigate which species use these structures. As wildcats occur in Ville3 and Ville4 the wire sheep fences along the road should be replaced through a fence that does not pose an additional risk on wildcats. As these two *core areas* represent the largest not fragmented wildcat habitats in the study area, measures to counteract fragmentation should be taken as soon as possible in order to ensure an exchange of the two areas. Initially, a reduction of the roadside greenery on those parts of the road where there is no cycle path could improve the visibility of the road. In Ville4, north of the B265, was an uncovered strip bordered the slightly elevated B265 already. A narrow and sparse hedge strip adjoined it. By increasing the density of the hedge strip, it could take on a guiding function in this area and possibly lead wildcats directly to the three possible crossing structures if the hedge strip is opened up in precisely these areas.

4.1.3.4 Connection Ville4 and Hürth1 and Berrenrath1

The LCPA revealed that the best way to connect all core areas would be achieved by connecting Ville4 and Hürth1. This connective path lead through a narrow, sheltered ditch that was framed on both sides by anthropogenic infrastructure. As the migration of wildcats through that ditch was rather questionable, the connection of Ville4 to Berrenrath1 seemed more practical. Nevertheless, the Berrenratherstraße has to be crossed. An abandoned bridge leading over the road was identified as potential crossing structure. In order to make it usable for wildcats, it has to be better integrated in the rest of the landscape. The slope running northwest of to both sides of the bridge creates a kind of boundary to the road and is thus actually a useful structure. However, to increase the accessibility of the bridge, the slope needs to be flattened on both sides of the bridge. Dense hedge structures should be planted to lead wildcats to the entrance of the bridge. Additionally, a visual protection towards the road should be installed on the bridge (personal communication Thiel-Bender, 2021). The remaining strip of paved ground on the bridge could be covered with a different substrate. From the northern end of the bridge wildcats can migrate towards Berrenrath1 along some wood strips. Although these wood structures were suitable for the migration of wildcats, a widening should be considered, in order to make the migration through an area that borders villages, and a highway more attractive. However, these structures directly led to a useful crossing structure of the A1. If measures are implemented at the bridge, wildlife cameras should definitely be installed here to see whether and which wildlife take up such crossing opportunities. Further cameras should be installed at S0.1 in order to check whether this structure is perhaps already being used by wildcats and whether a spread towards Berrenrath1 is already taking place along this path. Due to its elevated location, fencing of the A1 along the borders of Berrenrath1 is not considered necessary for now (personal communication Thiel-Bender, 2021). However, as the slope to the A1 flattens in the immediate vicinity of S7.1 is and therefore has a lower bordering effect, some rows of trees of the roadside greenery could be removed here. Instead, hedge structures should lead to S7.1. If possible, the asphalt surface under S7.1 and S0.1 could be removed (personal communication Thiel-Bender, 2021).

For the connection of Berrenrath1 with Hürth1, shelter structures across the agricultural area adjacent to Hürth1 should be introduced. Although the maximum distance to be covered across unsheltered land here was only about 200 m, the field to be crossed is bordered to the west by the settlement of Berrenrath and to the north-east by single houses of the settlement of Gleul. The distance between these two disturbing influences is only 250 m to 300 m. Perhaps the optimal solution would be to convert the agricultural area into an extensively used meadow with some woody structures so that the entire area provides shelter. To mitigate the disturbance of the settlements, denser and broader wood structures should be planted towards the borders of the settlements. Traffic of the Wendelinusstraße was readily assessable coming from both sides. The speed limit could be lowered from 70 km/h to 50 km/h, at least from Berrenrath to the junction with Aldenratherstraße. Since this restriction comes into effect shortly before Berrenrath anyway, this speed reduction could certainly take place a few hundred metres earlier. Leaving Hürth1 by crossing the Wendelinusstraße ends wildcats in the area around the Gotteshütte-pond. The safe crossing of the A1 northwards to Berrenrath1 would be possible via S7.1 again.

4.1.3.5 Connection Berrenrath1 and Kerpen1

Berrenrath1 and Kerpen1 were fragmented by the B264 across a distance of ≈ 3.5 km which was equipped with two suitable crossing structures. With a distance of 1.7 km between these crossing structures distributed in that way that they mitigated the fragmentation effect of the B264. However, the B264 was at the same level as Berrenrath1 and Kerpen1, so that no slope separated the road from the surrounding environment and wildcats were not guided directly to the crossing possibilities. Therefore, rows of roadside greenery should also be removed here to make crossing the road at places other than the underpasses unattractive. At the same time, hedges should be planted as guiding structures to the underpasses. If possible, the asphalt surface under S8.1 could be removed.

4.1.3.6 Connection Kerpen1 and Horrem1

Kerpen1 and Horrem1 were separated by the A4 and the Dürenerstraße. No sufficient crossing structures were located at either of them. Furthermore, the A4 was not only identified as obstacle but as barrier as a noise barrier was installed to both sides which was not permeable for wildcats. The least cost path showed the best connection between the two *core areas* diagonally across both the highway and Dürnenerstraße. This variant would only be possible by building a green bridge or a very broad underpass. Such a green bridge or underpass that passes directly over under both roads is probably not constructible. Crossing structures should nevertheless not be too far away from the proposed points, as the installation at other locations would end wildcats close to settlements. A connection via the alternative path P4 would also be possible. The A4 and Dürenerstraße would still have to be crossed and thus made permeable through suitable crossing structures but wildcats could keep a larger distance to settlements along that route. Unfortunately, the plans for the rehabilitation of the gravel pit could not be included in the scope of this work. However, a connection to Horrem1 would be possible via the already rehabilitated areas around the gravel plant and the Erlenbusch. In the area of the Erlenbusch, possibilities for crossing the A4 should then be created. A more detailed action plan for this alternative path and on-site explorations were unfortunately not possible within the scope of this study. What should not be underestimated concerning the connection of Kerpen1 and Horrem1 is that Horrem1 is a species protection forest in which many conservation measures have already been implemented and therefore represents a valuable habitat in the centre of the study area. The migration of species into and out of this *core area* should therefore be made possible at all costs. The A4 represents an insurmountable barrier for many species, cutting off this valuable habitat along its entire length of ≈ 3 km from the southern part of the study area. Therefore, the possibility of implementing both connection variants from Horrem1 to Kerpen1 in order to reduce the strong barrier effect of the A4 should be seriously considered.

For the reasons mentioned already, it is very important that Horrem1 is not fragmented any further. The connection of the Aachenerstraße to the A4 will do just that, unless sufficient crossing structures are provided. Construction in the form of an open-span viaduct would actually be the only justifiable solution.

4.1.3.7 Kerpen1 and Bergheim1

The Aachenerstraße caused the fragmentation of the *core areas* Kerpen1 and Bergheim1. The road did not offer any suitable crossing structures. As there was a wide grass strip on both sides of the road already, it can only be suggested that this is to be cut more regularly in order to maintain the desired effect of improved visibility of the road continuously.

4.1.3.8 Bergheim1 and Bergheim2

The Wacholderweg between Bergheim1 and Bergheim2 did also not offer usable crossing structures. Due to the fact that at least half of the road is built into a slope, i.e. there were steep ascents on one side and steep descents on the other, the construction of overpasses or underpasses will probably only feasible in the northern half of the road section. As the street is curvy and visibility is consequently low, vegetation to both sides of the roads should be replaces by a strip of shortly cut grass along sections without a cycle path and the speed limit should be reduced to 50 km/h.

4.1.3.9 Berheim2 and Paffendorf1

Along the ≈ 2.2 km long section of the B477 that separated Bergheim2 from Paffendorf2 two usable crossing structures were identified. This could be considered a sufficient number, but both crossing structures were located at the eastern end of the road section. Since the B477 ass also the most frequented road (15.255 mv/d) - apart from the motorways - in the study area, at least one further crossing possibility should be installed further west in order to reduce the fragmentation effect. Due to the high traffic density, a fence could also make sense for the B477, given that sufficient crossing options are available. Since the B477 was at the same level as the surrounding landscape, at least some of the trees of the roadside greenery should be removed and replaced by a grass strip. S14.2 was integrated very well in the landscape and the service roads lead directly to that crossing structure. S14.1 lay in a sink like the railway tracks, wildcats will probably only encounter this crossing structure if they follow the tracks.

4.1.3.10 Connection Paffendorf1 and Frimmersdorf1

The crossing structures S.02 and S.03 were both usable without the introduction of further measures. Furthermore, the railway tracks and the Erft lead wildcats to both structures. Of three possible crossing structures along the L116/L213 two were rated insufficient. The third would probably only be permanently usable if it was widened to create permanently walkable and dry riparian strips. Hence the L116/L213 lacked usable crossing structures as it intersected the *core areas* along a distance of ≈ 3 km. However, the choice of locations for crossing structures is limited, as the 3 km long border between Paffendorf1 and Frimmersdorf1 is interrupted by an industrial area and a golf course and is otherwise already too close to the settlements of Bedburg and Königshoven. Apart from the extension of the Mühlenerft subway, this left only one location at the northernmost points of the two *core areas*. In order to improve the visibility of the traffic, a part of roadside greenery could be replaced by a grass strip, at least in Paffendorf1. Since the roadside greenery in Frimmersdorf1 is very narrow already, this measure would be rather impractical in many parts of the road.

4.1.3.11 Connection Paffendorf1 and Sophienhöhe1

Paffendorf1 and Sophienhöhe1 are connected via the accompanying green structures of the Terra Nova Speedway. As described previously, it could not be clearly assessed to what extent this corridor-like structure would be used by wildcats. Therefore, it is recommended in any case to observe which species are present in the woody structures already. It is furthermore recommended that the Terra Nova Speedway's greenery is widened especially in places bordering villages, so that wildlife using these structures can keep as much distance as possible from the villages. If possible, the widening should also be carried out in other places to increase the chances that the structure is accepted as a corridor. This does not have to be done by expanding the woody structures but also by planting extensively managed wildflower verges along the adjacent agricultural land. A widening of the usable area for cover-bound species could also be achieved through the implementation of some stepping stones in the agricultural landscape, so that this can also be accessed by cover-bound species to larger extents. However, one thing should be taken into account when expanding the shelter structures. The Terra Nova Speedway offers the great advantage that all roads along this path are equipped with suitable crossing possibilities. Widening the cover structures could therefore guide wildcats to places without suitable crossing possibilities. In practice, the optimisation of the Terra Nova Speedway should therefore be realised in that way that it is widened in places where it does not border roads, while the cover structures narrow towards the roads, so that in the best-case wildcats are guided directly to the crossing possibilities of the Terra Nova Speedway. The crossing structures should definitely be broadened at the transition zone to the open-cast mine of Hambach, to enable a smoother migration from and to the Terra Nova Speedway. For example, the field parcel crossed by the least cost path could be converted into an extensively used meadow to optimize the transition between the corridor-like structure and the edge structures of the open-cast mine.

4.2 Results that contributed to the development of the habitat quality action plan

4.2.1 Habitat quality assessment

Figure 16 shows the habitat quality of the different core areas represented through the four factors: availability of breeding structures, availability of daytime resting spots, food availability and low-disturbance areas. Depicted are the mean rating values (mrv) for the different factors gained through the assessment by different experts. The exact mean values and the number of experts that assessed the habitat quality for the different core areas are shown in Table 11.

With total habitat quality factor rating of 11.93 and 11.32, the factors food availability and availability of daytime resting spots were the best rated factors across all core areas (Table X).

Only in the white area, the proportion of low-disturbance areas was rated better than the availability of food and daytime resting spots. The third best rated factor was the availability of breeding structures with a total habitat quality factor mean value of 7.59. Considerably worse was the valuation of the occurrence of low-disturbance areas in the *core areas* with a total habitat quality factor of 6.72 (Table 11).

Table 11: Mean rating values, total habitat quality, total habitat quality factor rating and number of experts that rated the four habitat quality factors for the different core areas.
The mean rating values of core areas corresponding to only one habitat area were counted twice for the calculation of the total habitat quality factor.

		Breeding structures		**Daytime resting spots**		**Food availability**		**Low-disturbance areas**		
Habitat area	**Corresponding *core areas***	**Mean rating value**	**N [Experts]**	**Mean rating value**	**N [Experts]**	**Mean rating value**	**N [Experts]**	**Mean rating value**	**N [Experts]**	**Total habitat quality**
pink	Ville1 + 2	1.00	2	1.00	2	1.00	2	0.90	2	3.90
blue	Ville3	0.83	2	1.00	2	0.83	2	0.60	2	3.27
brown	Ville4	0.89	3	0.89	3	1.00	3	0.67	3	3.44
green	Hürth1	0.53	5	0.47	5	0.50	4	0.40	5	1.90
white	-	0.33	1	0.33	1	0.33	1	0.40	1	1.40
red	Berrenrath1 + Kerpen1	0.50	4	0.67	4	0.67	4	0.55	4	2.38
turquoise	-	0.67	2	0.67	2	0.83	2	0.80	2	2.97
purple	Horrem1	1.00	1	1.00	1	1.00	1	0.60	1	3.60
yellow	Bergheim 1 + 2	0.67	5	0.73	5	0.80	5	0.60	5	2.80
salmon	Paffendorf1 + Frimmersdorf1	0.42	4	0.58	4	0.75	4	0.45	4	2.20
orange	Sophienhöhe1	0.75	4	1.00	4	1.00	4	0.75	4	3.50
Total habitat quality factor rating		10.71		11.32		11.93		9.22		

The *core areas* Ville1 and Ville2 showed the best total habitat quality (3.9) with the highest possible rating in three out of four *habitat quality factors*. The second-best rated habitat was Horrem1 with a total habitat quality of 3.6 (Table 11). Still, this area was rated by only one expert. The white area showed the lowest overall habitat quality and the lowest mean rating values for all four *habitat quality factors*. The *core areas* Hürth1, Frimersdorf1 and Paffendorf1 showed the second and third lowest overall habitat quality. The Sophienhöhe1 was assessed with the highest possible rating with regard to daytime resting spots and food availability (mrv = 1) but showed fewer breeding structures (0.75) and low-disturbance areas (mrv = 0.75). The turquoise area and Bergheim1 and Berheim2 got intermediate assessments for all four habitat quality factors (Figure 16, Table 11).

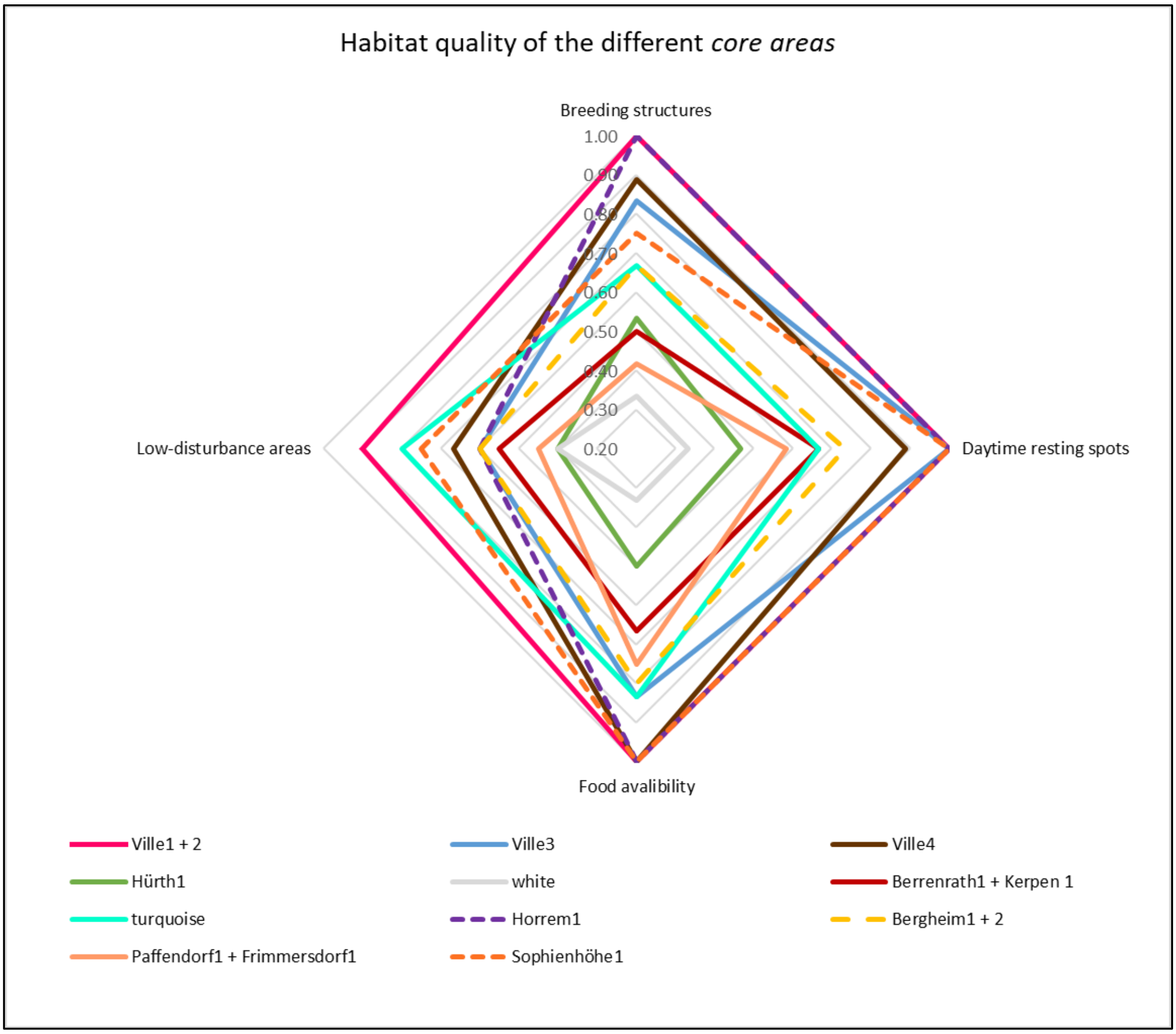

Figure 16: Mean rating values of the habitat quality assessments for the different core areas.
The habitat areas "turquoise" and "white" did not correspond to any core area and are thus listed under their habitat area names. Some core areas corresponded to the same habitat area and therefore got identical ratings. The results of the habitat quality of these areas are depicted together.

4.2.2 Effectivity and practicability of forest management-related wildcat conservation measures

Figure 17 summarises the mean effectivity and mean practicability values of different forest management-related wildcat conservation measures assessed by different experts and assigned to different conservation purposes, for the different *core areas*. The results offered that all introduced measures showed at least a mean rating value (mrv) of *medium* in their effectivity and practicability.

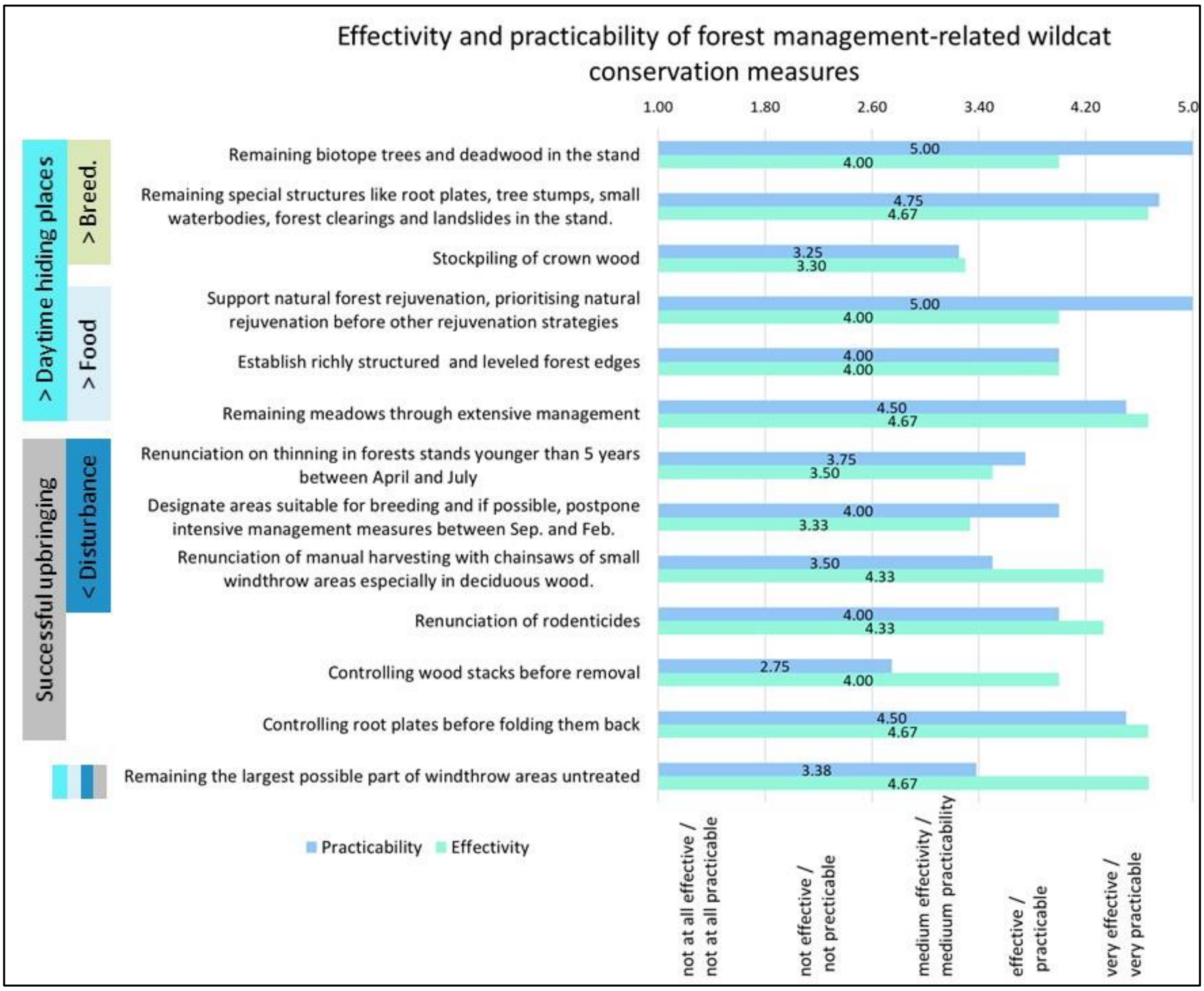

Figure 17: Mean rating values of assessed effectivity and practicability of forest management-related wildcat conservation measures resulting from ratification by different experts. The number of experts rating the practicability was 4 for all introduced measures. The number of experts rating the effectivity assessment was 3 for all introduced measures except for "Renunciation on thinning in forests stands younger than 5 years between April and July", "Support natural forest rejuvenation, prioritising natural rejuvenation before other regeneration" and "Establish richly structured forest edges", here N was 2. Coloured bars on the left indicate to which conservation purposes the measures were assigned to. The short forms are translated as follows: "< Disturbance" = "Reduced anthropogenic disturbance"; "> Food" = "Increase of food availability"; "> Daytime hiding places" = "Provision of daytime hiding places"; "> Breed." = "Provision of breeding structures"; "Successful upbringing" = "Successful upbringing of cubs". The measure "Remaining the largest possible parts of windthrow areas untreated" served all purposes except for increasing availability of breeding structures.

Of the three measures that aimed to provide breeding structures, the "stockpiling of crown wood" was least effective (mrv = 3.30) and least practicable (mrv = 3.25). The other two measures were rated as *very practicable* with a negligible difference in the mean rating values. (mrv = 5; 4.75). But "Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand" was rated as more effective (mrv = 4.67) than "Remaining biotope trees and deadwood in the stand" (mrv = 4). Although the higher effectiveness of the first measure would argue for prioritising this measure when it comes to proposing measures to increase the amount of breeding structures, both measures are proposed along with each other in the connectivity concept when it comes to the supply of breeding sites. The habitat quality assessment showed that the availability of breeding structures was the most critical factor in the study area. Since both measures were rated as *very practicable* the introduction of both measures might not decrease the practicability of the concept but significantly increase the chances of successful introduction of breeding structures. Additionally, “Remaining biotope trees and deadwood in the stand” is one of the measures that supports most other species besides the wildcat including bats, owls, woodpecker and insect (Hermann, 2005; Thiel-Bender, 2020; Trinzen, Manfred & Behrmann, 2015) and hence should be promoted as effective measurement. However, deadwood and biotope trees only occur in older stands. In young stands, the same effect can be achieved by artificially introducing these structures. Therefore, this measure is proposed in the action plan in relation to younger stands as alternative to “remaining” these structures in the stand, if appropriate.

Along the measures for an increased amount of daytime resting spots the two measures “Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand” and “Support natural forest rejuvenation, prioritising natural rejuvenation before other rejuvenation strategies” were both rated with the highest mrv for practicability (mrv = 5) and as *effective* (mrv = 4). “Remaining meadows through extensive management” was rated as more effective (mrv = 4.67) but less practicable (mrv = 4.5). As not every forest area contains meadows, this measure is very site-dependent and can therefore only be implemented at appropriate sites. Hence, the first two measures are in general preferred in terms of increasing daytime resting places. For the reasons mentioned above “Remaining biotope trees and deadwood in the stand” was also rated as measure of first priority in this context and is proposed along with the first two measures in the action plan. The third best measure to increase the availability of daytime hiding places was “Establish richly structures forest edges” with a mrv for effectivity and practicability of 4. The least appropriate measure was again “Stockpiling of crown wood” for which both effectivity and practicability were only rated as *medium* (Figure X).

Three of the forest management-related measures result in an increased food availability. Focusing solely on the assessment of practicability and effectiveness and their relationship "Remaining meadows through extensive management " would certainly be the preferred measure to propose in the connectivity concept. For the reasons mentioned above the measure “Support natural forest rejuvenation, prioritising natural rejuvenation before other rejuvenation strategies” is still preferred for the action plan except for *core areas* that contain meadows. “Establish richly structures forest edges” was placed on last position in the ranking. It should be noted, however, that the lower rating of the effectiveness of this measure may have been caused by inaccurate questioning during the interview. In the interview, Dr. Thiel-Bender, who rated the measure with medium effectiveness, emphasised that this measure is good for promoting prey, but to just introduce richly structured forest edges is not sufficient for promoting wildcats (Interview Thiel-Bender, 2021). If the question had been more clearly related to the food supply, the rating of the effectiveness would probably have been better. In addition, Manfred Trinzen emphasised that this measure is especially important to shape the transition from shelter to open land (Interview Trinzen, 2021). However, the site-dependency of the measures increasing the food supply should also not be disregarded. For example, narrow woodland strips do not contain meadows, but they often border agricultural land. Therefore, depending on the location, the introduction of richly structured forest edges could be preferred over extensive management of meadows in the connectivity concept, despite its better rating.

Measures to reduce anthropogenic disturbances were “Renunciation on thinning in forests stands younger than 5 years between April and July” (mrv practicability = 3.75; mrv effectivity = 3.50), “Designate areas suitable for breeding and if possible postpone intensive management measures between Sep. and Feb.” (mrv practicability = 4.0; mrv effectivity = 3.33), “Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood” (mrv practicability = 3.5; mrv effectivity = 4.33). All three measures were rated as *practicable* and did not differ much in their rating for practicability. Thus, in this case the effectivity was the decisive factor. Consequently, the prioritized method to reduce anthropogenic disturbance was “Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood”. Followed by “Renunciation on thinning in forests stands younger than 5 years between April and July” and “Designate areas suitable for breeding and if possible, postpone intensive management measures between Sep. and Feb”. Regarding the latter measure, it must be added that lower scores were given mainly because it is difficult to really predict in which areas the wildcat will actually use to rear its young (Interview Pechtheyden, 2021). However, if the location is known, this measure was considered much more effective. In this case, the prevention of disturbance is in any case prescribed by the protection status of the wildcat in the FFH directive (92/43/EWG 1992). Although the above-mentioned measures can help to reduce disturbance, they do not solve the main problem of many *core areas* that caused disturbance in the first place. The interviews on habitat quality revealed that the main factor causing disturbance in the *core areas* were locals and tourists seeking recreation our using the area for outdoor activities (in the following referred to as tourists) in combination with extensively develop path networks for those tourists. All introduced measures relate to disturbance caused by forest work. Hence although these measures can also contribute to the calming of the areas to some degree, in many *core areas* that are prone to anthropogenic disturbance these measures will have to be supplemented with measures to reduce anthropogenic disturbance caused by tourists.

The best measure to support a successful upbringing of cubs was “Controlling root plates before folding them back (mrv effectivity = 4.67; mrv practicability = 4.5), followed by “Renunciation of rodenticides” (mrv effectivity = 4.33; mrv practicability = 4.0). This was then followed by the measures to reduce anthropogenic disturbance in the order mentioned above. Although rated as effective (mrv = 4.0) “controlling of wood stacks before removal” was a measure that was just not applicable in forest practice (mrv = 2.75) as the removal of the wood piles is carried out by external companies (Interview Thiel-Bender; 2021, Interview Jüssen, 2021; Interview Stoffels, 2021) and therefore the exact time of collection is usually unclear. Nevertheless, forest workers should of course be informed about this measure so that it can be applied if the arrangement with an external company works out. But these probably will be individual cases.

“Remaining the largest possible part of windthrow areas untreated” supports four conservation purposes at once and was rates as *very effective* (mrv = 4.67). Unfortunately, the measure received the third lowest rating in terms of practicability (mrv = 3.38). This is mainly because the feasibility of this measure depends on many different factors and the situation in place. For example, whether the area is to be replanted or whether the windthrow is deciduous or coniferous wood. It is certainly less feasible for forest operations that are dependent on profit than for those that are not (Interview Stoffels, 2021; Interview Roland, 2021; Interview Jüssen, 2021). However, since the preservation of windthrow areas brings so many benefits, remaining the greatest possible part of windthrow areas is generally recommended for all *core areas*. The flexible formulation of the measure also leaves enough room for the forest workers, so that the measure can perhaps be better implemented.

Table 12: Ranking of forest management-related conservation measures resulting from the assessment of practicability and effectivity by experts.

Conservation purpose	Measure	# Ranking
Provision of breeding structures	Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand.	1
	Remaining biotope trees and deadwood in the stand	1
	Stockpiling of crown wood	2
Provision of daytime resting spots	Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand.	1
	Support natural forest rejuvenation, prioritising natural rejuvenation before other rejuvenation strategies	1
	Remaining biotope trees and deadwood in the stand	1
	Remaining meadows through extensive management	2
	Establish richly structured and levelled forest edges	3
	Stockpiling of crown wood	4
Increase of food availability	Support natural forest rejuvenation, prioritising natural rejuvenation before other rejuvenation strategies	1
	Remaining meadows through extensive management	2
	Establish richly structured and levelled forest edges	3
Reduced anthropogenic disturbances	Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood.	1
	Renunciation on thinning in forests stands younger than 5 years between April and July	2
	Designate areas suitable for breeding and if possible, postpone intensive management measures between Sep. and Feb.	3
Successful upbringing of cubs	Controlling root plates before folding them back	1
	Renunciation of rodenticides	2
	Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood.	3
	Renunciation on thinning in forests stands younger than 5 years between April and July	4
	Designate areas suitable for breeding and if possible, postpone intensive management measures between Sep. and Feb.	5
	Controlling wood stacks before removal	6

4.2.3 Habitat quality action plan

For the elaboration of the action plan, deficits in the habitat quality factors of the *core areas* were examined. During the elaboration of the action plan, particular attention was also paid to the additional explanations provided by the experts during the habitat quality assessment, as these contained important details on the ecological equipment of the *core areas*. The *core areas* are all addressed one after another in the following. In the framework of the habitat quality action plan he measures were only allocated at the scale of the *core areas* and not assessed to more precise locations within the *core areas*. For a "metre-precise" location of measures, exact local knowledge is required. Since people with exact knowledge, such as local foresters, are ulimately responsible for implementing the measures, it makes more sense to leave the selection of precise implementation points to them. Measures to support a successful upbringing of cubs are only proposed in *core areas* where the wildcat is already proven (Ville1 – Ville4).

4.2.3.1 Ville1 and Ville2

The core areas Ville1 and Ville2 did not show any deficit. Hence no measures to increase habitat quality need to be taken here. However, since wildcats have already been proven in these areas, some measures should be implemented here that contribute to the successful rearing of cubs. In any case, root plates should be controlled before folding back and the use of rodenticides is to be avoided. In addition, the manual harvesting with chainsaws of small windthrow areas especially in deciduous wood should be avoided, as this also has a positive effect on other species like badger, deer, roe deer, butterflies and grasshoppers (Thiel-Bender, 2021 unpublished). If the exact breeding sites of wildcats are known, they should of course be protected according to the FFH guidelines.

4.2.3.2 Ville3

The proportion of low-disturbance areas in Villle3 was *improvable*. Therefore, manual harvesting with chainsaws of small windthrow areas especially in deciduous wood should be waivered here, as this also supports other species. Since the occurrence of wildcats has already been proven in Vile 3 too, it is also advisable not to thin forest stands that are younger than 5 years, as this also has a positive effect on the rearing of the young. Further measures that support the successful upbringing of cubs should be implemented as described for Ville1 and Ville2. Since the anthropogenic disturbances are mainly caused by tourists, the network of paths should be cleared back at suitable points to create larger, contiguous low-disturbance areas.

4.2.3.3 Ville4

Ville4 showed the same ratings as Ville3 and wildcats were also proven here. Hence, the proposed measures are the same as for Ville3. Approximately two thirds of the area is allocated to the state forest, one third belongs to RWE. The areas of the state forest are highly frequented by tourists, especially in the area around the lakes, while tourists do not have access to the RWE areas (with the exception of some hunters). If there are opportunities to dismantle parts of the visitor path network in the state forest, these should be seized. Furthermore, the undisturbed areas resulting not for tourists developed RWE areas are to be preserved.

4.2.3.4 Hürth1

The core area Hürth1 showed deficits in the presence of breeding sites, food availability and low-disturbance areas. For the presence of daytime resting spots, the mrv was just above the threshold for a deficit. Hence measures to improve the status of all habitat quality factors need to be implemented. To increase the availability of daytime hiding and breeding structures, special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides are to be left untreated in the stand. Furthermore, biotope trees and deadwood should remain in the stand. As the forest stands are rather young the natural supply of deadwood and biotope trees is probably poor. Thus, those structures could be implemented in the stand artificially. Natural rejuvenation should be applied as rejuvenation strategy as this increases daytime hiding places and food availability. Satellite pictures indicate that the area south of the Otto-Maigler-lake contains some forest meadows, if this is the case these should be preserved. If there are no meadows within the stand, the food supply could be increased by a good connection to the adjacent agricultural land. Implementing hedge structures on the outer edges of the forest creates good conditions for mice and at the same time improves the transition to the agricultural land, which wildcats can also serve as hunting ground. By implementing a few steppingstone structures across the adjacent agricultural land, these areas could be made accessible for shelter-bound species. With regard to anthropogenic disturbances, Hürth1 could be divided into two parts: the northern area around Otto-Maigler-lake and the southern area, which extends southwards from Hürther-Wald-lake. The southern area was not accessible to tourists and was therefore protected from anthropogenic disturbance. The northern area, on the other hand, was described as heavily frequented by tourists, especially the public beach at the Otto-Maigler-lake (Interview Eßer, 2021; Interview Schmaus, 2021; Interview Pechtheyden, 2021; Interview Jüssen, 2021; Interview Walther, 2021). In order to avoid further disturbances in this area, the forest workers should refrain from the motor manual processing of windthrows. Since windthrow areas bring so many benefits, they should remain untreated in Hürth1 anyway. Mitigating the flow of tourists around the public beach will probably not be possible. However, if there are opportunities to reduce the network of paths in other areas around the Otto-Maigler-lake, these should definitely be seized. The undisturbed southern parts of Hürth1 should be preserved.

4.2.3.5 White

The white area could only be assessed by one expert whose local knowledge was limited to the part southwest of the railway line. The surroundings of the Gotteshütte-pond therefore remain unknown. All habitat quality factors were classified as deficient. The main reason for this was the youth of the stands (Interview Jüssen, 2021). Therefore, all measures to increase the food supply, increase the number of breeding and daytime resting sites and reduce anthropogenic disturbance that were placed as number 1 or 2 in the ranking should be implemented. As there are no meadows in the white area, the establishment of structurally rich forest edges is recommended to increase the food supply also towards the visitor paths. This could perhaps also mitigate the disturbance caused by the paths in the narrow area. All windthrow areas should remain completely unmanaged due to the unfavourable general condition of the area. Artificial introduction of deadwood and biotope trees could also increase the structural richness until the forest stand itself has reached an appropriate age.

4.2.3.6 Berrenrath1 and Kerpen1

Berrenrath1 and Kerpen1 showed a deficit in the availability of breeding structures and an *improvable* status regarding the other three habitat quality factors. The *core areas* were characterised by their long borders to agricultural land. Through the implementation of hedge structures in the transition areas, a better connection between these two habitats could be created and the food supply could be improved further. Even though the agricultural areas of Berrenrath1 was framed by wooded structures that enable the migration through Berrenrath1 for the wildcats, further wood structures of at least 0.5 ha to 1 ha should be implanted in the agricultural area. This would make agricultural area of Berrenrath1 also usable for the wildcat with the consequence that *core area* Berrenrath1 would extend to include the entire agricultural area and would not be limited to the narrow wood structures. In Kerpen1, some large agricultural areas could also be structurally enriched with two or three stepping stones, but the ratio between agricultural land and sheltering structures here is much more balanced than in Berrenrath1. An exemplary ratio between agricultural land and forest areas which probably suits best for the needs of the wildcat is demonstrated in Bergheim1 and Bergheim2 where the agricultural area was framed by sheltering structures in that way that distances across open land are never bigger than 1 km and service roads between the single fields are additionally equipped with single rows of sheltering wood structures.

As the stands were still young, deadwood and biotope trees were only present in the form of a few dying poplars trees (Interview Jüssen, 2021) which should be left in place. To improve the supply of breeding and daytime hiding places, other special structures should also be retained. Such special structures could be integrated in the areas artificially. Anthropogenic disturbances were mainly caused by tourists. Especially in the narrow forested areas, tourists caused considerable disturbance. In these areas, the path network should therefore be reduced if possible. On the part of the forest operations, the implementation of the first and second measures of the ranking could contribute to a reduction of disturbances. Further disturbances were caused by the adjacent agricultural areas. However, as a catalogue of measures for agricultural areas and an evaluation of these measures does not exist yet, no recommendations can be made here.

4.2.3.7 Turquoise

The turquoise area showed sufficient statuses of low-disturbance areas and food availability while the availability of daytime hiding- and breeding structures was *improvable*. Consequently, all measures that increase the availability of these structures and were ranked as number 1 should be implemented in this area.

4.2.3.8 Horrem1

This core area was also just assessed by one expert. This expert rated the availability of food, daytime hiding places and breeding structures with the highest possible value. Only the proportion of low-disturbance areas was rated as *improvable*. As the area was designated for species conservation, several parts were completely excluded from economic forest (Interview Jüssen, 2021). Thus, the proposition of forest management-related measures to decrease anthropogenic disturbances is pointless here. A reduction in anthropogenic disturbances can therefore only be achieved by reducing the visitor path network. The effects of the construction of the access road to the A4 have already been described in 4.3.1.6.

4.3.2.8 Bergheim1 and Bergheim2

These two core areas showed no *deficit* and were even rated as *sufficient* in their food supply. Nevertheless, the three remaining habitat quality factors could be improved. With regard to the presence of breeding sites, the area of the Königsdorfer forest in Bergheim1 must be considered separately from the other areas. The Königsdorfer forest was an older forest, which is why suitable structures for breeding sites can be found there (Interview Walther, 2021, Interview Rose, 2021, Interview Jüssen, 2021). The other areas, on the other hand, were young stands that originated from rehabilitation. Special structures such as root plates, tree stumps, small waterbodies, forest clearings and landslides should be preserved here. Due to the young age, there was not much dead wood or biotope trees that could be left in the stand yet. However, many hedges were found in the rehabilitation areas, which were suitable as daytime hiding spots. Both the number of daytime hiding places and breeding structures could be increased by the artificial introduction of deadwood and biotope trees.

4.2.3.9 Paffendorf1 and Frimmersdorf1

Both *core areas* were characterised by young forests stands resulting from rehabilitation. These were mainly narrow strips of woodland (≈ 100 to 350 m) surrounded by agricultural land, so that overall, these areas would rather be described as structurally rich agricultural land. *Deficits* were found in terms of breeding structures and undisturbed areas. The supply of daytime hiding places and food was *improvable*. Thus, special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides should remain untreated in the stand. Biotope trees and deadwood should be brought artificially in the stands to increase daytime hiding and breeding structures. To support the availability of daytime hiding places and food, natural rejuvenation should be supported. Although the measure was not rated quite as highly due to its practicability, structurally rich forest edges should be established in order to better shape the transition between these two landscapes and at the same time increase the food supply as well as the number of daytime hiding places. Forest workers can contribute to decrease disturbance by refraining from the manual processing of windthrows. However, as the main cause of disturbance were tourists and disturbance from agricultural processes, measures must focus on reducing those. Within the narrow forest areas, the paths should therefore be reduced, as they have a particularly high disturbance impact in a small space. With regard to agricultural activities, no recommendations can be made yet. As for Berrenrath1, the adjacent agricultural areas of Paffendorf1 and Frimmersdorf1 could also be made usable for wildcats by the implementation of sheltering structures in the agricultural landscape thus expending their potential habitat area.

4.2.3.10 Sophienhöhe1

Conditions in Sophienhöhe1 were only *improvable* with regard to the availability of breeding structures and low-disturbance areas. As the stands in Sophienhöhe1 were also still young, there was a lack of naturally occurring deadwood and biotope trees here too. However, this was already being helped by a deadwood concept and the artificial introduction of biotope trees. Special structures such as meadows, root plates and small scale water structures these are also left untreated (Interview Eßer, 2021; Interview Roland, 2021; Interview Stoffels, 2021; Interview Walther, 2021). The only remaining measure with regard to breeding structures was the stacking of crown wood. However, as this is more of an "emergency measure" (Interview Thiel-Bender, 2021) and less practicable, it is rather recommended to continuously apply the practices already carried out and thus increase the opportunities for breeding structures a little more. Anthropogenic disturbance could be reduced further by avoiding thinning in stands that are younger than five years and manual harvesting with chainsaws of small wind-throw areas especially in deciduous wood. Nevertheless, disturbances were mainly caused by tourists. Therefore, whenever possible, tourists' paths should be cut back and the development of new paths for tourists should be prevented.

5 Discussion

5.1 Summary of most important targets of the connectivity conservation concept for the Rhenish lignite mining area

Although the mitigation of the fragmentation effect of all the identified obstacles is a prerequisite for a functioning biotope network between the rehabilitated forest areas in RLMA, some points of the action plan must be emphasised as they are to be prioritised in their implementation. Due to their critical conservation status, the effective conservation of wildcats and the promotion of its further distribution in the RLMA are main targets of the conservation concept. Hence, priority is the sufficient connection and ecological equipment of *core areas* where wildcats are already present together with those directly adjacent to these *core areas* in order to prepare a further distribution of wildcats. Consequently, the mitigation of the fragmentation effect of the B265 between Ville2 and Ville3 is a priority, as it prevents the exchange of two of the qualitatively most valuable *core areas* in the study area. Additionally, the northern areas of Ville4 should be secured for nature conservation. They represent the northern end of the older and largest contiguous forest rehabilitation areas, so that species can spread further northwards from here, such as the wildcat. If these areas are dedicated to other development purposes, a connection between the Ville Forest and the northern rehabilitated areas is hardly feasible.

It could be argued that in general all measures should be implemented gradually from south to north, following the distribution pattern of the wildcat to the north. Although the wildcat is the target species of this concept, the connectivity conservation concept also serves other species. The absence of the wildcat in the northern areas is therefore no justification for not implementing the measures there. The largest barrier in the study area is the A4, which should be made permeable for wildlife without fail as soon as possible.

All in all, the absolute minimum requirement for the implementation of measures depends on the current distribution status of the wildcat and should always include the current distribution areas as well as the *core areas* adjacent to them. If these areas are connected and the habitat quality is sufficient further prioritisation could be based on the traffic density of the roads (roads with highest traffic density first) and the status quo of habitat quality (severe deficits first) within the RLMA regardless of their location in relation to wildcat distribution.

The most severe deficits in the rehabilitated forest habitats were the availability of low disturbance areas and breeding structure. Thus, visitor paths within these areas should be reduced whenever possible. RWE is already doing exemplary work in some areas, such as the Sophienhöhe, in terms of measures to increase structural richness of the forest areas. This should be extended to the other *core areas*. In addition, it should be ensured that such measures are also continued by subsequent owners, as the rehabilitation efforts made by RWE will be in vain if they are not continued. This was also pointed out by Imboden and Moczek (2015).

As there is still too little data on the use of non-wildlife specific crossing structures, as many of the identified suitable crossing structures as possible should be equipped with wildlife cameras in order to improve the data situation. For the same reason, a possible spread of the wildcat should be accompanied by a sufficient monitoring which could be realised using the lure stick method (see Hupe & Simon, 2007). There, the measures can serve other species. At last, the closer investigation of species using the sheltering structures of the Terra Nova Speedway could provide valuable data for the usage of corridor structures. A sufficient monitoring should also be considered here.

5.2 Discussion of methods

For the development of the action plans, various methods were combined within this study. For the application of these methods, established models as well as partly newly defined thresholds, and various geodata were used. Critical steps of the analysis are discussed below.

5.2.1 Least Cost Path Analysis

5.2.1.1 Target species for the connectivity concept

The wildcat was selected as target species for the present study. Within the framework of NABU's connectivity concept for Germany, connectivity paths were developed for three further species which, due to their large spatial requirements, are also suitable as target species for the connection of forest and structurally rich open land habitats: lynx (*Lynx lynx,* Kerr 1792), wolf (*Canis lupus*, Linnaeus 1758) and red deer (*Cervus elaphus*) (Hermann, 2007a). However, these three species were not as suitable as target species for a connectivity concept in the study area. Wolves rarely colonize areas with a road density higher than 0.45 km/km^2 (Mladenoff et al., 1999). With a road density of about 2 km/km^2, the study area is too much characterised by anthropogenic infrastructure to be suitable as a habitat for the wolf. Although the lynx is already present in the northern Eifel, it has not immigrated into the study area yet, just like the wolf. Although a migration from the Eifel into the study area could be discussed, the large spatial requirements of ≈ 170 km^2 for females and ≈ 260 km^2 for males (Schadt et al., 2002) make the study area as unsuitable for the lynx as for the wolf. Red deer, on the other hand, occur in the study area already. Due to their body size, they make even greater demands on crossing structures than wildcats and would therefore perhaps be particularly suitable as a target species in the study area. However, red deer are not endangered and are one of the managed species in NRW (Hermann et al., 2007a). In NRW, there are ten zones in which red deer are protected. Outside these zones, it is to be hunted. A connectivity network for red deer that allows migration between these zones makes sense (Hermann et al., 2007a), but none of these zones are located in the study area of this work. With red deer as the target species, a connectivity concept would be created for a species that is not supposed to spread in the study area. The wildcat therefore appears to be the best choice as target species for the connectivity concept in the study area.

5.2.1.2 Missing geodata

Many different geodata were used for the LCP. Unfortunately, geodata from biosphere reserves were not available. These data would probably not have had much influence on the results of the LCP, as most *core areas* were directly adjacent to each other and only separated by roads. Therefore, the positive effect of using protected areas as connectivity axis did not have a major influence on the outcome of the LCP. Nevertheless, the occurrence of biosphere reserves, like the other protected area categories, should be included in such analyses whenever possible. Furthermore, data on compensation areas of the district Düren were missing. The existence of this data would probably also not have influenced the result of the LCP any further, since with the exception of Sophienhöhe1, all *core areas* were located in the Rhine-Erft-District. The Terra Nova Speedway, which created the connection to Sophienhöhe1, was also located in the Rhine-Erft-District. Even if a connection to Sophienhöhe1 had been made via the northernmost areas of Frimmersdorf1, most of this connecting route would still have been located in the Rhine-Erft-District, so that even for such a variant, data on compensation areas would have been available for most of the connecting path.

5.2.1.3 Implementation probability values

For the LCP, *implementation probability values* were defined for the different categories of landowners and protection status. Due to the fact that the Erftverband is composed of six interest groups (Erftverband, n.d.), the probability of implementing measures on land owned by the Erftverband was estimated to be low. In retrospect, however, the fact that the Erftverband is a body of public law committed to the common- and the environmental well-being seems to be more decisive in determining the *implementation probability value*. If the study was repeated, the areas of the Erftverband would therefore better be assessed with the same probability value as the public areas. As most of the property areas of the Erftverband are directly associated with the river Erft because they are located in its floodplain or serve flood protection purposes, theses areas could even be assigned to higher probability values than public areas. However, the probability of the implementation is not as high as on RWE bat areas as interests of the Erftverband might not always be compatible with wildcat conservation measures while measures for the Bechtstein's bat and wildcats are very similar and thus implementable within the same areas.

5.2.1.4 Roads as obstacles

In the presented connectivity concept, roads with a traffic density of 2500 mv/d were assessed as obstacles and therefore measures to mitigate their fragmentation effect were proposed. Due to the high number of identified problematic roads, the threshold of 2500 mv/d might seem too strict, especially since traffic density on federal, state and county roads usually decreases at night, making crossing events less risky for wildlife. Furthermore, none of the roads identified as obstacles appears as a conflict point in the connectivity concept for Germany presented by the NABU (national wildcat concept NABU) (Hermann et al., 2007a) or in the national wildcat connectivity conservation concept published by the BUND (national wildcat concept BUND)(Vogel et al., 2009). This is because these concepts were developed on much larger scales and only conflict points for corridors with significance at European and national level were considered. However, both connectivity concepts emphasise that the problems of smaller roads have to be addressed at a local level (Hermann et al., 2007a; Vogel et al., 2009). Therefore, the inclusion of these obstacles was an important step in the development of a local connectivity conservation concept. Roads with 3000 mv/d were also included as obstacles in the conflict analysis in the wildcat connectivity concept for the state of North Rhine-

Westphalia of the BUND (wildcat concept NRW) (Klar, 2009b). Nevertheless, the wildcat concept NRW does not identify the same conflict points as in the action plan presented here. This is due to the fact that a conflict analysis in the wildcat concept NRW was only carried out for the Eifel region. Furthermore, in the wildcat concept NRW no corridor leads through the study area, although more than half of the *core areas*, defined here were also identified as suitable wildcat habitat on the larger scale of the wildcat concept NRW. All in all, the high number of identified road-related obstacles in the study area does not indicate a too strict valuation of obstacles but highlights the high degree of fragmentation in the study area. The fragmenting effect of roads with a traffic density of more than 2500 mv/d is proven (Klar et al., 2009) and thus measures need to be taken at all presented roads to sustainably reach connectivity in the study area.

5.2.1.5 Delineation of core areas

Wildcats also cross distances of 500 m unsheltered land (Hermann et al., 2007b). Hence, in future studies *core areas* and shelter structures could be expanded by a 500 m buffer zone that includes adjacent agricultural areas to represent the actual movement area of wildcats. This method was demonstrated in a connectivity concept to counteract fragmentation NRW (LANUV, 2012). It allows a better identification of areas where stepping stones and corridors need to be implemented and which areas are already accessible to wildcats.

5.2.2 On site explorations

For the on-site explorations and the subsequent classification of useful crossing structures it would have been advisable to set clearer characteristics for the classification of usable and non-usable crossing structures as demonstrated by Götz and Jerosch (2010) who subdivided underpasses into four categories of suitability by using six different rating criteria. Even though the assessments of the potential crossing structures are still considered factually correct, the application of these six characteristics would have increased the comparability between the crossing structures within this study and to those of others. In addition, the information gathered during the inspections would have been more targeted, so that potential differences between the crossing options might have been noticed. If some of these structures were to be equipped with cameras in order to investigate their use by wildlife in more detail, the data needed to classify these structures following the example of Götz and Jerosch (2010) should be collected in any case.

5.2.2 Expert Interviews

5.2.2.1 Habitat quality assessment: delineation of habitat areas

Instead of using the dimensions of the *core areas*, separate *habitat areas* were delineated for the habitat quality assessment. That way areas that were not identified as *core areas* due to their size but might intersect with the least cost path could also be included into the habitat quality assessment. Furthermore, it was assumed at the beginning of the study that every interviewed expert would know every *core area*. In this case, each expert would have had to go through the assessment of 13 *core areas* in the interview, i.e. 52 assessments (due to four different habitat quality factors). In order to reduce the interview effort for the experts, an attempt was made to unify larger ecologically similar areas by establishing *habitat areas*, so that the experts had to assess fewer individual areas. However, within the first two interviews it became clear that the experts knew much less areas well enough to assess them than expected. Most of the experts knew three to four areas well enough to rate them. To be clear, this does not mean that the chosen experts were not well versed in the field, but simply that no experts exist who know all the study areas. The original plan was to have the subdivision of the *habitat areas* reviewed by the first expert that was interviewed. As it showed this expert was not able to validate the subdivision of all habitat areas since his detailed knowledge was limited to the southern parts of the study areas. As a result, the subdivision of the *habitat areas* was reviewed by the first and second expert whereas both experts felt not too sure about some areas. Nevertheless, the subdivision could not have been changed after the second interview as the assessment areas of the experts started overlapping there. Comments in the interviews showed that some areas could have been subdivided in even smaller parcels due to some characteristics. The northern part of Hürth1 for example was much more prone to anthropogenic disturbances due to the public beach located there than the southern part of Hürth1 which was not accessible for tourists. Another example was the areas of state forest located in Bergheim1, where the forest stand was much older compared to the rehabilitated stands in the *habitat area*. Hence the lack of daytime hiding- and breeding structures was not as big in the patch of state forest as in the rest of Bergheim1. However, the ratings for the *habitat areas* were applicable for the development of the habitat quality action plan, as the experts pointed out such differences within the *habitat areas* during the interviews so that these were considered in the habitat quality action plan. Still, in the best case, the revision of the *habitat areas* would have taken place with perhaps three or four experts at the same time in order to discuss a sensible division. Since the experts' exact knowledge was limited to three or four of the subdivided areas anyway, the concern that the interviews with such small, subdivided areas would take too long was unfounded. Therefore, the dimensions of the *core areas* could simply have been used for the habitat quality assessment and supplemented by two or three further important areas, instead of deriving new *habitat areas*.

5.2.3.2 Habitat quality assessment: expanses of rated habitat areas

Although adjacent agricultural areas were included in the *habitat areas* in contrast to the *core areas*, the experts were asked to rate the habitat quality factors only with regard to the sheltered structures within the *habitat areas*. As explained before, the movement area of wildcats does not end at the border of shelter structures. Hence, for the assessment of the habitat quality, including a 500 m buffer zone into unsheltered land would have also made sense. This would probably not have had a significant effect on the habitat quality factors availability of daytime hiding places, availability of breeding structures and availability of low-disturbance areas, but in some *habitat areas* the food availability would probably have been rated higher.

5.2.3.3 Habitat quality assessment: number of experts

Most interviewed experts were able to assess three to four *habitat areas* since a really detailed knowledge about the areas was needed. The fact that no person could have that detailed knowledge for the entire study area made the search for enough experts to have every habitat area rated three times impossible. As a consequence, two *habitat areas* were only assessed by one expert and three habitat areas were assessed by only two experts. The search for more experts would probably have resulted in interviews with experts who could only assess one *habitat area*. The resulting effort would have been disproportionate for a master thesis. It is actually questionable whether there would have been more experts who could have been interviewed for some areas, as some *habitat areas* in the study area were privately owned and the foresters who managed them have already been interviewed as experts. However, data describing *habitat areas* that were assessed by only one or two experts (white, turquoise, Ville1, Ville2 and Ville3) are not as robust as such that were rated by three or more experts. Nevertheless, as the experts have always provided additional explanations for their assessments, for example why the food supply was not sufficient, the data obtained still seemed as the best possible option to build suggestions for measures to improve habitat quality on.

5.2.3.4 Habitat quality assessment: rating scale

Three of four habitat quality factors were assessed by the experts on a three-point rating scale. The three-point rating scale was chosen because an abundance of one structure per hectare was already estimated a lot (personal communication Thiel Bender, 2021) so that the subdivision of three categories made the experts deal with units of 0.5 structures per hectare. Therefore, a five-point scale did not seem applicable at all if the single steps on the scale should correspond to a quantifiable numerical value. However, during the interview, it turned out that it was even hard enough for the experts to apply the numerical values of the three-point scale to the matter so that in the end the assessment of the three habitat quality factors referred more to the descriptive titles of the steps on the scale (rare, medium, high) than to the numerical values. During the interviews it also became clear that the experts found it hard to realistically represent the conditions in place with only three ranking options. Two more intermediate options would have allowed to better mirror the conditions within some *habitat areas* in relation to the other areas. Therefore, abandoning the reference to numerical values, (which was also only partially given on the three-level scale anyways) in favour of a five-point descriptive scale would have enabled the experts to make more precise assessments. In the future, five ranking options with clear descriptions of what each rank implies should be developed.

5.2.3.5 Assignment of measures to conservation purposes

After the interviews the forest- and road-related wildcat conservation measures were assigned to the different conservation purposes. Assigning the measures to the respective purposes before the interviews and also showing these purposes to the experts might have made the aim of the individual measures clearer. This might not have had a big influence on the practicability or implementability rating but might have affected the rating of the effectiveness of measures. The way the measures were presented some experts anticipated the conservation purposes by themselves and rated the measures with regard to this exact purpose while others rated the effectivity of the measure with regard to its contribution to the overall habitat quality. Consequently, the later might have tended to rate measures less effective than the experts that referred to the specific conservation aim of a single measure. For a uniform understanding to what purpose a measure referred, a previous assignment to the conservation purposes shared with the experts would have been useful. Regarding the forest management-related measures, a previous assignment of the measures to the conservation purposes would have allowed a more targeted selection of measures. Particularly within the category of measures to reduce anthropogenic disturbance, it was noticeable, that there was a lack of measures that would have contributed to the reduction of disturbances caused by tourists. Such measures should be included in future projects.

5.2.3.6 Road construction- and agriculture experts

The implementability of the road-related measures was assessed by wildcat experts. Although all these experts have had experiences with the implementation of these measures, an additional assessment of the implementability by experts in the field of road construction would have increased the validity of the results and would have added one more important point of view to the development of the action plans. Especially the additional background information on what exactly makes the implementation difficult or in which context such measures are easier to implement would have been a valuable insight. Since wildcats can also use richly structured agricultural areas and since rehabilitation in the RLMA is an interplay of agricultural and forest rehabilitation, the inclusion of agricultural-related wildcat conservation measures in the catalogue of measures and the assessment of their practicability by farmers would certainly have increased the quality of the action plans. Therefore, these two groups of experts should be taken into account for future projects.

5.2.1.7 Selection of forestry experts

All forestry experts highlighted during the interviews, that the practicability of measures is closely interlinked to the economic pressure on the owner of the forest patch. For institutions such as the state, the federal states or companies such as RWE, which are not dependent on income from forest, many measures can be implemented even though they involve economic losses. Private forest owners, on the other hand, are often dependent on income from forest and therefore cannot afford to implement measures that reduce profits. Since only one of the four interviewed forestry experts also managed private forest areas, the opinion of private forest owners was underrepresented in the assessment of the practicability of the measures. If a higher proportion of private forest owners had been interviewed, many measures would probably have been assessed as less practicable. Since the study area mainly comprised areas of the state forest and RWE, the results collected were applicable to the study area. However, when transferring the results to other study areas, it should be taken into account, that other ownership structures may as well lead to different results when assessing the practicability of measures.

5.3 Comparison to other connectivity concepts

5.3.1 Comparison to the concept of the LANUV

The LANUV provided a set of geodata with areas of “outstanding importance” and “special importance” for a functional biotope that also addressed the expanses of the RLMA (LANUV, 2021). Unfortunately, these proposals could not be included in the LCP, as no further information was available on the extent to which efforts had been made to secure areas of “special importance” for nature conservation. Therefore, no probability values could have been derived on the base of this data. Nevertheless, the identified least cost path of this study only leads through land parcels that were also proposed for the creation of a biotope network by the LANUV. Thus, both concepts show great common sense.

5.3.2 Comparison to the delineated paths of Dr. Thiel-Bender

In 2020, Dr. Thiel-Bender was commissioned by RWE to conduct a feasibility study on the biotope network in the RLMA. The target species here was also the wildcat. The aim was to work out possible connectivity paths for the wildcat from the Ville and the Hürtgenwald towards the Sophienhöhe. Based on the results of this feasibility study, the task to develop a detailed connectivity plan in the RLMA arose, which was tacked in the present study (connectivity concept RLMA). Since the paths delineated by Dr. Thiel-Bender were the basis for the connectivity concept RLMA, the results of both connectivity concepts will be briefly compared in the following. Dr. Thiel-Bender presented four potential connectivity paths within her feasibility study (Figure 18) which were methodologically based on on-site explorations on foot and by car. Detailed planning for all paths would not have been possible in the scope of the presented study. The focus of the investigations was placed on the eastern connecting path of the Ville with the Sophienhöhe as this was declared the most feasible one (personal communication Thiel-Bender, 2020). Since the path developed in the course of this work differed significantly from the original path of Dr. Thiel-Bender, the reason for this will be briefly explained. The differences were due to the fact that the aims of the two concepts were different. The aim of Dr. Thiel-Bender's study was to design a connecting path from the Ville to the Sophienhöhe, which should include the bat protection areas created by RWE. Therefore, this path was oriented in the direction of Kerpen and reached the Sophienhöhe from the south, as the Erbwälder south of the open-cast mine Hambach were connected within the conservation efforts for the Bechstein's bat. The task for the connectivity concept RLMA had changed in that way that the focus was no longer primarily on the connection of the Sophienhöhe with the Ville, but on the connection of all forest rehabilitation areas. The *core areas* north of the A4 that were essential parts of the connectivity concept RLMA were not included in Dr. Thiel-Bender's study area. The further distribution of wildcats towards the Erbwälder is also possible in the connectivity concept RLMA (although not displayed in the maps) as they are connected to the Sophienhöhe over wooded structures along the still active path of the open-cast mine Hambach. The result of both connectivity concepts is in the end the same: the Ville is connected to the Sophienhöhe. But the advantage of the connectivity concept RLMA is that it leads through less densely populated areas and thus connects several suitable habitats for wildcats on the way from the Ville to the Sophienhöhe, instead of only creating a connecting path between these suitable wildcat habitats.

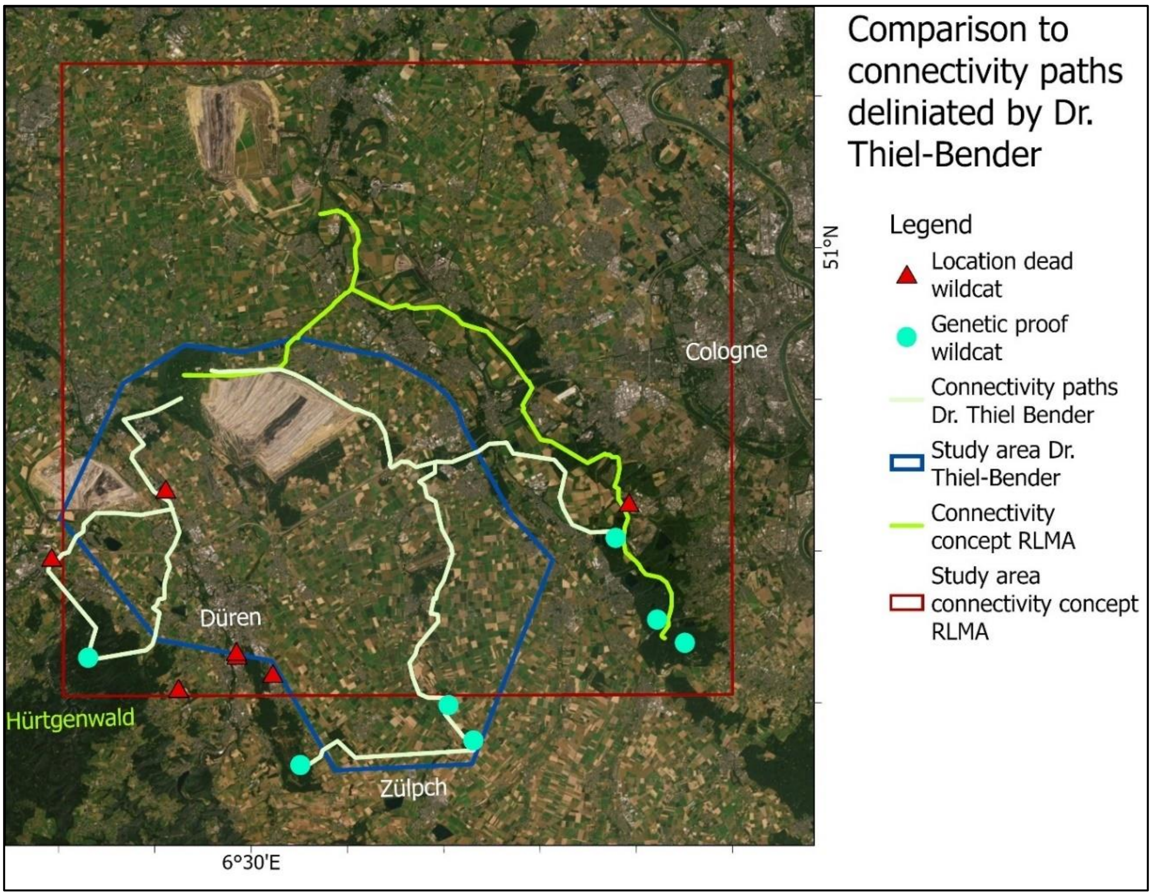

Figure 18: Comparison of the connectivity paths delineated by Dr. Thiel-Bender to the connectivity concept for the RLMA developed in this study. Basemap: Land NRW, LVermGeo RLP, Esri, HERE, Garmin, METI/NASA, USGS, Land NRW, Earthstar Graphics.

6 Outlook

6.1 Transboundary connectivity

The issue of biodiversity loss has fortunately gained attention during the last decade and projects on biodiversity and connectivity conservation have been launched. In order to establish a functional biotope network in NRW or throughout Germany, such concepts must be coordinated with respect to one another so that a sensible network of complementing paths is created. During the working process of this study, LANUV and BUND provided geodata of their connectivity concepts with the wildcat as target species (connectivity concept LANUV, connectivity concept BUND). Figure 19 shows excerpts of both connectivity concepts as well as the connectivity path of the concept in the presented work (connectivity concept RLMA) and what the transboundary linkages to other connectivity paths could look like. For this reason, the data from the LANUV and the BUND were not processed further, but simply included in the map for visualisation purposes (therefore, the LANUV and BUND network concepts are shown as polygons and the connectivity paths developed within the framework of this project are shown as lines). For a better overview, the *core areas* of the connectivity concept RLMA were not included in the map. Instead, the connectivity path for the RLMA was displayed as a continuous line. In order to extend the biotope network of the RLMA to a transboundary scale, two connectivity paths would have to be developed. First, a connection to the Eifel-region has to be implemented by connecting the Sophienhöhe with the Hürtgenwald. Such a connection could be achieved using the areas around the open-cast mine Inden and the floodplain of the river Inde (Thiel-Bender, 2020 unpublished). The biggest obstacles here are probably the wide areas of unsheltered land between the Hürtgenwald and the Inden open-cast mine. The discovery of a dead wildcat near the Jülich research centre (Figure 19) shows however, that a migration through that landscape is already possible for single individuals. It is therefore even more important to remove obstacles along this path so that wildlife can migrate freely between the Hürtgenwald and the Sophienhöhe. Second, a connection from the Ville to the Kottenforst and the Flamersheimer forest should be planned. The path from the Ville to the Kottenforst seems rather permeable for wildlife already, as a nearly continuous band of forest connects them. Nevertheless, a conflict analysis with regard to highly frequented streets should be conducted here to eliminate the risk factors for migrating wildlife. A connection to the Flamersheimer forest would be important as a dense network of connectivity paths of other connectivity concepts emerges here. At first glance, the biggest obstacles on this path are the A61 and large agricultural areas without shelter structures. Klar (2009b) also identified the connection between the Ville and Kottenforest to the Flamersheimer forest as an important part to increase connectivity for wildcats in NRW. She also described the A61 as critical point along with two other roads (Klar, 2009b). In order to increase the exchange between the RLMA and other regions, connectivity concepts for the path shown in Figure 19 should be planned in detail and implemented locally.

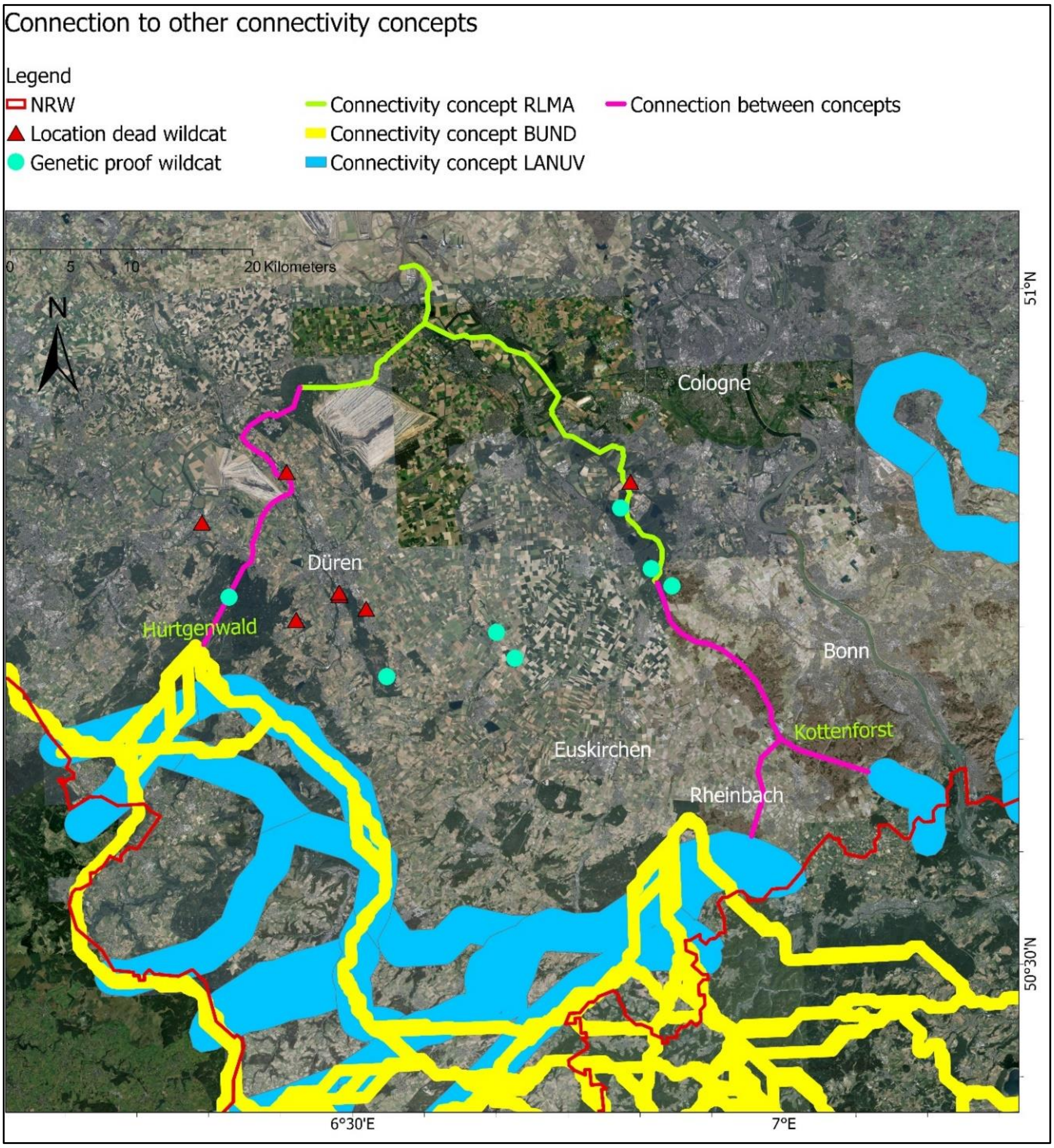

Figure 19: Overview over possible connections to other connectivity concepts. Data of locations of dead wildcats and genetic proof of wildcats were retrieved from Dr. Thiel-Bender. Data of the connectivity concept of the LANUV were retrieved on request from LANUV Fachbereich 22 - Planungsbeiträge zu Naturschutz und Landschaftspflege, Biotopverbund; Leibnizstraße 10 45659 Recklinghausen. Data of the connectivity concept of the BUND were retrieved on request from Kaiserin-Augusta-Allee 5 10553 Berlin. Basemap: Land NRW, LVermGeo RLP, Esri, HERE, Garmin, METI/NASA, USGS, Land NRW, Earthstar Graphics.

6.2 Complementation of the connectivity concept for the Rhenish lignite mining area

The proposed connectivity concept for the RLMA could be supplemented by including target species which's habitat requirements are not represented by wildcats to improve habitat quality in the entire RLMA. The target species selected by the RRC for the agricultural, forest and aquatic habitats of the RRC could be used as a guideline (Eßer et al., 2021).

The RLMA is characterised by agricultural and forest rehabilitation. As the wildcat also expands its habitat into richly structures agriculturally dominated landscapes (Jerosch et al., 2018) it is suitable as a target species for linking the rehabilitated agricultural and forest areas of the RLMA. In future, the rehabilitated agricultural areas could therefore be examined more closely with regard to their suitability as habitat for wildcats. The wildcat could thus become the target species of the entire rehabilitated landscapes in the study area. Here it is important to identify measures that do not have a negative impact on open-habitat species. A new catalogue of measures would have to be drawn up, which could then be assessed again by wildcat and agricultural experts in terms of practicability and effectivity. A measure potentially useful for wildcats and open-habitat species might be wildflower verges.

7 Conclusion

Connectivity conservation is a key tool to counteract biodiversity loss. Hence, projects on biodiversity conservation and connectivity conservation have been launched at larger scale. Although these concepts are an important step towards a functioning biotope network, concepts on a much smaller scale and therefore higher resolution are necessary for the actual implementation of measures. The presented connectivity concept for the RLMA fills precisely this gap by proposing detailed measures on a local scale that can be implemented directly. The interdisciplinary approach that regards ecological and practical aspects in the LCP and in which experts of different disciplines were consulted for the assessments of measures has resulted in a concept that is both effective and practical. The basis for the concept was an LCP in which implementation aspects such as landownership and protected areas were included in addition to the ecology of the wildcat. The inclusion of these aspects as described here increases the likelihood that measures can actually be implemented along the calculated path. For the future, this approach could be transferred to other areas at local scale for the development of connectivity concepts. For a better exchange of information, the presented concept could be transferred into geodata, where the core areas are attributed with the proposed measures.

The connectivity concept for the RLMA clearly shows that roads are the biggest hinderance for species' migration in the RLMA. The implementation of a functional biotope network in the RLMA is therefore associated with great efforts. Consequently, it is absolutely necessary to further investigate the possibilities of reducing the fragmentation effects of roads. Here, the main focus should be on measures that can be implemented at existing roads. Although it is a step forward that measures to reduce the fragmentation effect have to be implemented at newly constructed roads, this does not change the level of fragmentation in our landscape that we are facing already. The subsequent installation of subways, overpasses and fences at existing roads therefore definitely requires greater attention. The greatest barrier in the study area was the A4. As that highway cuts off a valuable habitat in the center of the study area from the southern rehabilitated forest areas (Figure 10), measures to compensate its fragmentation effect are of high priority. In the connectivity action plan of this study various measures are described to provisionally mitigate the fragmentation effect of the many roads with a traffic density of more than 2500 mv/d. However, these measures do not replace the installation of underpasses, overpasses and fences which are needed to increase connectivity in the study area. Furthermore, areas in in the RLMA must be permanently secured for nature conservation. Permeable roads are no longer of any use if they are blocked by settlements or industrial areas. An example of areas that need to be secured would be those in the northern Ville, as these make the connection between the high-quality older rehabilitation of the Ville and the younger rehabilitation areas possible in the first place.

The results of the habitat quality assessments revealed that the habitat quality of forest areas is closely related to their age. Therefore, an important instrument in nature conservation are measures that protect typical characteristics of old-grown forests or introduce them artificially into younger stands to create habitats which are usually only found in old-growth forest until they have reached the appropriate age. The preservation of biotope trees and deadwood is a very effective and at the same time very practicable measure and should therefore be applied in all forest areas in the RLMA.

It is not possible to predict whether wildcats will really spread along the entire rehabilitation areas up to the Sophienhöhe. Many *core areas* are very close to settlements or are disturbed by tourists. It therefore remains to be seen whether wildcats will show a higher tolerance to these disturbances. Therefore, monitoring the distribution of the wildcat in the RLMA is of great interest for nature conservation. Great attention should also be paid to the use of crossing structures, as more data is needed to improve the permeability of roads. In particular, the effectiveness of guiding structures such as hedges towards crossing structures should be further investigated, as these in combination with existing crossing structures could be a good tool to decrease mortality rates of wildlife at roads. The promoting of the distribution of wildcats through appropriate measures increases the connectivity and habitat quality of forest areas in the RLMA and thus contributes to the conservation of biodiversity and associated functioning ecosystem services in the rehabilitated lands.

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Appendix

Appendix 1 Detailed workflow of LCP in ArcGIS Pro

Detailed workflow of the applied functions in ArcGIS Pro for the performance of the LCP. The six steps refer to the six steps described in the chapter 4.2 whereas some steps were subdivided further for a better overview.

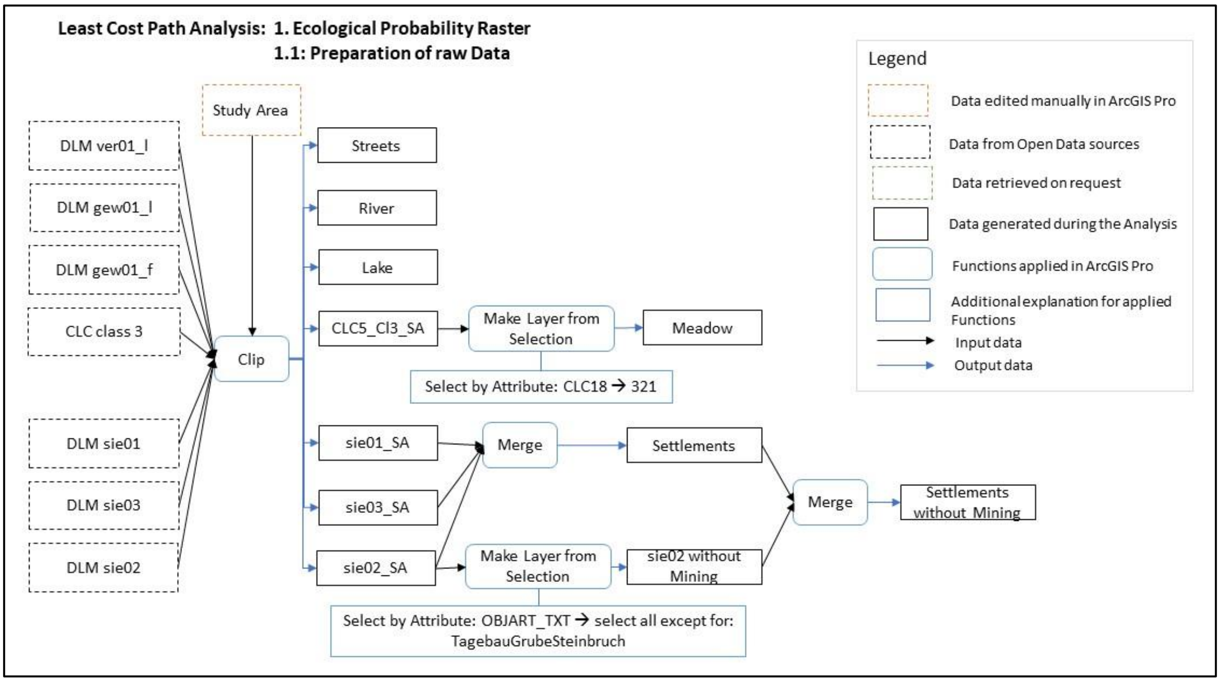

Figure 20: Detailed workflow of LCP conduction in ArcGIS Pro. Step 1.1.

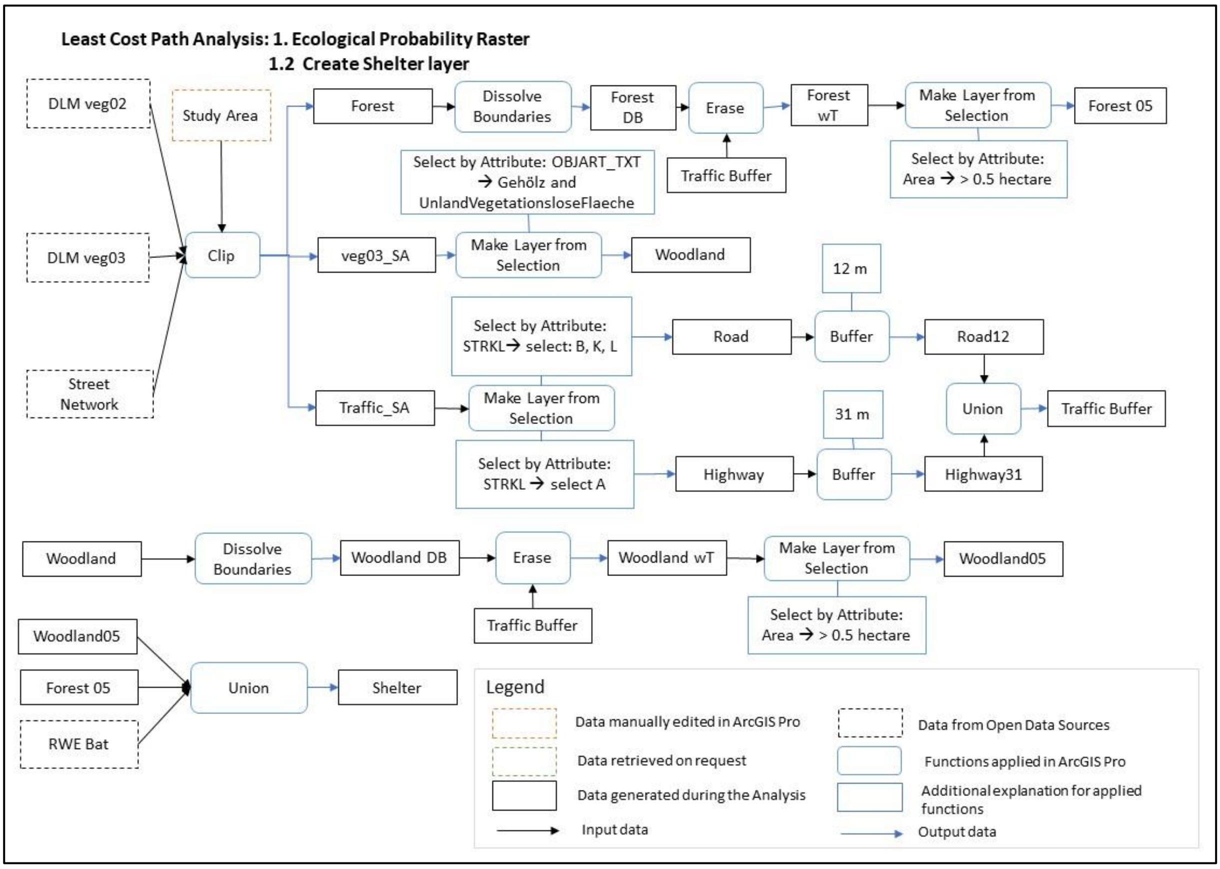

Figure 21: Detailed workflow of LCP conduction in ArcGIS Pro. Step 1.2.

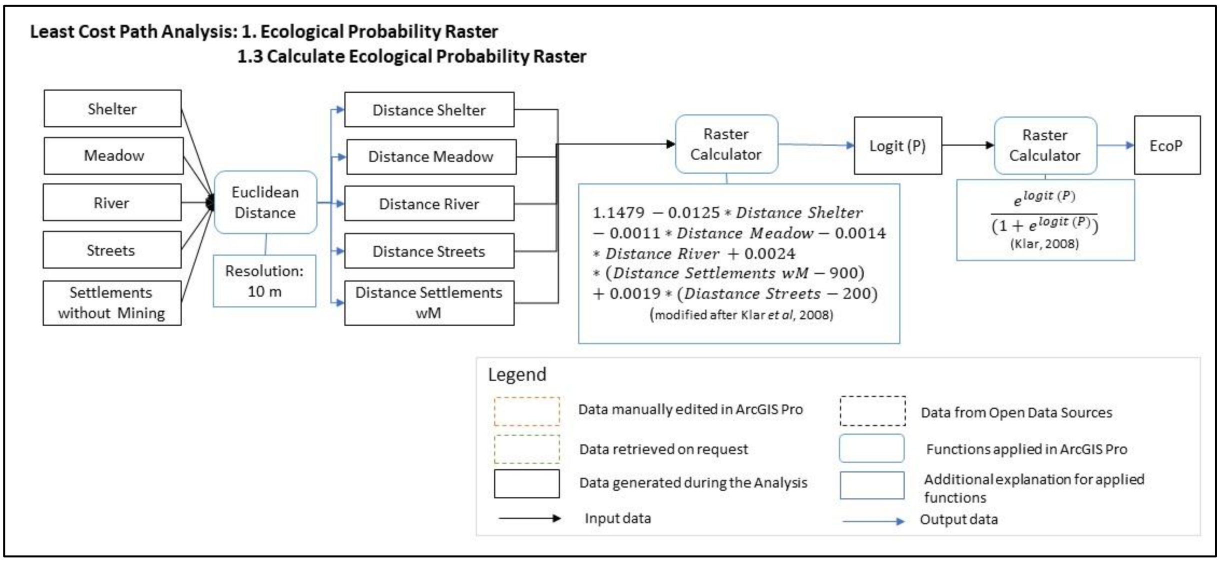

Figure 22: Detailed workflow of LCP conduction in ArcGIS Pro. Step 1.3.

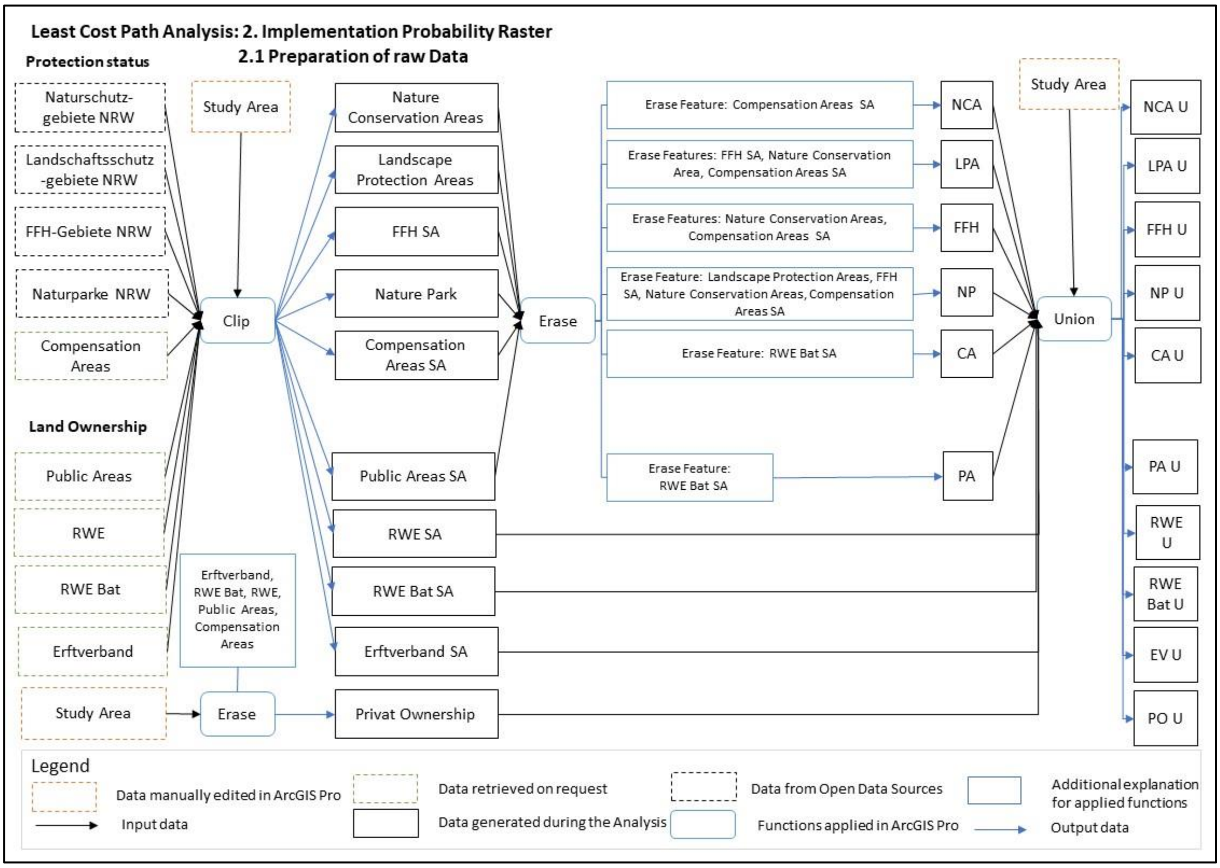

Figure 23: Detailed workflow of LCP conduction in ArcGIS Pro. Step 2.1.

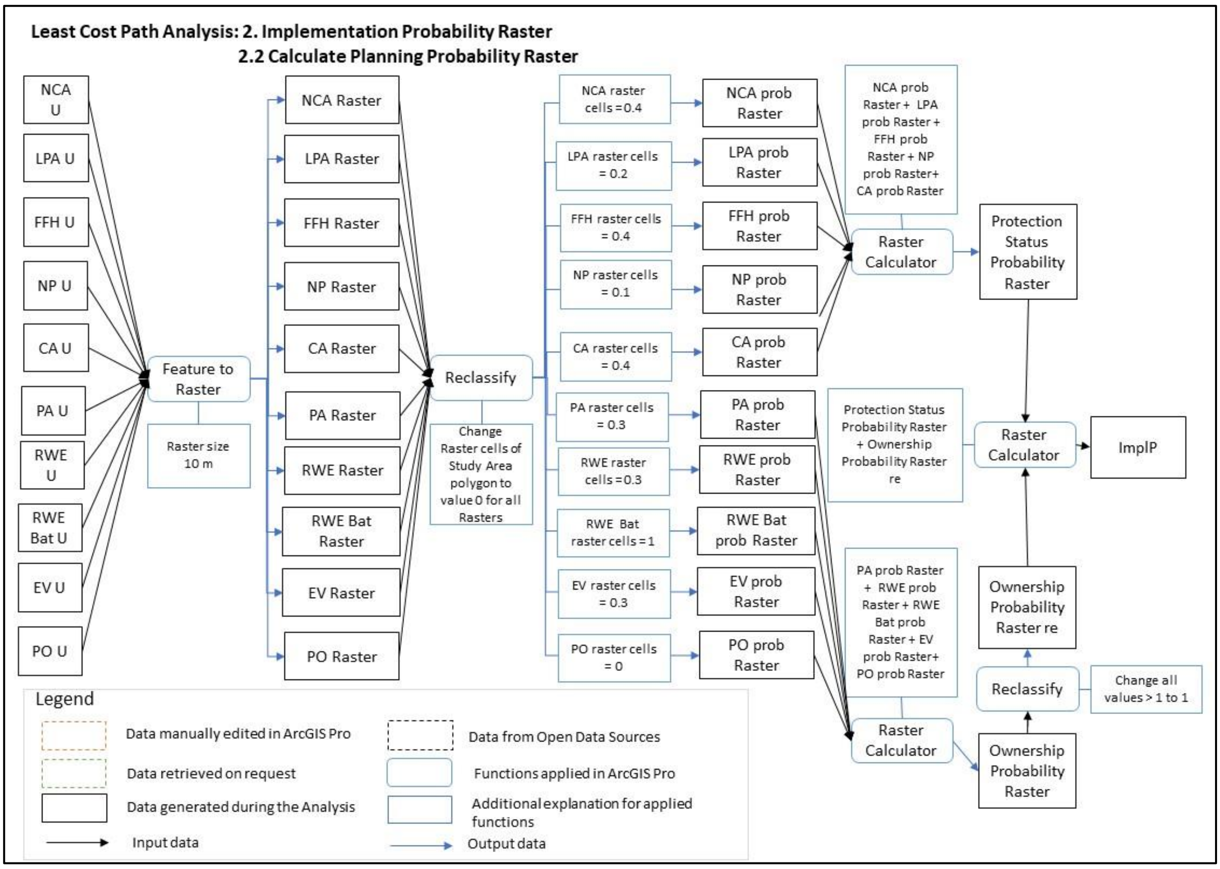

Figure 24: Detailed workflow of LCP conduction in ArcGIS Pro. Step 2.2.

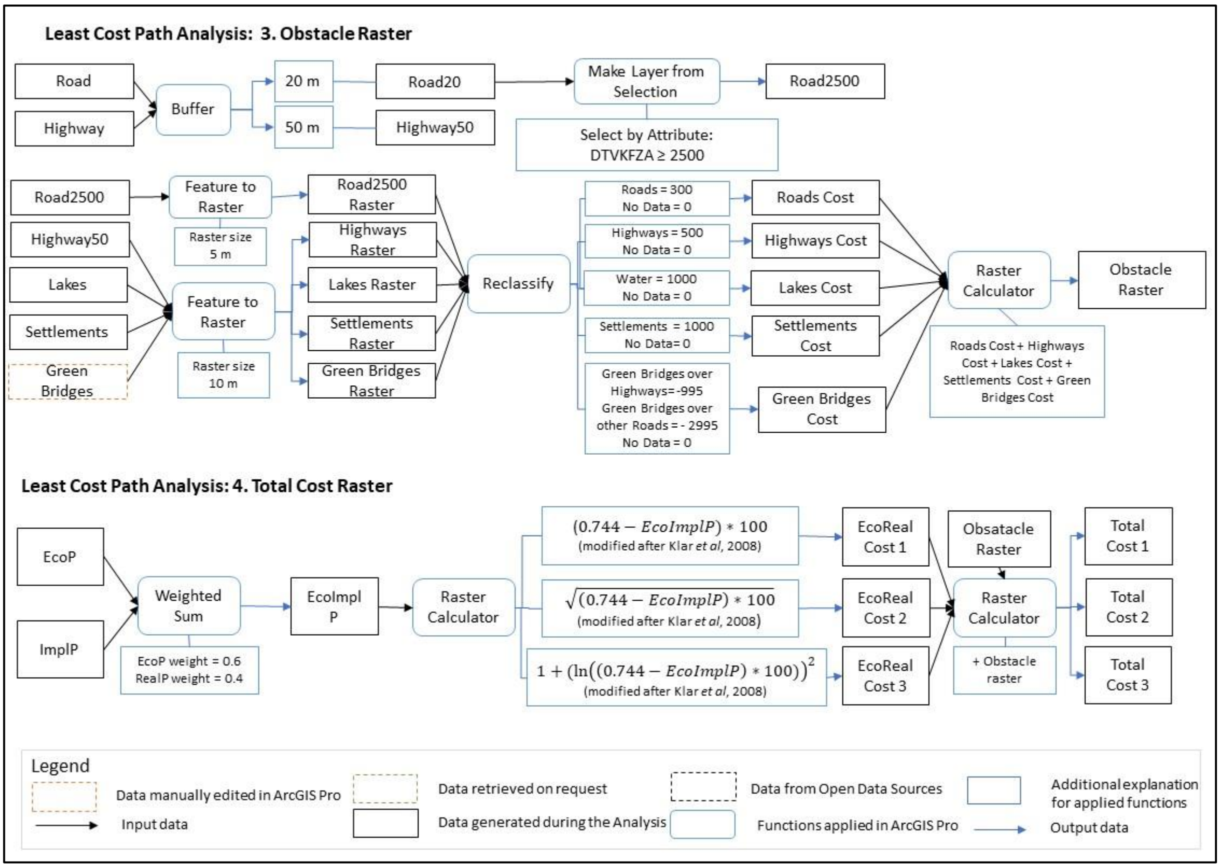

Figure 25: Detailed workflow of LCP conduction in ArcGIS Pro. Step 3 and 4.

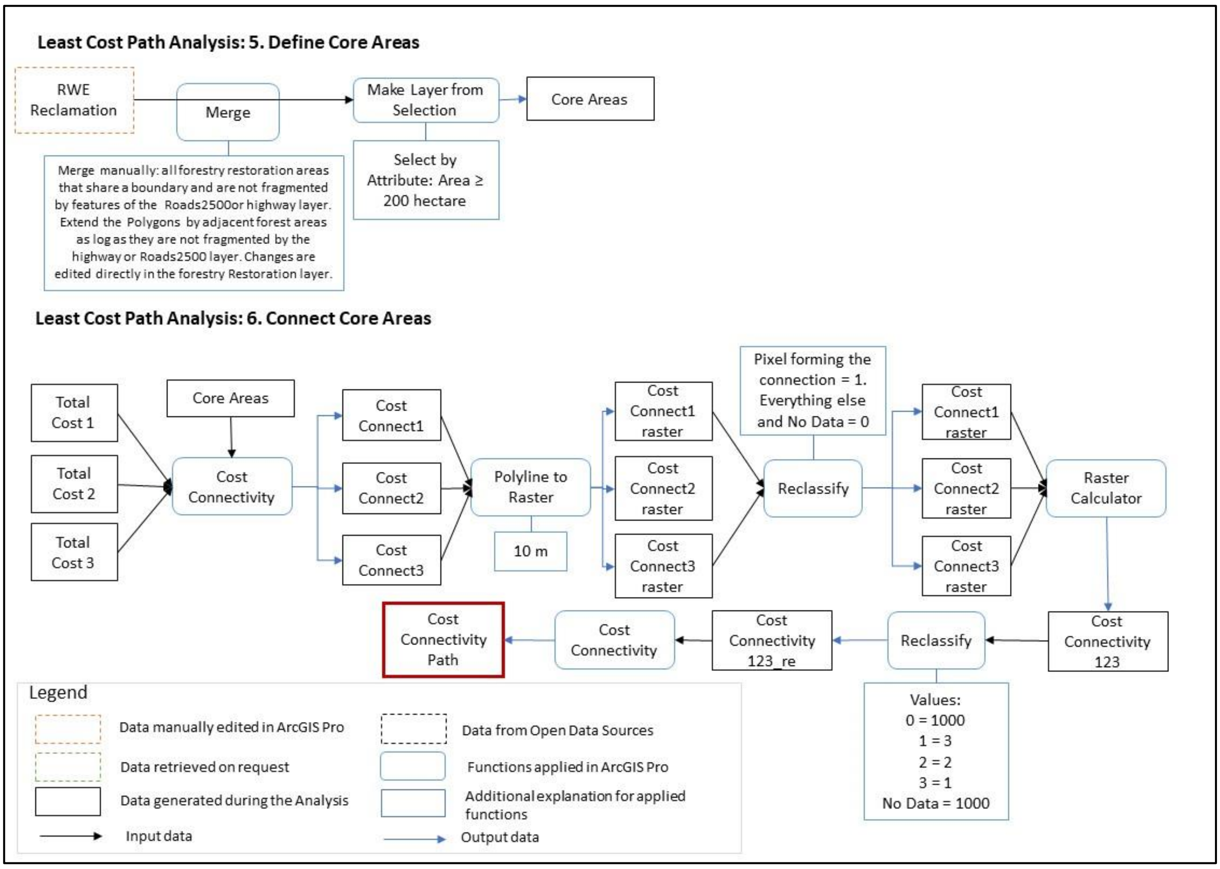

Figure 26: Detailed workflow of LCP conduction in ArcGIS Pro. Step 5 and 6.

Appendix 2 Experts' Profiles

The information presented in the experts' profiles were, unless indicated otherwise, retrieved during the expert interviews (see submitted audio files).

Table 13: Personal description of Experts

Name	Eßer, Gregor
Field of Expertise	RLMA
Current Profession	Head of Rehabilitation Research Centre, RWE Power (Forschungsstelle Rekultivierung)
Professional Background	- Diploma Biology and Geography University Bonn - 10 years in engineering offices with main focus on aquatic ecology - through the work for the Rehabilitation Research Centre best knowledge of some of the rehabilitated h*abitat areas*, also detailed knowledge about older rehabilitation areas (Ville) through the conduction of guided tours in these areas
Rated Habitat Areas	blue, brown, green, red, turquoise, salmon, orange
Name Field of Expertise Current Profession	Jüssen, Lukas Forest Forester of the forest district Frechen for the Agency of Forest and Wood NRW (Landesbetrieb Wald und Holz NRW)
Professional Background	- studied forester after state examination acquisition of the forest district Frechen - supervises half of the Rhein-Erft-Kreis and within his area of jurisdiction forests are owned by the municipalities as well as private forest persons
Rated Habitat Areas	green, white, red, turquoise, purple
Name	Dr. Klar, Nina
Field of Expertise	Wildcat
Current Profession	Head of Unit for Species and Biotope Conservation at the Authority for the Environment, Climate and Agriculture Hamburg (Behörde für Umwelt, Klima und Agrarwirtschaft (BUKA) in Hamburg)
Professional Background	- Internship at Öko-Log Freilandforschung first experiences with wildcats - Diploma Thesis about wildcats in the Eifel - Doctoral Thesis included the development of a wildcat habitat model, a wildcat connectivity conservation concept and investigation of the effects of traffic on wildcats - experience with practical implementation of wildcat conservation measures in the field of road construction work but not with the practical implementation of measures in forest areas
Name	Pechtheyden, Frank

Field of Expertise	Forest
Current Profession	Forester of the Forest district Ville-Seen for the Agency Forest and Wood NRW (Landesbetrieb Wald und Holz NRW)
Professional Background Rated Habitat Areas	- studied Forester, Fachhochschule Göttingen and vocational training as forester - 7 years of experience in supervision of municipally owned and private forest - since acquisition of forest district Ville-Seen supervision of state-owned forest (Pechtheyden, 2021) pink, blue, brown, green
-	

Name Field of Expertise Current Profession	Roland, Günther Forest Employee Rehabilitation Research Centre, RWE Power (Forschungsstelle Rekultivierung)
Professional Background	- vocational training as forest worker - 40 years experience as forest worker, since two years employee of the Rehabilitation Research Centre with main focus on ecology - through work as forest worker for RWE and employee of the Rehabilitation Research Centre detailed knowledge about some *habitat areas*
Rated Habitat Areas	yellow, salmon, orange, Erbwälder, Lörsfelder Busch / Dickbusch, Kerpener Bruch /Parrig

Name	Dr. Rose, Udo
Field of Expertise	RLMA
Current Profession	Biologist for Erftverband
Professional Background	- Diploma Biology University Cologne, then doctorate in Biology - over 30 years at Erftverband in Bergheim, mainly limnologic aspects but due to landownership of the Erftverband and resident in Bergheim knowledge of some *habitat areas*
Rated Habitat Areas	red, yellow, Parrig / Kerpener Bruch

Name	Schmaus, Hermann
Field of Expertise	RLMA
Current Profession	Retired
Professional Background	- worked as electrician in the factory Ville-Berrenrath for 40 years - performs ornithological mappings in the study area for 50 years therefore excellent knowledge about some of the *habitat areas*
Rated Habitat Areas	brown, green

Name	Stoffels, Michael
Field of Expertise	Forest
Current Profession	Employee Rehabilitation Research Centre, RWE Power (Forschungsstelle Rekultivierung)

Professional Background	- vocational training as forest worker - 37 years of forest work experience - through employment with Rhein-Braun (later RWE) and Rehabilitation Research Centre detailed work in old and young rehabilitated areas, thus detailed knowledge of some *habitat areas*
Rated Habitat Areas	pink, red, yellow, salmon, orange

Name	Dr. Thiel-Bender, Christine
Field of Expertise	Wildcat
Current Profession	Adviser for species conservation at BUND NRW, freelance work in the fields of: consulting for nature conservation and field research
Professional Background	- Diploma Biology University Bonn - Diploma Thesis about wildcats in the Eifel - Doctoral Thesis about servals in Africa - by now 15 years of experience in the field of wildcat conservation work

Name	Trinzen, Manfred
Field of Expertise	Wildcat
Current Profession	Wildlife Biologist
Professional Background	- studied chemistry and biology, then diploma in Biology in Saarbrücken - working with wildcats for more than 20 years - work is at the interface of research and practical implementation of measures - experience with practical implementation of measures in the field of road construction and forest

Name	Walther, Henning
Field of Expertise	RLMA
Current Profession	Employee Rehabilitation Research Centre, RWE Power (Forschungsstelle Rekultivierung)
Professional Background	- Diploma Landscape planning FH Weinstephan - Since 1990 Employee RWE Power, for 6 years Rehabilitation Research Centre - through the work for RWE Power detailed knowledge about some of the *habitat areas*
Rated Habitat Areas	green, yellow, salmon, orange

Appendix 3 Interview Guidelines

Interview Guidelines RLMA Experts

0) Permission

Hello Mr/Mrs …. before we officially start with the interview, I would like to ask you for permission to record this interview and to submit the .mp3 file together with my thesis. Furthermore, I would ask for permission to use, analyse, and discuss the data generated during this interview within the frame of my master’s thesis. I would also like know if it would be ok for you if your data collected within this interview would be presented in such a way that they could be clearly attributed to your person or if you would prioritise an anonymised presentation of your statements.

1) Welcome and Introduction

Hello Mr/Mrs. …. my name is Anna Merk and I am a Student of the International Master of Environmental Sciences. Thanks a lot for taking time for this interview. As mentioned before this interview is conducted within the frame of my master’s thesis which I am writing in cooperation with the Rehabilitation Research Centre. The main objective of the thesis is the development of a connectivity conservation concept for the RLMA with the wildcat as target species. For that purpose, the habitat quality in the study area and various wildcat conservation measures are to be rated by experts.

2) Introduction Experts

Mr/Mrs … could you please introduce yourself and delineate your professional background?

3) Knowledge of the study area

3.1 In our preliminary briefing, you have already seen a map that shows the delineation of the study area. Are you familiar with the study area?

3.2 Within the study area, different forested areas were delineated and marked in different colours. Are you able to distinguish these areas from one another using the map and assess them individually?

3.3 In the preliminary briefing I gave you an example of the knowledge required to rate the habitat quality regarding wildcats. Which of the delineated areas do you know well enough to rate them?

4) We would start with the assessment of the habitat quality now. As I told you before there are four criteria for the habitat quality assessment. I will give you a definition for each criterion before you start rating the areas you know one after another. The rating scale for the first three criteria reaches from rare [0 – 0.5 structures per hectare] over medium [0.5 – 1 structure per hectare] to high [> 1 structure per hectare]. Please note that the numerical values are only a guideline to get an initial idea of how to define rare, medium and high, but that the most important thing is that the assessed proportion between the different areas is realistic. You can always answer with “I do not know”. If possible, please give reasons for your assessment by describing the ecological equipment of the areas. Although the delineated areas might include agricultural areas, please rate the delineated areas only with regard to the forested patches.

4.1 Assessment Breeding Structures

Definition *(red out to the expert and additionally shown on screen or handouts)*

Structures used as breeding places by wildcats need to be dry, provide shelter and preserve the cubs from weather effects. Elevated spots are preferred. Structures suitable for breeding are for example: wood stacks, hollow trunks, deadwood piles, root plates and rock crevices.

Criterion		**rare [0 – 0,5 / ha]**	**medium [0,5 - 1/ha]**	**high [> 1/ ha]**	**I do not know**	**Further description of the area**
Structures for Breeding	Habitat area (colour)					
	Habitat area (colour)					
	Habitat area (colour)					

4.2 Assessment Day-time hiding places

Definition *(red out to the expert and additionally shown on screen or handouts)*

Wildcats use various resting places during the day. These include: root plates, hedge structures, old forest stand with a dense shrub and herbs layer, unmanaged windthrow areas, levelled forest edges with hedge structures and shrubs, abandoned perches, deadwood piles and hollow trunks.

Criterion		rare [0 – 0,5 / ha]	medium [0,5 - 1/ha]	high [> 1/ ha]	I do not know	Further description of the area
Day-time hiding places	Habitat area (colour)					
	Habitat area (colour)					
	Habitat area (colour)					

4.3 Food supply

Definition *(red out to the Expert and additionally shown on screen or handouts)*

The main food source of wildcats is mice. If available they also hunt lizards, insects, frogs, small birds and rabbits. Structures that increase the density of prey include: hedge structures, stump forests, multi-stemmed or crippled trees, forest meadows, meadow valleys, openings, naturally reforested areas, unmanaged windthrow areas and levelled forest edges with shrubs and hedges.

Criteria		rare [0 – 0,5 / ha]	medium [0,5 - 1/ha]	high [> 1/ ha]	I do not know	Further description of the area
Food supply	Habitat area (colour)					
	Habitat area (colour)					
	Habitat area (colour)					

4.4. Anthropogenic disturbances

Definition *(red out to the expert and additionally shown on screen or handouts)*

Wildcats are sensitive to human disturbances. Therefore, calm areas in forests are important, where the animals can retreat. For example, areas that are not accessible by walkers, athletes, or other tourists. Ideally, there are even areas that are excluded from forest management.

Please note that the rating scale changes from a three-point to a five-point scale now. The proportion of areas with low anthropogenic disturbances can be assessed with: very low [<10 %], low [11 – 30 %], medium [31 – 50 %], high [51 – 70 %] very high [> 70 %].

Criterion		Very low [< 10 %]	low [< 11 - 30 %]	Medium [31 – 50 %]	high [> 51 - 70 %]	Very high [> 70 %]	I do not know	Further description of the area
Areas of low anthropogenic disturbance	Habitat area (colour)							
	Habitat area (colour)							
	Habitat area (colour)							

5) Is the anything you would like to add that is related to the habitat quality for wildcats in the RLMA?

6) Additional Questions

6.1 For Dr. Udo Rose: As you are an Expert for the Erft could you please describe the structures along the Erft within the study area? Are there many wooded structures at the riversides or are they dominated by open land?

Interview Guidelines Forestry experts

0) Permission

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1) Welcome and Introduction

Hello Mr/Mrs. …. my name is Anna Merk and I am a Student of the International Master of Environmental Sciences. Thanks a lot for taking time for this interview. As mentioned before this interview is conducted within the frame of my master's thesis which I am writing in cooperation with the Rehabilitation Research Centre. The main objective of the thesis is the development of a connectivity conservation concept for the RLMA with the wildcat as target species. For that purpose, the habitat quality in the study area and various wildcat conservation measures are to be rated by experts.

2) Introduction Experts

Mr/Mrs … could you please introduce yourself and delineate your professional background?

3) Knowledge of the study area

3.1 In our preliminary briefing, you have already seen a map that shows the delineation of the study area. Are you familiar with the study area?

3.2 Within the study area, different forested areas were delineated and marked in different colours. Are you able to distinguish these areas from one another using the map and assess them individually?

3.3 In the preliminary briefing I gave you an example of the knowledge required to rate the habitat quality regarding wildcats. Which of the delineated areas do you know well enough to rate them?

4) Return of the Wildcat

4.1 How do you feel about the wildcat's return to the forests of the RLMA? Does it bring benefits or does the return of the wildcat involve a more effort for foresters or forest workers?

4.2 Who decides on the implementation of measures within a for?

5) We would start with the assessment of the habitat quality now. As I told you before there are four criteria for the habitat quality assessment. I will give you a definition for each criterion before you start rating the areas you know one after another. The rating scale for the first three criteria reaches from rare [0 – 0.5 structures per hectare] over medium [0.5 – 1 structure per hectare] to high [> 1 structure per hectare]. Please note that the numerical values are only a guideline to get an initial idea of how to define rare, medium and high, but that the most important thing is that the assessed proportion between the different areas is realistic. You can always answer with "I do not know". If possible, please give reasons for your assessment by describing the ecological equipment of the areas. Although the delineated areas might include agricultural areas, please rate the delineated areas only with regard to the forested patches.

5.1 Assessment Breeding Structures

Definition *(red out to the expert and additionally shown on screen or handouts)*

Structures used as breeding places by wildcats need to be dry, provide shelter and preserve the cubs from weather effects. Elevated spots are preferred. Structures suitable for breeding are for example: wood stacks, hollow trunks, deadwood piles, root plates and rock crevices.

Criterion		**rare [0 – 0,5 / ha]**	**medium [0,5 - 1/ha]**	**high [> 1/ ha]**	**I do not know**	**Further description of the area**
Structures for Breeding	Habitat area (colour)					
	Habitat area (colour)					
	Habitat area (colour)					

5.2 Assessment Day-time hiding places

Definition *(red out to the expert and additionally shown on screen or handouts)*

Wildcats use various resting places during the day. These include: root plates, hedge structures, old forest stand with a dese shrubs and herbs layer, wind-throwing areas, forest edges with hedge structures, abandoned perches, deadwood piles and hollow trunks.

Criterion		**rare [0 – 0,5 / ha]**	**medium [0,5 - 1/ha]**	**high [> 1/ ha]**	**I do not know**	**Further description of the area**
Day-time hiding places	Habitat area (colour)					
	Habitat area (colour))					
	Habitat area (colour)					

5.3 Food supply

Definition *(red out to the expert and additionally shown on screen or handouts)*

The main food source of wildcats is mice. Partly they also hunt lizards, insects, frogs, small birds and rabbits. Structures that increase the density of prey include: hedge structures, stump forests, multi-stemmed or crippled trees, forest meadows, meadow valleys, openings, naturally reforested areas, unmanaged windthrow areas and levelled forest edges with shrubs and hedges.

Criterion		**rare [0 – 0,5 / ha]**	**medium [0,5 - 1/ha]**	**high [> 1/ ha]**	**I do not know**	**Further description of the area**
Food supply	Habitat area (colour)					
	Habitat area (colour)					
	Habitat area (colour)					

5.4. Anthropogenic disturbances

Definition *(red out to the expert and additionally shown on screen or handouts)*

Wildcats are sensitive to human disturbances. Therefore, calm areas in forests are important, where the animals can retreat. For example, areas that are not accessible by walkers, athletes or other tourists. Ideally, there are even areas that are excluded from forest management.

Please note that the rating scale changes from a three-point to a five-point scale now. The proportion of areas with low anthropogenic disturbances can be assessed with: very low [<10 %], low [11 – 30 %], medium [31 – 50 %], high [51 – 70 %] very high [> 70 %].

Criterion		**Very low [< 10 %]**	**low [< 11 - 30 %]**	**Medium [31 – 50 %]**	**high [> 51 - 70 %]**	**Very high [> 70 %]**	**I do not know**	**Further de-scrip-tion of the area**
Areas of low anthropo-genic disturb-ance	Habitat area (col-our)							
	Habitat area (col-our)							
	Area (col-our)							

6) Is the anything you would like to add that is related to the habitat quality for wildcats in the RLMA?

7) The second part of the interview deals with the practical implementation of measures that can be taken to protect wildcats or biodiversity in general. I will introduce some of these measures and ask you to assess from a forest perspective how practical it is to integrate them in everyday forestry work. Each measure can be rated as either not at all practicable, not practicable, medium practicability, practicable or very practicable. You can also answer with “I do not know”. You are also welcome to explain why a measure is more or less feasible.

Measures (after Thiel-Bender, 2020; Trinzen and Behrmann 2015; Hermann 2005)	**not at all practicable**	**not practicable**	**medium practicability**	**practicable**	**very practicable**	**I do not know**
Controlling wood stacks before removal						
Controlling root plates before folding them back.						
Remaining parts of windthrow (uprooting by wind) with ground level structures untreated.						
Renunciation on thinning in forests stands younger than 5 years between April and July						
Remaining biotope trees and deadwood in the stand.						
Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand.						
Designate areas suitable for breeding and if possible, postpone intensive management measures between Sep. and Feb.						
Stockpiling of crown wood						
Remaining and support coppicing as forest management strategy.						
Remaining meadows through extensive management.						
Support natural reforesting and prioritise natural regeneration before plantings						
Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood.						
Remain 5 - 10 % of big windthrow areas and ca. 5 root plates per hectare						
Establish richly structured forest edges						
Renunciation of rodenticides						

8) Additional questions added to the catalogue as a result of previous interviews

8.1 Does the ownership of forest areas have an impact on the practicability of conservation measures? [asked: Michael Stoffels, Günther Roland and Lukas Jüssen]

8.2 Are there any measures that are realised already in the habitat areas you know? [asked: Frank Pechtheyden]

8.3 The purple area is designated to become a species conservation forest. What conservation measures are taken within this area? [asked: Lukas Jüssen]

8.4 Within the purple area a road connection from the Aachener Straße to the A4 is built. Do you know if there are any measures planned that will enable safe migration of wildlife across that connective road? [asked: Lukas Jüssen]

Interview Guidelines Wildcat Experts

0) Permission

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1) Welcome and Introduction

Hello Mr/Mrs. …. my name is Anna Merk and I am a Student of the International Master of Environmental Sciences. Thanks a lot for taking time for this interview. As mentioned before this interview is conducted within the frame of my master's thesis which I am writing in cooperation with the Rehabilitation Research Centre. The main objective of the thesis is the development of a connectivity conservation concept for the RLMA with the wildcat as target species. For that purpose, various wildcat conservation measures are to be rated for their effectiveness by experts.

2) Introduction experts

Mr/Mrs … could you please introduce yourself and delineate your professional background?

3) Experience practical implication of conservation measures

This interview deals with the effectiveness of wildcat conservation measures. Could you gain practical experience with the implementation of such measures through your professional career or education?

4) We would start with the assessment of the wildcat conservation measures now. I will introduce some selected wildcat conservation measures and ask you to assess their effectiveness from a conservationists point of view. Each measure can be rated as not at all effective, not effective, medium effectiveness, effective or very effective. You can also answer with "I do not know". You are also welcome to explain why a measure is more or less feasible.

Measures (after Thiel-Bender, 2020; Trinzen and Behrmann 2015; Hermann 2005)	**not at all practicable**	**not practicable**	**medium practicability**	**practicable**	**very practicable**	**I do not know**
Controlling wood stacks before removal						
Controlling root plates before folding them back.						
Remaining parts of windthrow (uprooting by wind) with ground level structures untreated.						
Renunciation on thinning in forests stands younger than 5 years between April and July						
Remaining biotope trees and deadwood in the stand.						
Remaining special structures like root plates, tree stumps, small waterbodies, forest clearings and landslides in the stand.						
Designate areas suitable for breeding and if possible, postpone intensive management measures between Sep. and Feb.						
Stockpiling of crown wood						
Remaining and support coppicing as forest management strategy.						
Remaining meadows through extensive management.						
Support natural reforesting and prioritise natural regeneration before plantings						
Renunciation of manual harvesting with chainsaws of small windthrow areas especially in deciduous wood.						
Remain 5 - 10 % of big windthrow areas and ca. 5 root plates per hectare						
Establish richly structured forest edges						
Renunciation of rodenticides						

4) Road measures

4.1 Do you have practical experiences with the implementation of wildcat conservation measures that can be taken in the field of roads?

4.2 How would you in general rate the hinderances in the implementation of wildcat conservation measures in the field of roads? Is there a difference between already existing roads and newly constructed roads?

5) The second part of the interview focuses on measures that can be taken in the field of road construction work. This time I would kindly ask you to rate the introduced measures on two scales. The first thing to be assessed is how hard or easy it is to get the introduced measures realised. So how likely it is that they are implemented at already existing roads or how much effort it takes to get them realised. The second rating is again with regard to their effectiveness on the same scale used before. As before you can always answer with "I do not know" or give additional explanations for your rating.

			Implementation			
Measures	not at all imple-mentable	not im-ple-mentable	medium implant-ability	imple-mentable	very im-ple-mentable	I do not know
Wildcat secure fences						
Speed limits						
Wildlife overpasses						
Wildlife underpasses						
Upgrading existing un-derpasses						
Remaining a stip of shortly cut grass be-tween the road and shelter giving structures to increase the visibility of bypassing traffic						

Measure	Effectiveness completely uneffective	uneffective	middle	effective	very ef-fective	I do not know
Wildcat secure fences						
Speed limits						
Wildlife overpasses						
Wildlife underpasses						
Upgrading existing crossing structures						
Remaining a stirp of shortly cut grass be-tween the road and shelter giving structures to increase the visibility of bypassing traffic						

6) Additional questions added to the catalogue as a result of previous interviews

6.1 How would you assess the general willingness of foresters and forest workers to implement wild-cat conservation measurements in their management district? [asked: Dr. Christine Thiel-Bender]

6.2 Are wildlife crossing structures only effective if the rest of the road is secured by a wildcat-safe fence? [asked: Manfred Trinzen, Dr. Nina Klar]

Appendix 4: Critical points and potential crossing structures – Impressions from the on-site explorations

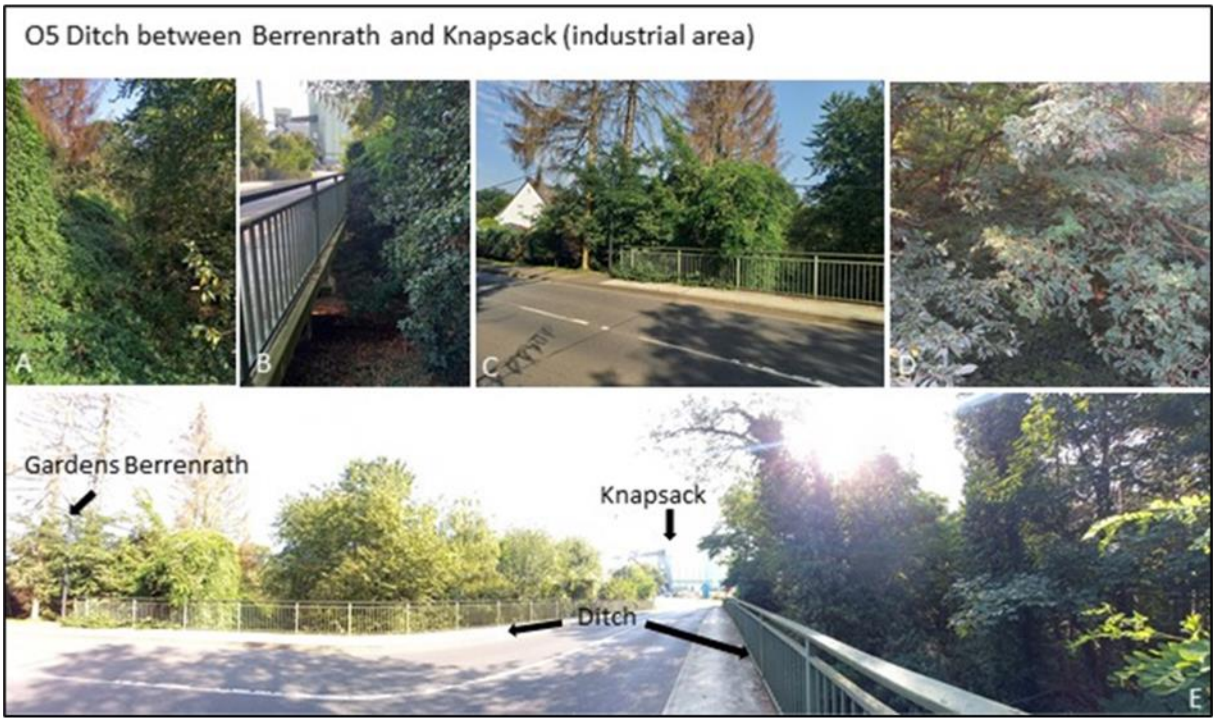

Figure 27: Ditch between Berrenrath and Knapsack (industrial area).
***A**: vegetation at the western side of the ditch bordering gardens of the village Berrenrath. **B**: Bridge leading from Berrenrath to Knapsack over the ditch. **C**: Street crossing the ditch showing direct bordering of the village Berrenrath. **D**: Vegetation structures of the ditch. **E**: Overview of environment and vegetation of the ditch.*

Figure 28: O6 Wendelinusstraße.
***A**: Wendelinusstraße from Berrenrath to Gleul with cycle path. **B**: Ditch between Wendelinusstraße and adjacent fields. **C**: Fields between Hürth1 and Wendelinusstraße with narrow hedge structure on the left bordering gardens of Berrenrath.*

Figure 29: O12 Wacholderweg.
***A**: Slope securing structures. **B**: Low slope securing structures. **C**: Roadside greenery towards Bergheim1. **D** Roadside greenery towards Bergheim2. **E**: Vegetation Adjacent to Wendelinusstraße in Bergheim2*

Figure 30: P1 woodland structures between Berrenrath, A1 and Berrenratherstraße.
***A**: Fields between railway tracks and A1. **B**: pedestrian path through wood structures west of Berrenrath. **C**: Fields adjacent to wood structures west of Berrenrath. **D**: Vegetation of wood structures bordering the railway tracks.*

Figure 31: S0.1 Underpass A1.
***A**: Underpass A1 towards Ville4. **B** Drainage creek leading from underpass towards Berrenratherstraße. **C**: Environment of Ville 4 before underpass.*

*Figure 32: S0.2 underpass Mühlenerft L213. **A**: Underpass Mühlenerft L213 overview. **B**: Underpass Mühlenerft L213 with pedestrian path.*

Figure 33:S0.3 railway underpass L213. ***A****: Railway tracks and underpass from L213.* ***B****: Railway tracks with grass strips to both sides leading under the underpass of L213.*

Figure 34: S1.1 underpass Phantasialandstraße.
A: *riding path underpass of Phantasialandstraße (L194).* ***B:*** *Phantasialandstraße above the riding path underpass.*

Figure 35: S2.1 and S2.2 underpasses A553. ***A:*** *S2.1 service road underpass under A553.* ***B:*** *S2.2 service road underpass under A553.* ***C:*** *surrounding environment north of S2.2 in the core area Ville3.*

Figure 36: S3.1, S3.2 and S3.3 underpass and drainage structures L265.
A*: S3.1 underpass L265.* ***B****: S3.2 drainage structure with sheep wire fence* ***C****: S3.3 drainage structure with sheep wire fence.*
D*: vegetated sheep wire fence along north side of L26.*

Figure 37: S4.1 bridge Berrenratherstraße.
***A**: Vegetation growing over bridge. **B**: Berrenratherstraße with abandoned bridge. **C**: Remaining paved segment of bridge.*

Figure 38: S7.1 railway underpassA1.
***A**: Connection through railway underpass from P1 towards Berrenrath1: **B**: Pedestrian pathway to both sides of railway underpass.*

Figure 39: S8.1 underpass Holzstraße (L264).
***A**: Underpass L264. **B**: Distance from underpassS8.1 to concrete plant and edge of Kerpen1.*

Figure 40: S8.2 railway underpass L264, Holzstraße

Figure 41: S9.1 bridge A4.
***A**: pedestrian bridge over A4. **B**: fields and adjacent wood structures north of A4 behind the bridge towards Horrem.*

Figure 42: S9.2 underpass A4.
***A**: underpass A4 and elevation of A4 compared to surrounding environment. **B**: Close proximity of underpass to Horrem. **C**: underpass leading towards settlement of Horrem and sheltering wood structures of roadside greenery of A4. Noise protection of A4.*

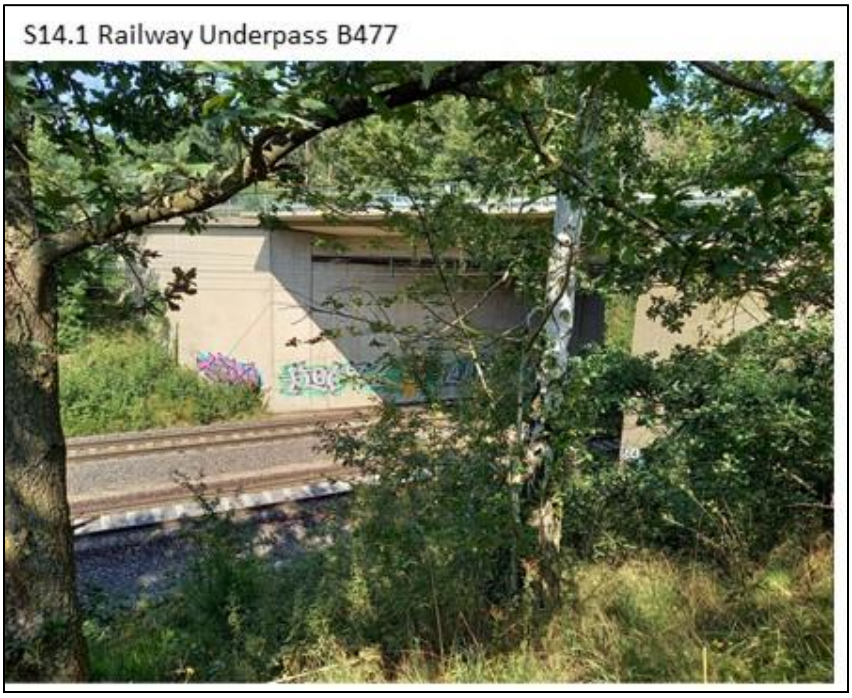

Figure 43: S14.1 railway underpass B477.

Figure 44: S14.2 underpass B477.

Figure 45:S15.1 bridge L361 Terra Nova speedway.

Figure 46: S16.1 underpass L116 Mühlenerft.
***A**: underpass Mühlenerft. **B**: L116 over Mühlenerft. **C**: Riparian of Mühlenerft at the underpass that might be dry when Mühlenerft keeps less water*

Figure 47: S16.2 underpass L213 Mühlenerft.
***A**: Underpass L213 Mühlenerft with pedestrian path. **B**: Floodplain vegetation in Frimmersdorf1 one behind underpass of Mühlenerft. **C**: Further example of vegetation in Frimmersdorf1 nearby 16.2.*

Figure 48: S16.3 underpass L213.
Probably used as retreat by homeless people.

S17.1 Bridge A61 Terra Nova speedway

Figure 49: S17.1 bridge A61 Terra Nova speedway.

S18.1 Bridge B55 Terra Nova speedway

Figure 50: S18.1 bridge B55 Terra Nova speedway.

*Figure 51: Terra Nova speedway. **A**: Example vegetation along Terra Nova speedway. **B**: Example grass strip and wood structures along Terra Nova speedway. **C**: End of Terra Nova speedway leading to the edge of the open-cast mine Hambach. **D**: Terra Nova speedway with adjacent fields.*

Appendix 5: Additional habitat quality assessments

Table 2:Mean rating values of the four habitat quality factors for additional habitat areas.

Additional *habitat areas*	**Breeding structures**		**Daytime resting spots**		**Food availability**		**Low-disturbance areas**	
	Rating [mean value]	N [Experts]	Rating [mean value]	N [Experts]	Rating [mean value]	N [Experts]	Rating [mean value]	N [Experts]
Erbwälder	1.00	2	1.00	2	0.67	2	0.90	2
Dickbusch and Lörsfelder Busch	0.83	2	0.83	2	0.67	2	0.80	2
Parrig and Kerpener Bruch	0.50	2	0.83	2	0.83	2	0.60	2