Final project report

Project acronym		FUNgreen
Project title		Functional connectivity and green infrastructure
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	Entity (Company/organization)	Stockholm University
Project period (Start date – End date)		1st February 2017- 30th September 2020
Project website, if applicable		fungreenproject.weebly.com

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1. Short description for publicity

Focusing on species rich grasslands in Sweden, Germany and Belgium, FUNgreen studied (i) how the ability of plant species to move across landscapes (functional connectivity) helps maintain high biodiversity and healthy ecosystem functions and (ii) how "green infrastructure" habitats such as grasslands, hedgerows, road verges and forest borders can assist plant species dispersal by acting as habitat corridors and stepping stones for movement. There has been a widespread loss of grassland over the last 50 years, reducing the ability of grassland plants to move between remaining, more isolated habitats. This isolation is linked to a lower richness of plant species and disrupted pollinator networks. Road verges, hedgerows and forest edges do support a range of plant species, and may play a role in maintaining biodiversity within the landscape, but environmental conditions in these habitats are unsuitable for many specialised grassland plants. Furthermore, green infrastructure habitats are of lower importance as sources of food for pollinators and for their nature conservation and cultural value, unless they are well-connected to core grassland areas. Ancient grasslands in particular are a source of unique species and much remaining genetic diversity within landscapes. Reducing and reversing the rate of connectivity loss is therefore an important conservation priority. Linking semi-natural grasslands through habitat restoration and actively promoting and optimising the movement of grazing livestock which can transport seeds through the landscape can help increase the diversity of species present, and reduce negative effects of past habitat loss on biodiversity and ecosystem functions.

2. Summary

European landscapes have changed considerably over the last 50 years, with grassland habitat lost from all study regions in Belgium, Germany and Sweden. This has led to a reduction in how easily grassland plant species can move across landscapes. Remaining grassland areas are now often surrounded by large areas of forest or intensive farmland, resulting in distances between habitats which are too great for plants to cross without assistance. This lower landscape connectivity leads to lower genetic diversity and smaller populations of grassland specialist plants within semi-natural grasslands, and disrupts important pollination networks.

Long-term grassland management is key to building plant species and genetic diversity within landscapes. Many species found in older grasslands are often not present in recently restored grasslands or in surrounding “green infrastructure” habitats such as road verges and hedgerows. Such green infrastructure has high nature conservation value primarily where it is either in close proximity to grassland habitats or it is linked to grasslands through dispersal corridors and the movement paths of dispersal vectors such as grazing livestock, which are highly effective in transferring plant seeds (particularly in late summer where seed production is at its peak). Fewer grassland specialist plants were found in recently restored grasslands, but the capacity for pollination and seed production did not clearly differ from that in older grasslands. Over time the plant species found in these grasslands will become more similar to those in ancient grasslands, provided surrounding landscape connectivity is high enough for species to reach the newly created habitats.

Although many grassland specialist plants are less capable of using green infrastructure habitats, these hedgerows, road verges and forest borders do provide habitat for a range of species and can contribute to landscape scale biodiversity. Many of the species which benefit from a varied landscape are also important for ecosystem services such as carbon storage. Green infrastructure features such as road verges can also help transfer genetic diversity through the landscape through seed and pollen flow, provided they are well linked to core-grassland sites.

These insights can be used to maximise effective landscape management and the positive impact of green infrastructure on biodiversity and the provision of ecosystem services. Conservation targeting grassland species should focus upon preserving existing semi-natural grasslands and linking them as much as possible other habitat, including by moving grazing livestock through the landscape to help transport seeds and overcome dispersal limitation for vulnerable plant species.

3. Objectives of the research

The FUNgreen project aimed to investigate how the dynamic attributes of plant functional connectivity interact with green infrastructure in the maintenance of biodiversity and ecosystem services. This included proposed comparisons of functional connectivity in fragmented landscapes with both high and low amounts of green infrastructure, and assessments of the role of active management to enhance functional connectivity through moving herds of cattle and sheep. Seed dispersal in these landscapes was evaluated through genetic analyses, recruitment experiments and modelling. The effects of dispersal on biodiversity, genetic diversity and a range of ecosystem services were investigated and used as the basis of models which will help shape future landscape management.

The objectives were:

- Assess current, past and potential future levels of green infrastructure and functional connectivity in important grassland landscapes across Europe

- Investigate dispersal in these landscapes, and the importance of varying green infrastructure and managed functional connectivity
- Determine which types of plant species benefit most from green infrastructure and enhanced functional connectivity
- Quantify and predict benefits to key ecosystem services of improved functional connectivity, to aid planning for future green infrastructure

4. Project activities and achievements

4.1. General description of activities over the duration of the project

1. Digitisation of green infrastructure habitats for grassland vascular plants

Aerial photographs covering all 36 study landscapes were sourced from local agencies for both the present day and the mid-20th century. Using these photographs, important land cover types and linear features within a radius of 1600 metres around the centre of focal grasslands were digitised in detail by partners from Stockholm University, CEH and Lactuca, with region specific inputs also obtained from KU Leuven and Regensburg University. Potential green infrastructure habitats that needed to be covered for planned analyses were determined through discussions with all project partners. This included all forest, grassland, arable fields, midfield islets and built up areas, as well as roads, forest borders and hedges. These data were utilised in all subsequent spatial and connectivity analyses across all four work packages.

2. Functional connectivity mapping

We generated various functional connectivity statistics for study landscapes. This work was led by Lactuca and CEH. Due to a lack of empirically measured data we opted to use hypothetical resistance values following similar approaches in the literature. Existing literature was extensively surveyed and combined with expert opinion within the project group to determine resistance values for grassland plant dispersal for different land cover types. These values were applied to digitised landscape maps to produce resistance surfaces for past and present. Further GIS processing converted these to a series of connectivity maps and statistics, which model the ability of seeds to move across the study landscapes, as dispersed by different vectors (including wind, moving livestock, humans, birds etc). These maps allowed us to identify landscapes and areas within which have low functional connectivity, which can be related to the plant species present, genetic diversity and pollinator networks (as per focal patch and green infrastructure surveys).

3. Plant species sampling

Plant species present across all 36 focal grasslands were fully inventoried over the course of summer 2017 (Sweden and Germany) and 2018 (Belgium, delayed in 2017 due to drought in study sites). This involved carrying out both small-scale plot inventories (10 x 1 metre plots per focal grassland, 360 plots in total) and full patch surveys (a complete inventory of all species within focal grasslands, 36 total patches). This analysis, in combination with the quantification of connectivity change from points 1 and 2, was written up into a scientific manuscript (revision submitted), led by Stockholm University.

A full survey of landscape green infrastructure habitats was carried out in summer 2018. This involved fieldwork by Stockholm University, KU Leuven and Regensburg University. All plant species present in 4-hectare sections of landscapes around focal patches were recorded. Landscape sections were randomly selected, covering a variety of green infrastructure types. Ten sections were surveyed in each landscape, resulting in 360 4-hectare sampling areas across focal landscapes. Field data was processed and combined with spatial and connectivity data in analyses to investigate the ability of green infrastructure to support grassland plant species and the importance of functional connectivity in facilitating this. This work has formed the basis of a scientific manuscript (in preparation), led by CEH and Lactuca. A further scientific article investigating the effects of changing links within the landscape is also in preparation, led by Stockholm University.

4. Genetic analyses

Leaf material was collected for two study species (*Galium verum* and *Campanula rotundifolia*) at various points within both focal grasslands and in surrounding green infrastructure elements, at increasing distances from focal grassland patches. DNA was extracted by from plant material collected. Tests were successfully carried out to identify useable microsatellite primers from congeneric species and the extracted DNA and analytical procedure was sent to external laboratories in Belgium and Sweden for PCR processing and genotyping. Genetic diversity data from this was obtained in late 2018. We obtained 3260 genetic samples from this work, which were used in combination with landscape compositional data to investigate patterns in dispersal and genetic diversity in our study areas. These analyses form the basis of a scientific manuscript (in preparation). All field, lab and analytical work for this aspect of the project was led by KU Leuven.

5. Pollinator surveys

Full pollinator censuses were carried out in Sweden (2017 & 2018), Belgium (2018) and Germany (2018) by IMDEA (Spain). These surveys were delayed due to finances not reaching project partners early enough in the first year of the project to allow staff to be hire for a full field season. Each focal grassland was visited on multiple occasions, and interactions between flowering plants and pollinating insects recorded. This information was used to generate pollination networks within focal grasslands, allowing a detailed assessment of the important interactions between plant and pollinator species, and the way in which this is influenced by grassland management and surrounding landscape connectivity. Results from this will form the basis for a scientific article investigating the effects of functional connectivity on pollinator networks, writing led by IMDEA.

6. Seed set experiment

Led by IMDEA (Spain), discussions were held within the group as to the most effective way of conducting a field experiment to determine levels of seed production in focal grasslands. Study species and a strategy for marking plants and collecting ripened seeds were decided upon. Individual plants from two species were marked in each focal grassland (10 per species per grassland). Fruits from these marked plants were then allowed to ripen for a few weeks, before all seeds produced were harvested and shipped to Spain to be counted and analysed. Data from this will contribute to a scientific article, in preparation, writing and analysis led by IMDEA, assessing how levels of seed production are related to pollinator networks and landscape connectivity.

7. Seed attachment experiment

With co-operation from a local shepherd, experiments were carried out in Germany to investigate the attachment of different seeds to grazing sheep. Animals were allowed to graze species rich areas for a controlled amount of time, and seeds recovered from their fur counted and identified. A second experiment was also carried out, with marked seeds of varying morphologies and sizes applied to areas on the fleece of sheep. The animals were then allowed to graze, and the presence of the marked seeds examined daily for two weeks following application. These results will form part of a scientific manuscript describing the different potential for seed dispersal by various animal species. This work was led by Regensburg University

8. Midfield islet genetic diversity

As part of a Masters project investigating the ability of midfield islets in Sweden to act as stepping-stones for grassland plant species, a number of such habitats were inventoried in summer 2018. Plant species composition and environmental data were collected both in focal grasslands and nearby midfield islets, selected to cover a gradient of sizes and distances to nearest focal grassland. This work is currently being written up as a draft manuscript.

9. Ecosystem services

To investigate ecosystem services provided by landscape green infrastructure, a number of service related variables were obtained from plant survey data and pollinator surveys. Digital photographs were collected in each focal area to potentially investigate recreational services in landscapes. Assessments of ecosystem services and the importance of functional connectivity in controlling different functions will be written up for publication. This is currently in preparation, led by CEH and Lactuca.

4.2. Table of deliverables

Deliverable and Milestone Name			Lead partner (country and designation)	Date of delivery (mm/yyyy)		Comments
				Initially planned	Delivered	
Work Package	***Deliverable or Milestone***	***Full Name***				
Ex: WP1	T1.1	Building and managing a geodatabase with present and historical data	Partner 1- Sweden, Stockholm University	05-2018	06-2018	Detailed maps of past and present landscape composition available for all project partners. Past and present links between survey areas modelled to enable analyses of levels of change over time and effects on shared species to be completed. Manuscript regarding this in progress.

Deliverable and Milestone Name			Lead partner (country and designation)	Date of delivery (mm/yyyy)		Comments
				Initially planned	Delivered	
WP1	T1.2	Ecological and biogeographic characterization of focal landscapes and grasslands	Partner 1 – Sweden, Stockholm University	09-2018	09-2019	Plant surveys carried out in focal grasslands. Belgium focal survey delayed until 2018 due to local drought, delaying publications dependant on this. Green Infrastructure plant survey carried out in all countries. Seed traps and dung collection no longer planned due to budget restrictions. Paper on landscape and connectivity change in the regions and the effects on grassland diversity submitted.
WP1	T1.3	Web site, means to communicate results	Partner 1 – Sweden. Stockholm University	03- 2017	03-2017	Website describing project aims up and periodically updated with project news and activities. Swedish translation in place.
WP2	T2.1	Evaluation of the pollination communities in the research areas	Partner 4 – Spain, IMDEA Mallorca	09-2018	03-2019	Pollinator survey carried out later in focal grasslands due to administrative delay in receiving funds. Also disrupted due to drought. MS currently in preparation.

Deliverable and Milestone Name			Lead partner (country and designation)	Date of delivery (mm/yyyy)		Comments
				Initially planned	Delivered	
WP2	T2.2	Quantification of pollination effectiveness	Partner 4 – Spain, IMDEA Mallorca	09-2018	09-2018	Seed set experiments carried out in all focal grasslands. MS in preparation.
WP2	T2.3	Quantification of seed dispersal effectiveness	Partner 4 – Spain, IMDEA Mallorca	02-2019	NA	Not carried out due to time and budget constraints on fieldwork
WP3	T3.1	Select study plant species	Partner 2 – Belgium, KU Leuven	03- 2017	04-2017	Completed. *Galium verum* and *Campanula rotundifolia* selected as study species
WP3	T3.2	Sample and genotype the model species	Partner 2 – Belgium, KU Leuven	09-2017	09-2017	Genetic material collected at 3260 strategically chosen locations within study landscapes. Campanula was not present in sufficient numbers in Germany to be sampled.
WP3	T3.3	Infer genetic connectivity among grassland fragments through grazing animals and green infrastructure	Partner 2 – Belgium, KU Leuven	12-2019	02-2020	Analyses completed and manuscript in preparation.

Deliverable and Milestone Name			Lead partner (country and designation)	Date of delivery (mm/yyyy)		Comments
				Initially planned	Delivered	
WP4	T4.1	The amount of functional connectivity and realised dispersal	Partner 5 – UK, Centre for Ecology and Hydrology	06-2019	06-2019	Functional connectivity maps produced for all landscapes. Connectivity between genetic sampling sites has been calculated. Analyses of radiation and dispersal from focal grasslands completed and manuscript in progress
WP4	T4.2	Ecosystem services	Partner 5 – UK, Centre for Ecology and Hydrology	02-2019	02-2019	Ecosystem services quantified across all study landscapes using a variety of trait based and plant compositional data.
WP4	T4.3	Combining functional connectivity and ecosystem services	Partner 5 – UK, Centre for Ecology and Hydrology	05-2019	04-2019	Analyses completed, modelling the likely changes in service delivery in landscapes with changes in functional connectivity. Draft manuscript in progress.

4.3. Scientific outcomes

- Objective 1. Assess current, past and potential future levels of green infrastructure and functional connectivity in important grassland landscapes across Europe

Analyses of landscape change over the last 50 years across study regions showed that levels of connectivity are considerably lower than those in the past. While there were some increases in green infrastructure habitats such as road verges, hedgerows and forest borders (Figure 1A), this was not enough to offset losses in semi-natural grassland and grazed open forests. Given the inability of many grassland species to utilise green infrastructure habitats, this suggests that the current focus on creating networks of green infrastructure are unlikely to be sufficient to counteract past landscape changes. At a more local scale patterns were more varied. Although in general connections within the landscape declined over time, in many cases parts of the landscape did become better connected. This was more often the case in landscapes which have seen the least loss of seminatural grasslands, where there have been more new road verges created as connecting elements, and where intensive land uses such as arable land and improved grasslands have become less common. Linking these landscape patterns to grassland biodiversity highlighted that grassland specialist species depend upon a key interaction between functional connectivity and continuity over time. This forms part of deliverables T1.1 and T1.2 and will result in a publication adding new evidence regarding the role of functional connectivity and green infrastructure in determining grassland biodiversity, and the effectiveness of restoration in European landscapes. This work was led by Stockholm University as part of Work Package 1, with inputs from CEH and Lactuca at the analytical stage, and all project partners at the design and interpretation stages.

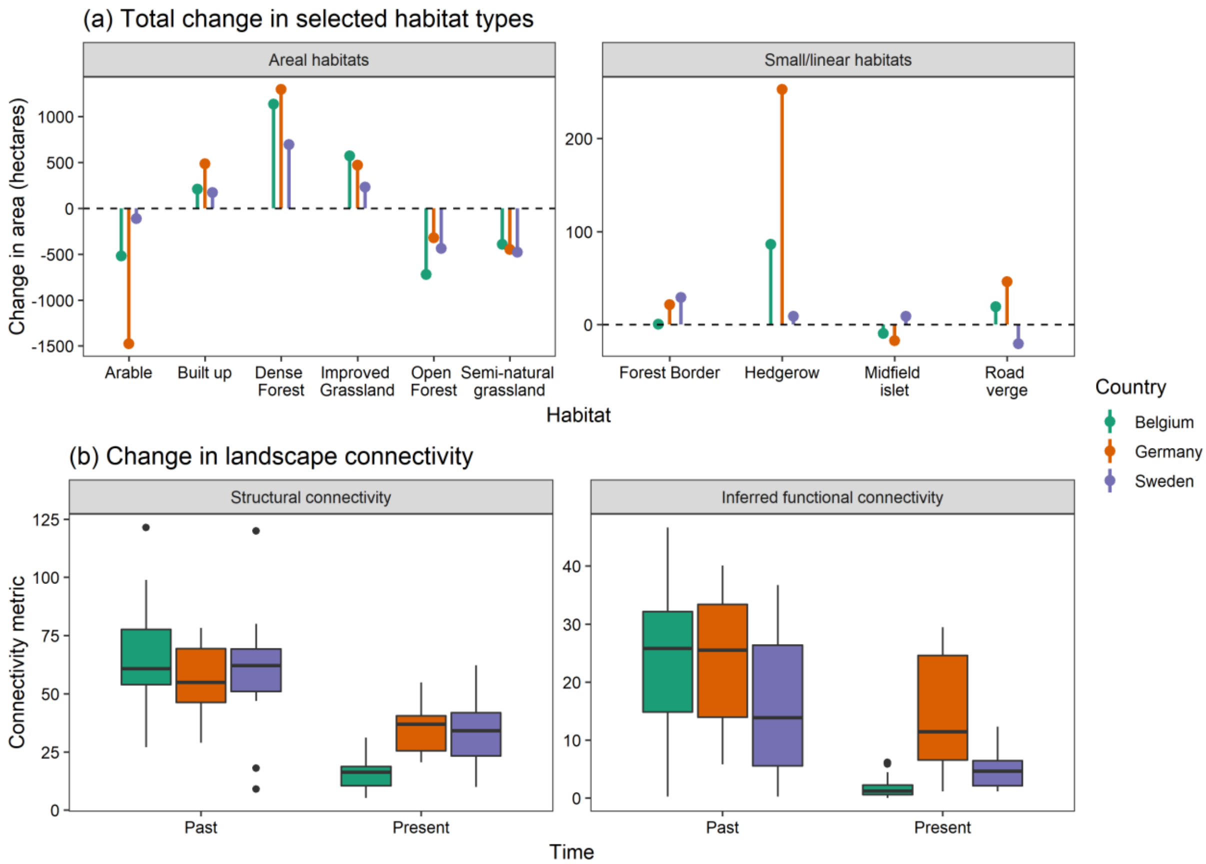

Figure 1. Changes in (a) landscape composition and (b) landscape structural and functional connectivity between the mid 20th Century and 2018 in European landscapes. 36 study landscape (12 per country). Past landscape data from 1952-1960, present landscape data from 2018.

- Objective 2. Investigate dispersal in these landscapes, and the importance of varying green infrastructure and managed functional connectivity

Modelling of changing landscape connections has shown that functional connectivity, and the presence of green infrastructure is an important factor in allowing species to disperse between parts of the landscape. Well-connected areas shared more species, with historical connections appear to be more important the present-day connections. This suggests that many plant species have not yet adapted to past landscape changes. High historical functional connectivity is most important for species with low dispersal capability, and species more highly specialised toward semi-natural grasslands (Figure 2). This work addresses deliverables T1.2, and was led by Stockholm University as part of Work Package 1.

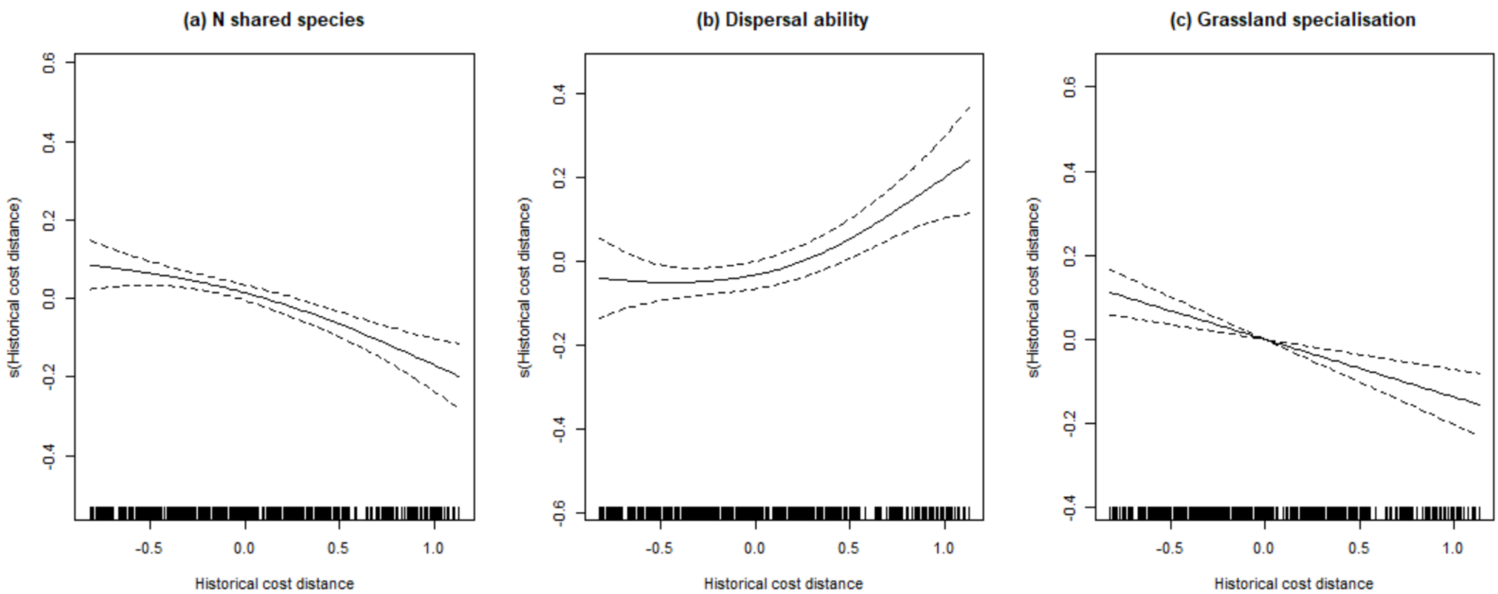

Figure 2. Modelled relationship between increasing historical cost distance and (a) number of species shared between landscape subsegments, (b) mean dispersal distance of species shared between landscape subsegments and (c) mean grassland specialisation of species shared between landscape subsegments, showing the relationship between decreasing functional connectivity (higher cost distance between areas) and the number and characteristics of shared species. Modelled smooth terms taken from mixed effects generalised additive models, including local and landscape green infrastructure amount as smooth covariates and survey country and focal landscape as random effects.

Pollinator networks and pollination effectiveness were assessed through field surveys and experiments. Pollinator networks were strongly determined by landscape composition, with greater levels of functional connectivity leading a greater number of visits by pollinators (deliverable T2.1). This has a knock-on effect on pollination effectiveness in grasslands, which was assessed through field experiments to determine seed production in grassland habitats with different levels of functional connectivity (deliverable T2.2). No clear patterns between restored and ancient grasslands could be identified, suggesting that in many cases pollination is sufficient for effective reproduction in restored grassland sites. No direct effect was observed of landscape composition on reproductive success, however the wider landscape may still influence this indirectly through greater flower density. These analyses were led by IMDEA Mallorca as part of Work Package 2.

Experiments were carried out to investigate the effectiveness of grazing animals in dispersing seeds. Seed dispersal through both ingestion and via fur was extensive, and was found to be at its greatest in late summer where seed production is at its peak. Moving animals between species rich grasslands and restoration target sites during this period is therefore likely to be most effective from a functional connectivity perspective. Grazing cattle were found to be more efficient seed dispersers than sheep and goats, when considering rules for stocking densities in target regions. These experiments were led by Regensburg University.

Analyses of genetic diversity highlighted the importance of focal grassland habitats as a source of genetic diversity within study landscapes. Landscapes with larger amounts of green infrastructure, particularly road verges, displayed higher genetic diversity (Figure 3). This suggests that green infrastructure habitats can play an important role in maintaining genetic diversity in landscapes, and can act to transmit genetic diversity from the source (ancient grassland patches) into the wider landscape. These analyses support the role of green infrastructure as seed and pollen dispersal corridors, but that their conservation utility in this role depends upon the presence of grassland sites in close proximity. This work was completed as part of Work Package 3, led by KU Leuven, and relates to deliverable T3.3.

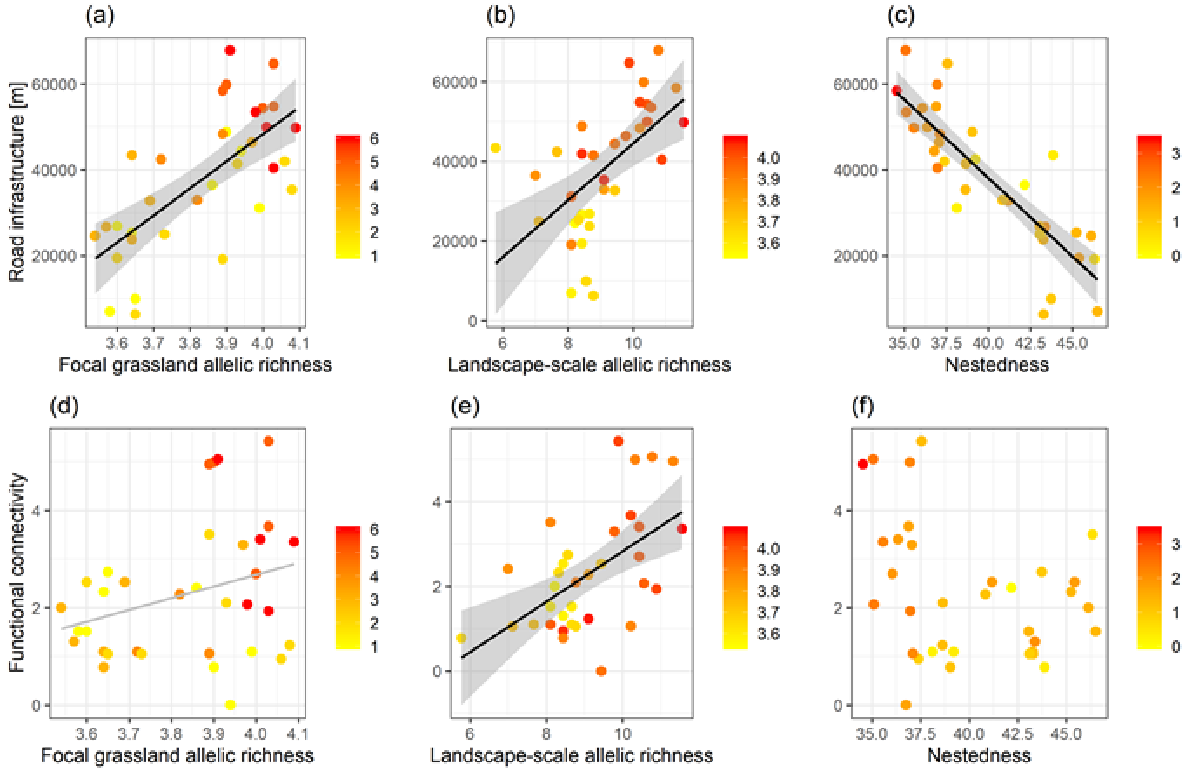

Figure 3. Impact of green infrastructure (road network) vs. the impact of functional connectivity on genetic variation of the grassland perennial Galium verum across 35 landscapes in NW-Europe, modelled via General Linear Models: (a) & (d) allelic richness in the focal grassland (color legend = population size), (b) & (e) landscape-scale allelic richness (color legend = allelic richness in the focal grassland) and (c) & (f) degree of nestedness of the landscape population genetic structure (NODF metric, Almeida-Neto et al. 2008). Black regression lines identify significant relations at $p < 0.05$.

These analyses indicate the various ways in which functional connectivity can contribute to aspects of biodiversity in European landscapes. Through examining the effects of functional connectivity on plant species occurrence, seed production, pollinator networks and genetic diversity, we have been able to provide novel empirical insight into the extent to which functional connectivity, and green infrastructure as a true connecting element within landscapes, can benefit biodiversity through facilitating seed and gene flow. Our results suggest that linking landscapes through green infrastructure is likely to be effective in increasing functional connectivity, but it may take some time for the benefits to be seen in plant communities.

- Objective 3. Determine which types of plant species benefit most from green infrastructure and enhanced functional connectivity

Our results show that potential green infrastructure habitats (road verges, hedgerows and forest borders) do not effectively support core grassland species. Many species found in focal grasslands are not found in green infrastructure habitats. These habitats do contain a number of species, but many of these come from non-grassland species pools within the landscape. In particular, species inhabiting green infrastructure habitats tend to be those able to tolerate fertile, more shaded conditions, and with higher dispersal capability. Green infrastructure tends to contain more grassland species where there is a greater area of green infrastructure present (Figure 4c), where this comprises more remnant grassland habitat area, and where the green infrastructure is more functionally connected to grasslands (Figure 4b). Results from this contribute to deliverable T4.1, and the upcoming publications provides important insights into which plant species can utilise green infrastructure and how changes in green infrastructure availability and landscape functional connectivity are likely to affect different plant species. This work was led by CEH and Lactuca as part of Work Package 4.

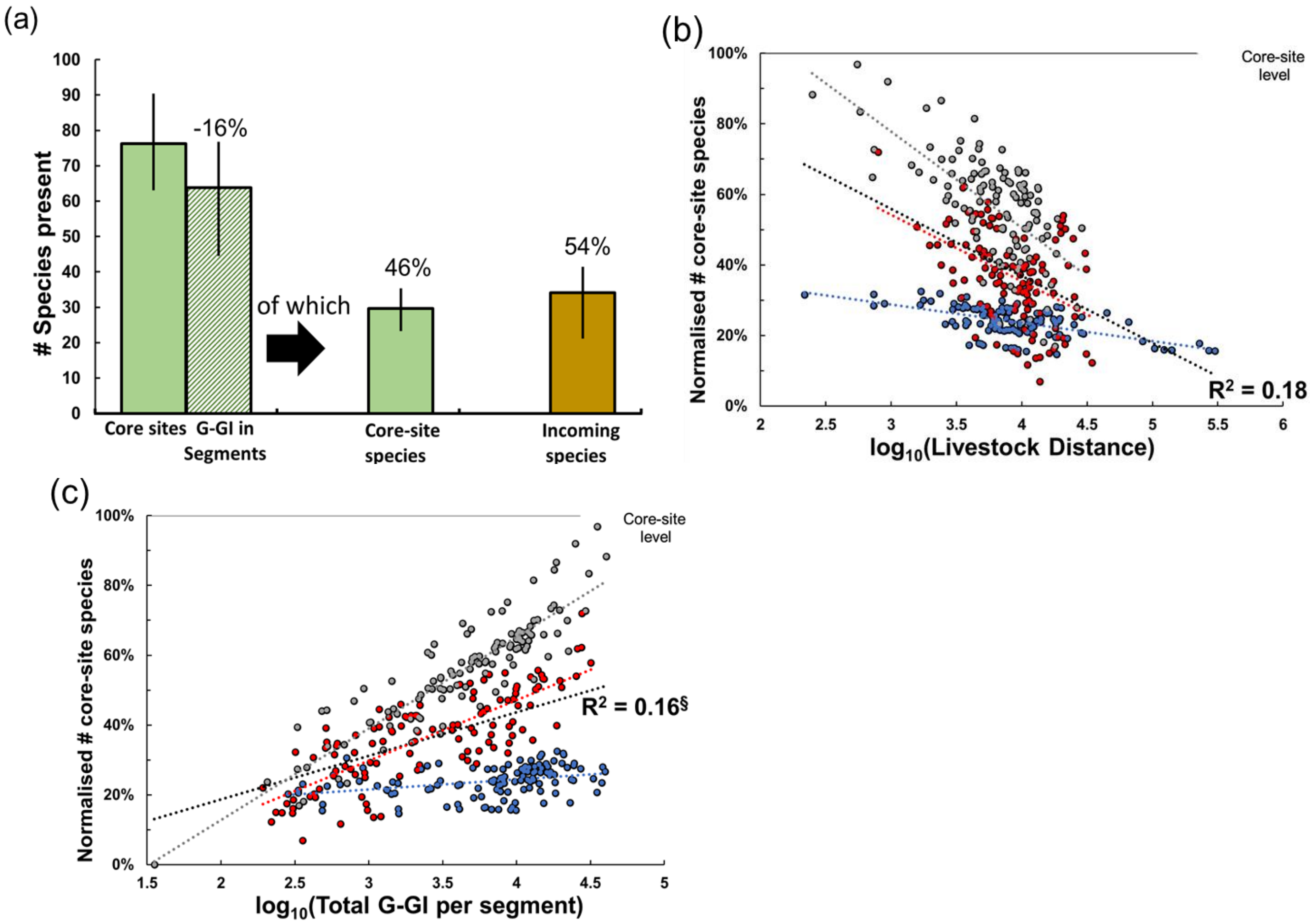

Figure 4. a) α-diversity of all species and of core-site species in green infrastructure, error bars indicate the among region range (highest-lowest); b) normalised core-site α-diversity in green infrastructure with livestock cost resistance distance (100% = core site values); c) normalised core-site α-diversity in green infrastructure with total GI area. The black line indicates the relationship for all sites with its accompanying R2 for the overall relationship; the blue line and points represent Sweden, red Belgium, and grey Germany.

- Objective 4. Quantify and predict benefits to key ecosystem services of improved functional connectivity, to aid planning for future green infrastructure

Project results show that green infrastructure varies in its ability to provide similar ecosystem services to core semi-natural grasslands. Green infrastructure habitats showed lower values for nature conservation, pollination and recreational services than focal semi-natural grasslands, but were similar for carbon storage (Figure 5). Differences were driven primarily by differences in species composition between these sites. Predictions of ecosystem service delivery in future scenarios suggest that increasing functional connectivity through the creating of new green infrastructure such as road verge and optimising herding routes for livestock dispersal vectors have the potential to significantly improve ecosystem service delivery. This is particularly the case for nature conservation and pollination services, while carbon storage and recreational value are less sensitive to functional connectivity. These results contribute to the completion of deliverables T4.2 and T4.3 and will form part of a scientific manuscript on ecosystem service provision. This work was led by CEH and Lactuca as part of Work Package 4.

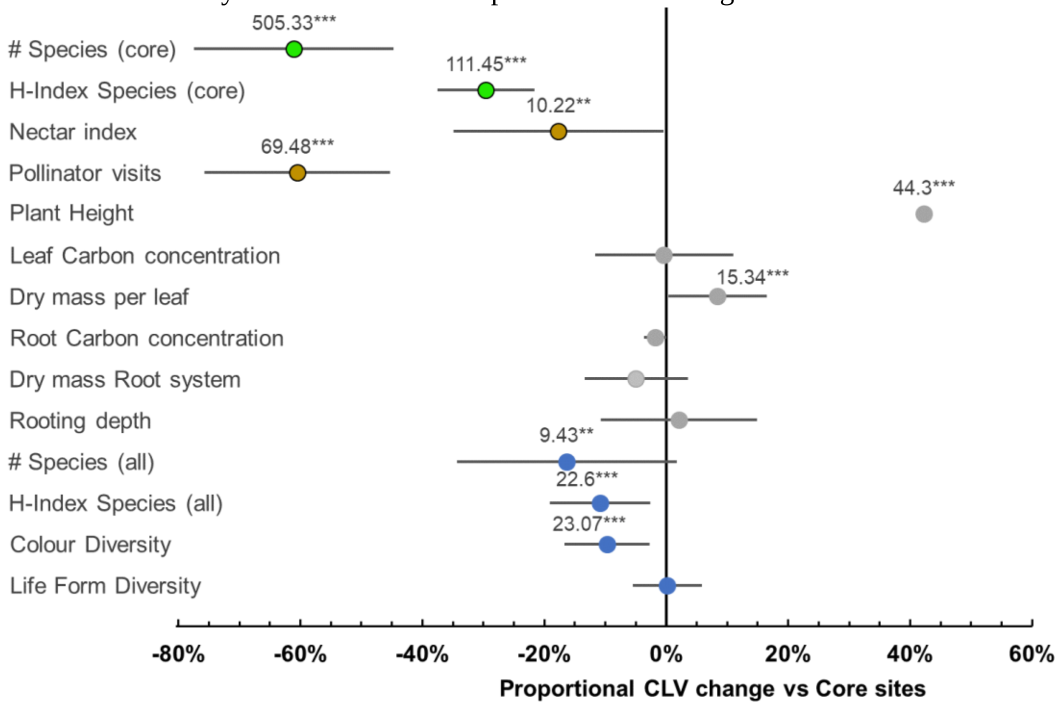

Figure 5. Normalised proportional community level values (CLV) (mean ± ½ std) in green infrastructure compared to associated core sites with GLM tested significance (F-values when α<0.05). P< 0.01; *** P<0.001. Green markers: Nature conservation; brown: Pollination; grey: Carbon storage; blue: Recreation service.**

Together, the information gained from the completion of these objectives provides a novel, comprehensive investigation into functional connectivity for grassland plants in European landscapes. By quantifying and comparing the important drivers of species, genetic and functional diversity at different scales we are able to add to understanding of how biodiversity and ecosystem services are controlled by dispersal and landscape composition, and inform conservation management plans. In particular, our results highlight the fact that while landscape "green infrastructure" can contribute to biodiversity and ecosystem services, that this is (a) situational and depend on local environmental conditions, (b) depends upon connection to core grassland habitat and (c) can be considerably less effective for many of the most specialised grassland plants. Given this, increasing functional connectivity of grassland habitats through targeted restoration and through incentivising the creation of grazing networks which can help disperse the most vulnerable species between core areas of managed habitat are likely to be the most effective conservation measures.

4.4. List of project meetings

Date	Place	Participating partners	Meeting title and object
27/02/2017	Leuven	All	Project kick-off meeting
06/04/2017	Skype	Stockholm University, Lactuca, KU Leuven, IMDEA	Management meeting to plan fieldwork, discuss future meetings and sort consortium agreement issues.
24/04/2017-26/04/2017	Stockholm	Stockholm University, CEH, Lactuca	Work package 1 and 4 working group meeting
07/06/2017	Leuven	All	Belgium field site visit, to familiarise everyone with this area and discuss specific fieldwork questions.
05/07/2017-07/07/2017	Regensburg	Regensburg University, Stockholm University	Meeting to discuss field sampling protocols and visit study landscapes
12/02/2018-13/02/2018	Stockholm	All	Annual meeting to discuss progress and future plans
08/05/2018-09/05/2018	Regensburg	Regensburg University, Stockholm University, KU Leuven, IMDEA	German field site visit, to familiarise everyone with this area and discuss specific fieldwork questions.
23/07/2018-25/07/2018	Regensburg	Regensburg University, Lactuca	German field site visit to specifically look at landscape composition and discuss green infrastructure mapping.
23/07/2018-25/07/2018	Mallorca	All	Annual meeting, used to discuss results obtained from the project, publications and communications resulting from this and how they are to be managed within the project
11/10/2019	Skype	Stockholm University, KU Leuven, IMDEA, Regensburg University, Lactuca	Update on progression of planned analyses and paper writing.
1/7/2020	Skype	Stockholm University, CEH, Lactuca	Meeting to discuss reviewer comments on submitted manuscript, and strategy for addressing this.
28/9/2020	Skype	All	Management meeting to discuss ongoing progress on producing manuscripts from FUNgreen work, and potential future activities arising from the project.

4.5 Follow up activities and plans for further exploitation of the results

1. Scientific projects to ensure the data and understanding from FUNgreen are utilised to their maximum potential

Field experiments to investigate the process of spatial and temporal plant species dispersal and how this is influenced by grazing animals, via a PhD student studying functional connectivity in Swedish grasslands, and the effects of spatial and temporal dispersal on plant species colonisation of restored grassland sites.

LiM-project (5 million SEK from SEPA 2019-2021) title: Integrating past and present statistics and geodata to identify landscape-scale indicators for biodiversity in fragmented landscapes

Summary: The focus is on different grassland habitats, as biodiversity hotspots, in rural landscape across all biogeographical regions of Sweden. A combination of historical and present open-source landscape geodata and regional statistics will be used to identify timing and magnitude of fragmentation, land use and habitat quality. By investigating fragmentation and habitat quality change over time from different region we will identify thresholds when fragmentation starts to become negative for biodiversity. To develop indicators for biodiversity we need to measure plant biodiversity (gene, species, community, function) in 48 landscapes across Sweden. We will also analyse if and how green infrastructure in rural landscapes can improve landscape biodiversity. Finally, we will make suggestions for how landscape fragmentation should be monitored. The project will report on how changes in land use of semi-natural and cultural environments affect the ecological context of different species, their habitats, structures and functions in rural landscape in a Nordic context.

2. Ensuring the results and practical implication of FUNgreen are effectively communicated to practitioners, stakeholders and the public

Results from the project will be presented at upcoming meetings on green infrastructure at a national level, to ensure that important evidence and practical recommendations resulting from FUNgreen results are communicated to land managers and other conservation stakeholders. This includes participation in projects aiming to quantify whether present habitat levels are sufficient to protect biodiversity, and integrating project results relating to the importance of functional connectivity.

We will produce an instruction manual of how to use green infrastructure, where such habitats are likely to be most effective and the benefits that can be obtained through effective management, targeted for conservation managers across Europe.

5. Stakeholder engagement in the project

5.1 Before the project's start

- Collaboration with Günther Czerkus who is the President of the German Union of Professional Shepherds ("Bundesverband Berufschäfer e.V."; https://www.berufsschaefer.de) in an experiment concerning the optimization of migration routes and the evaluation of seed dispersal distances by sheep. The experiment was conducted in the Western Eifel in Germany.
- Consultation a group of local farmers and land managers in all study regions (Sweden, Belgium and Germany) about the management history of landscapes and the movement of grazing animals, used to inform study site selection.

5.2 During the project

- In agreement with the union of the conservation of the countryside of the county Regensburg ("Landschaftspflegeverband" Regensburg) collaboration with family Graml (http://www.rotviehhof-am-jurasteig.de; https://www.facebook.com/RotviehhofamJurasteig) testing the seed dispersal effectiveness of different livestock (cattle, sheep, goat) for calcareous grassland species in a field experiment. The farmers provided the animals. The selected calcareous grassland was provided by the union of the conservation of the countryside (Josef Sedlmeier, Ansgar Lemper, Heidrun Weidele) and the municipality of Kallmünz (Bernhard Huebl).
- August 2019: Excursion for the stakeholders who lent the animals (farmers) and granted the access to the sites (landscape managers) in Kallmünz. Results from the dispersal experiments with cattle, sheep and goats and the effect of the grazing of the different animals during the experimental period was presented. Previously, only sheep and goats were allowed by the landscape managers to "manage" the calcareous grasslands. The preliminary results presented convinced the landscape managers to allow cattle grazing in the future. Around 30 people attended this excursion.

5.3 Foreseen after the project's end

- Swedish funding application for further investigation of types of landscape change, landscape management and affected species which are most relevant to stakeholders, with scenarios to be determined in collaboration with land managers/users.
- Cousins is one of the national scientific experts (out of 2) in a group to produce favourable reference values for the Swedish grassland habitats. The work is commissioned by Swedish EPA. Based on historical data grassland habitat amount and spatial distribution will be used for all different grassland types in all Swedish biogeographical regions. The commission asks to incorporate connectivity as a measurement of habitat quality and functionality and also to include effects on genetic diversity. Meetings 24 September 2020, December 2020.

6. Dissemination of results

6.1 List of scientific publications

See attached Excel table listing publications resulting from FUNgreen.

6.2. Dissemination of results to scientists and scientific organisations (1-page max)

- The German study region and the field study sites were presented on an excursion during the "Seed trait workshop" in Regensburg with around 20 participants (e.g. Prof. Dr. Jeffrey Walck, Middle Tennessee State University, USA, Prof. Dr. Fernando Silveira, University of Belo Horizonte, Brazil, Dr. Arne Saatkamp, IMBE, University of Marseille).
- Project and results presented in an oral presentation by Sara Cousins (Stockholm University) at the IAVS conference in Palermo on June 21st 2017.
- „ Participation at the Conference "Erfolgskontrollen im Naturschutz" organised by the BfN (Bundesamt für Naturschutz), which is the federal scientific institution for national and international nature conservation aspects. The conference took place from the 4th to the 7th of December on the island Vilm (Germany). Talk by Patricia Krickl (Regensberg University) including goals and first results concerning FUNgreen, especially with focus on the German proposal. Resulting publication: Krickl, P. & Poschlod, P. (2020): Monitoring der Auswirkungen von Rodungsmaßnahmen ehemals verbuschter und aufgeforsteter Kalkmagerrasen 1992/1993 - 2018 – Eine vegetationsökologische und funktionelle Bewertung. Naturschutz und Biologische Vielfalt: Im Druck.
- Project and results presented in an oral presentation at the IAVS conference in Bremen on the 16th July 2019 by Patricia Krickl (Regensburg University).
- Project and results presented in an oral presentation at the Seed Ecology conference in Regensburg on the 1st of August 2019 by Patricia Krickl (Regensburg University)
- Project and results presented in oral presentations at the BES conference in Belfast on December 12th 2019, by Adam Kimberley (Stockholm University) & Danny Hooftman (Lactuca).
- Project presented by Sara Cousins (Stockholm University) at the BiodivERsA final conference for projects funded in 2015-2016 in Brussels 12th-13th November 2019.

6.3 List of dissemination activities with stakeholders

- Workshop in the Eifel region (Germany) with participants from science (RLP Agroscience), representatives of the shepherd's union, active shepherds, and governmental representatives for nature conservation and agriculture. Regensburg University.

- Workshop in the Eifel within the additional project "importance of sheepherding for plant diversity" with presentation of Peter Poschlod and poster by Patricia Krickl and student assistants (Regensburg University).
- Landschaftspflegetag"(Get together of people working actively in landscape conservation) in Heidenheim (Germany) on the 18th of October 2018. This event was organised by the LEL (Landesanstalt für Landwirtschaft, Ernährung und Ländlichen Raum), which is a governmental institution located in Baden-Württemberg. Approx. 100 participants including environmental ministry state secretary Dr. Andre Baumann, district president of Stuttgart Wolfgang Heimer and many local shepherds. Talk by Prof. Dr. Peter Poschlod on "Artenvielfalt durch Beweidung: Naturschutz braucht Biss" – aims of Fungreen project were presented during the talk and their applicability for people working on conserving species rich grasslands. More information: (https://lel.landwirtschaft-bw.de/pb/MLR.LEL-SG,Lde/Startseite/Akademie+Laendlicher+Raum/181018_Landschaftspflegetag)
- Project and results presented by Sara Cousins (Stockholm University) to local land managers and researchers at a workshop at Tovetorp research station, Sweden on November 27th 2018.
- Cousins was one of the national experts within the reference group for reporting Sweden's grassland status according to article 17 (Habitat directive) under 2018. Report published 2019, Meetings 12 June and 16 November 2018,
- Cousins was invited speaker to present results from FUNgreen at the Final seminar for the LIFE Coast Benefit project. Norrköping 14-16 May 2019. 70 participants
- Betesdjur till sjöss bevarar mångfald på skärgårdsöar (*Grazing animals preserve diversity on archipelago islands).* Cousins gave an invited presentation at Miljöövervakningsdagarna, Nyköping 26-27 september 2018. Miljöövervakningsdagarna (*Environmental monitoring days*) is the yearly conference for all county boards in Sweden and public land managers. 150-200 participants
- July 2019: Public launch of the exhibition "Samen – Schätze der Menschheit" at the University of Regensburg. Presentation by Prof. Dr. Peter Poschlod (Regensburg University). Content of the talk and the exhibition included topics of the FUNgreen work. At the event were appr. 40 people including the cooperation partners for the dispersal experiment, the farmer family Graml. In the following month many guided tours through the exhibition by Prof. Dr. Peter Poschlod including FUNgreen as topic.
- Swedish Environmental Protection Agency "Science days" 2019 Cousins reported major findings from FUNgreen and the start of the LIM-project.
- Representatives from FUNgreen (Sara Cousins and Alistair Auffret, Stockholm University) presented at a two-day workshop on managing green infrastructure held in Nykoping, Sweden by Sörmland county board, September 28th-29th 2018.
- Meeting between Stockholm University and the reserve management group of Nynas Nature Reserve, part of the Swedish study area, to discuss conservation management plans for the area, and potential to integrate these with future scientific research.

6.4 Dissemination of results to stakeholders (1-page max)

- Website made available to the public, describing the goals and background to the project. Will be used to share results and research output summaries following publication of papers.
- Twitter account used regularly to share project news.
- Field brochures places in vehicles during fieldwork, to explain to passing public what work is being done and the aims of the project.
- Exhibition with the title "A life for botany – A unique contemporary witness of change of habitat and biodiversity." The aim of the exhibition was to show the changes in our cultural landscape since the 1960 compared to nowadays. Included was a poster about the main study region "Kallmünz". Around 80 visitors were participating in the opening of the exhibition and there were several hundred people visiting the exhibition during October and November 2019.

- May 2019: Annual public excursion for the „Offenhaltungsversuche Baden-Württemberg" including a stop at the study site Haarberg-Wasserberg were goals and first results of the FUNgreen project were presented by Prof. Dr. Peter Poschlod and Patricia Krickl (Regensburg University).
- May 2019: Presentation of FUNgreen goals at a public event organised by cooperation partners (family Graml). https://www.mittelbayerische.de/region/regensburg-land-nachrichten/die-gaertner-auf-vier-pfoten-21364-art1801058.html
- May 2019: Excursion for the public organized by the „Regensburgisch Botanische Gesellschaft" to Kallmünz. Here the experiment on dispersal via cattle, sheep and goat conducted for FUNgreen as part of the German proposal was presented. Around 40 persons attended.
- Several interviews for local and national papers and radio in January 2018 (Sweden)
- Several interviews including filming of the fieldwork on connectivity through seed dispersal for a film documentation of the ZDF (Second German Television; IDtv Film-& Fernsehproduktion, Hartmut Idzko) about shepherds, sheep and shepherding (Germany). The film was aired in the beginning of 2019 and reached a wide audience.
- Online university press release https://www.natgeo.su.se/forskning/forskningsnyheter/betesdjur-till-sj%C3%B6ss-bevarar-sk%C3%A4rg%C3%A5rdens-v%C3%A4xter-1.369305
- Kor på gott och ont. Vetenskapsradion Klotet (national radio) 17 June 2020 https://sverigesradio.se/avsnitt/1515797

Non-English language publications

- Cousins SAO 2019 Biologisk mångfald genom djurflytt mellan öar. Vi Skärgårdsbor 3: 16-17.
- Svenska Dagbladet (Sweden's 2nd largest broadsheet newspaper) debate 18th February 2019 Offra inte Sveriges betesmarker
- Cousins SAO, Plue J 2018 Betesdjur till sjöss bevarar mångfald på skärgårdsöar. Havsutsikt 1: 9-11
- Cousins SAO 2017 Historiska kartor visar vägen Skog och mark: 33-35
- Krickl et al. 2018: Die Ausstellung „Ein Leben für die Botanik – Einzigartiger Zeitzeuge des Wandels von Lebensraum- und Artenvielfalt, HOPPEA. The publication will reach more than 600 members of the oldest botanical society of the world, the Regensburg Botanical Society, and is available in any larger scientific library.
- Betesflytt viktigt för artrikedom. Interview by BM Jafner in Husdjur 4/2018
- Skärgårdens landskap – I behov av project eller förbättrade villkor för skärgårdsbonden? Text by AC Utbult Almkvist (farmer) In Vi Skärgårdsbor 3: 17

7 Global Impact assessment indicators

7.1 Impact statement

FUNgreen has provided a comprehensive overview of the effects of functional connectivity and green infrastructure in European landscapes, and how changes in landscape composition and green infrastructure availability influence plant species diversity, plant genetic diversity, plant-pollinator interaction networks and ecosystem functions. While results indicate an important role for functional connectivity in biodiversity conservation, the different aspects of FUNgreen highlight the fact that different species, taxonomic groups and scales of diversity do not respond in a uniform way to functional connectivity, and particularly to the presence of green infrastructure habitats. While green infrastructure habitats such as hedgerows and road verges are valuable connecting elements for some species, and can contribute to important genetic diversity and ecosystem services, they are of less value for grassland specialist species and for nature conservation unless they are embedded in a well/connected landscape, with greater amounts of core-seminatural grassland present, ideally managed by the movement of rotationally grazed livestock on well optimised paths through the landscape. Our results point to ways in which this can most effectively be done, and highlight where difference types of green infrastructure can provide a benefit to biodiversity, and where it is less effective. This will help inform grassland management, grassland restoration schemes and landscape habitat network design across European countries. Project partners are involved in a number of such schemes as expert advisors, and will be able to promote the important practical implications of our work for landscape management in these applied settings. Furthermore, these results have been disseminated to land managers and the general public through a number of exhibitions, excursions and presentations. This has already led to a change in grassland management policy in our study sites. Additionally, project results have contributed to a greater scientific understanding of dispersal processes for grassland species in human-managed landscapes. These results are being written up for publication in a range of high-impact journals.

7.2 Synthetic figures for the project publications (including interactions with stakeholders)

Please indicate synthetic figures of project publications, including a summary and an analysis of project publications as follows (example):

10 published papers, 1 submitted and 9 in preparation (listed in the publication list template). Intended journal targets include Landscape Ecology (Impact factor (IF) = 3.4), Biological Conservation (IF = 4.7), Journal of Applied Ecology (IF = 5.8), Ecography (IF = 6.5).

International dimension and multi-partnership for publications

		Number of publications
Multi-partner publications	**Peer-reviewed journals**	9
	Books or chapters in books	0
	Communications (conferences)	3
Single-partner publications	**Peer-reviewed journals**	1
	Books or chapters in books	0
	Communications (conferences)	2
Outreach initiatives including interactions with stakeholders	**Popularization articles**	7
	Popularization conferences	7
	Others	12

7.3. Other scientific outputs

Not applicable in this project

7.4. Assessment and follow-up of personnel recruited on fixed-term contracts (excluding interns)

Identification			Before recruitment for the project			Recruitment for the project				After the project			
Surname and first name	Sex M/F	E-mail address	Last diploma obtained at time of recruitment	Country of studies	Prior professional experience, including post-docs (years)	Partner who hired the person (Organisation and Country)	Position in the project (1)	Duration of missions (months) (2)	End date of mission on project	Professional future (3)	Type of employer (4)	Type of employment (5)	Promotion of professional experience (6)
Kimberley, Adam	M	adam.kimberley@natgeo.su.se	PhD	United Kingdom	Postdoc (2 years)	Stockholm University, Sweden	Post-doctoral	42	30/09/2020	Still working on the project	Teaching and public research	Researcher	Yes
Björk, Maria	F	NA	Bachelor's degree	Sweden	NA	Stockholm University, Sweden	Field worker & GIS technician	6	09/2017	Open-ended contract	Other private	Field assistant	No
Bernstein, Maria	F	NA	Bachelor's degree	Sweden	NA	Stockholm University, Sweden	Field worker	4	09/2017	Open-ended contract	Other public	Field assistant	Yes
Kapás, Rozália	F	rozalia.kapas@natgeo.su.se	Masters	Hungary	NA	Stockholm University, Sweden	Field worker	2	09/2018	Doctoral student	Teaching and public research	Student	Yes
Lindgren, Jessica	F	jessica.lindgren@natgeo.su.se	PhD	Sweden	Postdoc (1 year)	Stockholm University, Sweden	GIS technician	6	07/2018	Post-doctoral position	Teaching and public research	Researcher	Yes
Hooftman, Danny	M	danny.hooftman@lactuca.nl	PhD	Switzerland	Postdoc (7 years), Permanent research position (6 years)	Stockholm University, Sweden	Individual contractor	36	03/2020	Open-ended contract	Other private	Researcher	Yes
Silvia Santamría	F	sil.santamariab@gmail.com	PhD	Spain	NA	IMEDEA, CSIC Spain	Post-doctoral	24	07/2019	NA	NA	NA	NA
Rafel Beltran	M	rbeltran@imedea.uib-csic.es	Masters	Spain	Tecnician	IMEDEA, CSIC Spain	Technician	3	11/2019	Contracted in another project	Public Organization	Technician	No
Jan Plue	M	jan.plue@natgeo.su.se	PhD	Belgium	Postdoc (7 years)	KU Leuven, Belgium	Post-doctoral	36	03/2020	Open-ended contract		Researcher	Yes
Gerrit Peeters	N	Gerrit.peeters@kuleuven.be	Bachelor's degree	Belgium	NA	KU Leuven, Belgium	Technician	36	03/2020	Open-ended contract	Teaching and public research	technician	Yes
Krickl, Patricia	F	Patricia.Krickl@biologie.uni-regensburg.de	Masters	Germany	NA	Regensburg University, Germany	Doctoral student	39	05/2020	fixed-term contract	Teaching and public research	Student	Yes
Muck, Svenja	F	NA	Bachelor's degree	Germany	NA	Regensburg University, Germany	Field worker/ student job	8	01/2018	Gain master degree	Teaching and public research	Student	Yes

Feichtmeier, Lukas	M	NA	Bachelor's degree	Germany	NA	Regensburg University, Germany	Field worker/ student job	5	05/2019	Open-ended contract	Other private		Yes
Segieth, Sebastian	M	NA	Bachelor's degree	Germany	NA	Regensburg University, Germany	Field worker/ student job	2	05/2019	Gain master degree	Teaching and public research	Student	Yes
Senninger, Lisa	F	NA	Bachelor's degree	Germany	NA	Regensburg University, Germany	Field worker/ student job	4	09/2019	Gain master degree	Teaching and public research	Student	Yes

Table filling-out aid
(1) Position in the project: post-doctoral, doctoral student, engineer or equivalent, technician, individual contractor, other (specify)
(2) Duration of missions: indicate the total duration in months of the project missions carried out or planned
(3) Professional future: Open-ended contract, fixed-term contract, entrepreneur, still working on the project, post-doctoral position (abroad or not), student, between jobs, without any news
(4) Type of employer: teaching and public research, research public institution (EPIC), large company, SME/VSE, company creation, other public, other private, self-employed, other (explain)
(5) Type of employment: engineer, researcher, lecturer-researcher, executive, technician, other (explain)
(6) Promotion of professional experience: indicate whether the current position promotes the experience gained from the project

7.5. Data Management and timeline for open access

Databases, including all spatial data and processed plant species, plant genetic and pollinator network data will be made available via Figshare once analyses are complete. Papers from the project will target journals with open access options to meet open access requirements from funding bodies.