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Rapid Assessment and Ground Truthing of Habitat Composition and Analysis of Semi-Natural Habitat Diversity of Proposed Greenway Developments

Abstract

Across Europe, Greenways upcycle disused railway infrastructure into non-motorised public infrastructure, often with limited consideration to potential ecological synergies. Pre-development, disused transport corridors become relatively undisturbed and potentially host diverse semi-natural habitats. The study objectives were 1) to produce a highly detailed and accurate dataset using remote sensing with rapid assessment techniques for ground truthing and 2) subsequently examine habitat diversity existing along a proposed Greenway. A 7000 ha study corridor was based on a disused railway proposed as a transfrontier Greenway connecting the Republic of Ireland and the United Kingdom. The study applied a rapid-assessment virtual validation techniquealongside remote sensing and accuracy assessment. Inter-relationship between semi-natural habitat diversity and land-use intensification was examined. Remote sensing accuracies of 89% and 99% for a real and linear habitat classification were obtained. Degrees of land-use intensification were observed throughout the corridor, highlighting the importance of maintaining and enhancing remaining semi-natural habitat that exists along the proposed Greenway route. Through understanding the landscape matrix composition and semi-natural habitat diversity, European Greenwayscan achieve multi-functionality for ecosystem conservation, forming integral components of Green Infrastructure.

Julien Carlier[1]*, James Moran[2]

[1)]Institute of Technology Sligo, Sligo, County Sligo, Ireland

[2)] Galway-Mayo Institute of Technology, Old Dublin Rd, Galway, Ireland

*Corresponding author: Julien Carlier. Institute of Technology Sligo, Sligo, County Sligo, Ireland. Email: julien_carlier18@hotmail.com

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1 Introduction

The benefits of the wide range of ecosystem services provided by biodiverse landscapes are essential to our existence, including provisioning, regulation, maintenance, and cultural services (CICES 2017). Safeguarding biodiversity within landscapes facing intensification is therefore considered crucial to sustainable land use and change (e.g. Chenoweth et al. 2018; Bommarco 2013). Safeguarding biodiversity in rural landscapes is largely interdependent on maintaining both habitat heterogeneity and agricultural production diversity (Donald & Evans 2006). Pressures from expanding transport infrastructure demands and the urbanisation of European landscapes is causing a gradual fragmentation of rural habitats (European Environment Agency 2011; 2016). The increase of natural and semi-natural habitat fragmentation as a result of unsustainable land-use intensification is recognised as a significant and increasing threat to ecosystem services and biodiversity world-wide (Secretariat of the Convention on Biological Diversity 2014; Saunders et al. 1991). In response to European Member States failing in their previous obligations to stop biodiversity loss by 2010 (Commission of the European Communities 2001) a new Biodiversity Strategy aims to halt biodiversity loss by 2020 (European Commission 2011).

The identification of spatial relationships between ecological landscape features and their make-up in order to promote the development of a European ecological network is one of the key examples cited in the application of the European Spatial Development Perspective (European Commission 1999). Indeed, with the recent increases in anthropogenic landscape transformations, there are increasing interests in the mapping of habitat spatial composition and arrangement within landscapes to measure impacts and inform sustainable development (Vogiatzakis et al. 2006). The protection and enhancement of multi-functional ecosystem services through establishing Green Infrastructure is part of Target 2 of the EU 2020 Biodiversity Strategy. Green infrastructure is defined as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” (European Commission 2013). Preserving and enhancing ecosystem services provided by green corridors is also recognised by the European Green Infrastructure Strategy (European Commission 2011, 2013).

Due to their spatial and linear properties, Greenways can host a range of ecologically important habitats that provide a range of ecosystem services (Larson et al. 2016) and can contribute towards the establishment of Green Infrastructure (Keith et al. 2018). In Europe, Greenway developments typically upcycle disused transport infrastructure (e.g. railways, tramways, canal towpaths) to develop new routes for safe, non-motorised and recreational journeys (European Greenways Association 1998). Past research has examined the potential for such corridors to provide both recreational and ecological functions in Europe (Jongman & Pungetti 2004; Toccolini et al. 2006; Fumagalli & Toccolini 2012) and in the US (e.g. Keith et al. 2018; Larson et al. 2016; Ahern 2013). Studies examining vegetation edge habitats along certain transport infrastructure (e.g. railways and canals) highlight the presence and importance of linear habitat and their roles as ecologically significant corridors (Morelli et al. 2014; Vandevelde et al. 2014; Faiers & Bailey 2005).

The expansion of the European Greenway network presents significant opportunities to integrate the spatial planning concept of Green Infrastructure with biodiversity conservation objectives. This could be integrated as part of Greenway development and design, including through the identification, monitoring, preservation and enhancement of natural and semi-natural habitats. However, despite this potential fundamental role, surprisingly little focus has been given to the mapping and evaluation of the habitat diversity potential of Greenway corridors on which its sustainable development can depend. To date, few European studies exist evaluating recreational Greenways as a preservation and enhancement conservation planning tool, although some have focused on *post Greenway development* studies, i.e. the conversion from disused or abandoned infrastructure to multi-functional trails (e.g. Toccolini et al. 2006; Fumagalli & Toccolini 2012). This poses two major problems as i) a certain level of (possibly irreversible) damage can occur to existing natural heritage through development and maintenance stages, potentially leading to associated retrospective restorative cost, and ii) opportunities for enhanced and synergistic ecological Greenway design and management may have lapsed. The recording and classification of Greenway- specific habitat spatial and morphological data prior to any development work is therefore highly desirable to help inform ecologically sensitive and complementary Greenway development and maintenance. As European Greenway networks expand and interconnect, opportunities exist for the realisation of the European Spatial Development Perspective recommendation of a spatially coordinated approach and corresponding national initiatives for the progression and success of a European ecological network. The objectives of this study are to produce a baseline dataset using remote sensing combined with rapid assessment techniques for ground truthing and to examine the habitat diversity that exists along a proposed Greenway route. The research hypotheses are i) that Google Street View imagery can be used to support remote sensing of European Greenway corridors to produce a highly detailed and accurate habitat map for further interpretation, and ii) European Greenway corridors can host a diverse range of semi-natural habitats with the potential to interconnect semi-natural habitats within landscapes undergoing intensification.

2 Methods

2.1 Study area

A 70 km^2 study area was based on the footprint of a 70 km disused railway in the North West of Ireland (Atlantic European Biogeographical Region) to a width of 500 m either side of the route (Fig. 1). This railway corridor is currently proposed as a cross-border Greenway development connecting the Republic of Ireland and the United Kingdom. The study area lies predominantly in a lowland setting (22 to 200 m above sea level). Annual rainfall in the region varies from 1200 to 2000 mm and the annual average temperature is 10 °C (Walsh 2012). The average wind speed is 21.6 km/hour. The route passes through a High Nature Value landscape of valley floors carpeted with undulating drumlin farmlands composed of predominantly rushy pastures, semi-improved agricultural and wet grasslands, typically enclosed by a dense network of hedgerows and treelines (Sullivan et al. 2017; Minogue 2002). The underlying geology is mainly of limestone, shale and sandstone formations (Geological Survey of Ireland 2004).

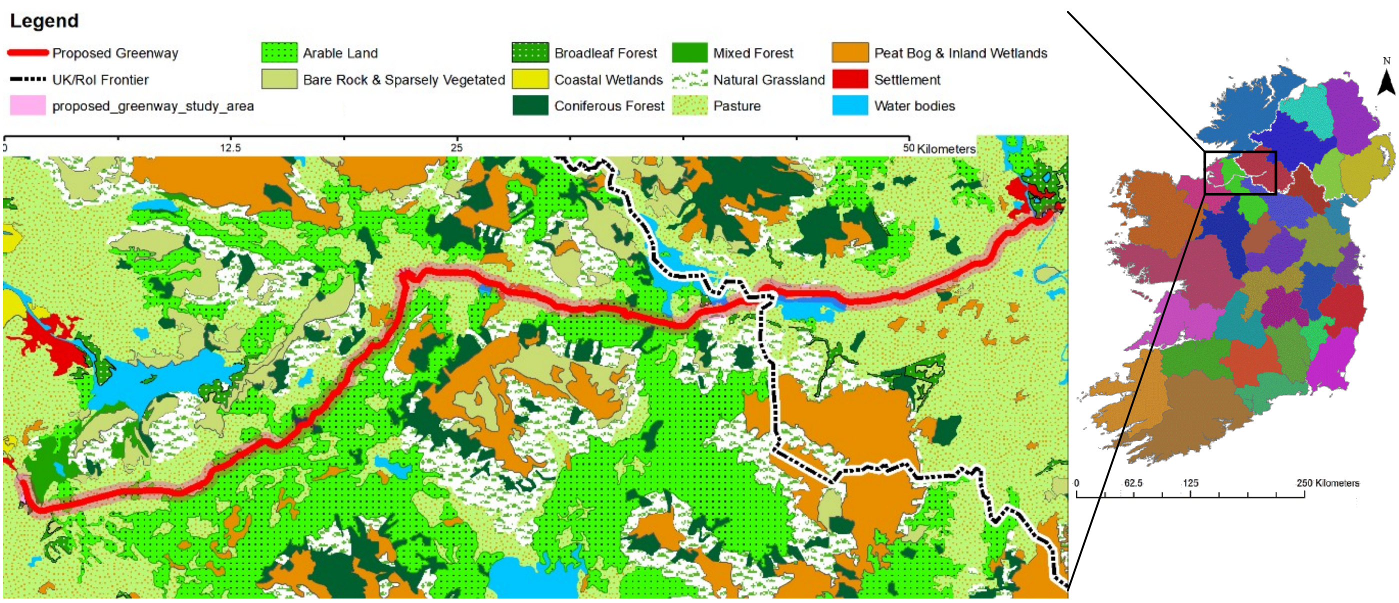

Figure 1: Location of the study area across three counties of the Republic of Ireland (Sligo, Leitrim, Cavan) and the United Kingdom (Fermanagh).

2.2 Habitat database generation

Principal steps in generating the habitat database involved generating a one kilometre wide 'buffer' study area using the proposed Greenway route as the central linear feature in ArcGIS 10.2.2 (ESRI 2014). Using available dataset overlays and satellite imagery, the full extent (7000 ha) of the study area was photointerpreted. Fig. 2 illustrates a step by step process flow of the mapping methods applied in this study.

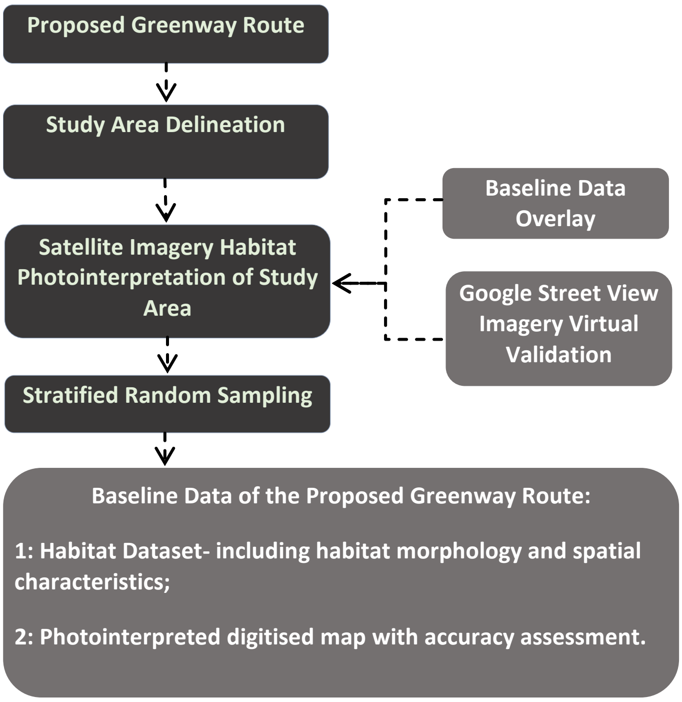

Figure 2: Schematic outline of the methodology steps used to produce a baseline dataset of habitat features occurring along a proposed Greenway route corridor.

2.2.1 Photointerpretation of satellite imagery

World Imagery map data collected on 07 November 2011, available from ArcGIS, was applied as a basemap. World Imagery maps provide a resolution of 0.6 m in most parts of Western Europe. Photointerpretation of map imagery was undertaken to achieve detailed mapping of habitats within the study. Best practice guidance for habitat survey and mapping (Smith et al. 2011) was used and habitat classification followed the Irish national standard guide to classification level three (Fossitt 2000) using ArcGIS. Areal habitats were photointerpreted and digitised as polygon features, followed by linear habitats photointerpreted and digitised as polylines. Polylines were then overlaid onto polygon features and used to further define areal habitats (e.g. individual field parcels) using the 'split polygon' ArcGIS tool. Overlap and gap errors between polygons created during digitising were identified and corrected using ArcGIS 'topology rule'.

2.2.2 Google Street View virtual validation

The use of Google Street View (Google 2018) provided a means for investigating and cross referencing aerial habitat photointerpretation (Fig. 3). The Street View resolution was of sufficient quality to enable a detailed virtual validation system similar to that of vehicle surveying. Street View provided further validation of ground conditions, seasonal vegetation variation, composition and structure and aerial map shadows. The Street View imagery date varied between 2010 and 2011 which generally coincided with that of the World Imagery basemap. Since the railway followed a predominantly lowland setting along valley floors, it typically interacted with a dense network of public road infrastructure- all of which were surveyed by Google Street View. A majority of the corridor remote sensing was supported by this panoramic imagery photointerpretation.

2.3 Accuracy assessment

An accuracy assessment typically provides an extent of correctness of land-cover interpretation or classification (Foody 2002; Congalton & Green 2008). Accuracy assessment of land-cover maps compare the map ground interpretation against the true classification of the same spatial area or site, and sampling strategies are commonly applied to select sampling sites in order to limit time constraints of sampling an entire study area (Stehman 2000).

The study area was split into the three broad landscape character areas identified using an overlay of Landscape Character Types for the region (Geological Survey Ireland, n.d.) and stratified random sampling was performed within the respective character areas (Table 1). A proportionate number of sampling sites were randomly generated for each landscape character area using ArcGIS 'Create Random Points'. Optimum sampling site area was determined post pilot site sampling and a 320 m diameter sampling site was designed by creating a 'Buffer' using ArcGIS.

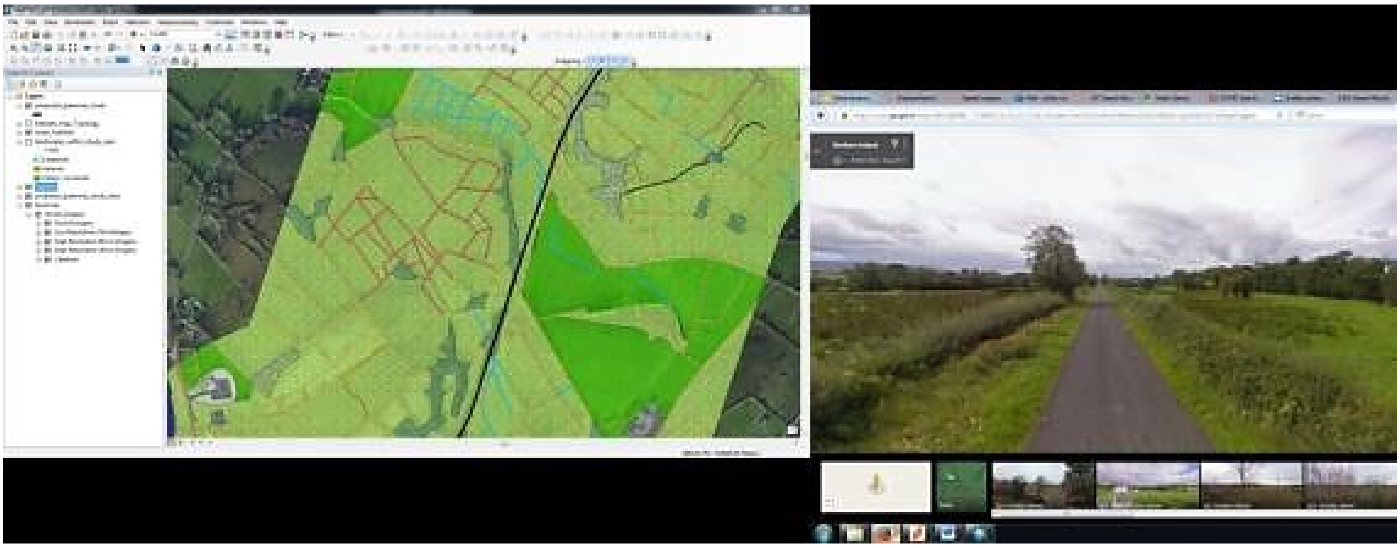

Figure 3: Screen grab displaying habitat digitisation and Google Street View used to aid habitat photo interpretation.

Table 1: Breakdown of study area into landscape characters and respective proportional number of sample sites.

Landscape Character Type	Area [km²]	No. of Sites
Valleys & Lowlands	42	21
Lakelands	18	9
Uplands	10	5
	Total: 70 km²	Total: 35 sites

Groundtruthing of the interpreted habitats within sampling sites was performed by a walkover survey of linear habitat and over the longest diagonal of habitat polygon features, to verify the feature assigned habitat class. A map of the sample sites was printed at a scale of 1:5000 displaying the interpreted habitats to be validated on-site. Additional notes such as the damage, removal or change of habitats were also noted. Verified habitats were input as valid or invalid within the habitat database; where a habitat interpretation was invalid, the corrected habitat was referenced.

Accuracy estimation was performed by comparing surveyed habitats against the respective habitats interpreted from satellite imagery using an error matrix. The error matrix consisted of cross referencing photointerpreted habitats with the groundtruthed habitats, giving the correct classification results through diagonal entries (Stehman 1996; Congalton & Green 2008). Groundtruth validated respective photointerpreted habitats polygons and polylines were rasterised in ArcGIS to obtain pixel values for (a) photointerpreted and (b) correct and incorrectly classified groundtruthed habitats. Error matrix tables were built for both rasterised linear and patch habitats using 'Combine' and 'Pivot Table' tools in ArcGIS, and the resulting text table exported to Microsoft Excel spreadsheet. The map accuracies derived from error matrixes include: overall accuracy, individual habitat classification accuracies for both Fossitt habitat classification levels 2 and 3, and kappa coefficient (Congalton & Green 2008) (overall homogeneity between results). The kappa coefficient is defined as:

$$\hat{K} = \frac{N * \sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{k} (x_{i+} * x_{+i})}$$

Where…

$\sum_{i=1}^{k}$ is the sum across all rows in the matrix,

x_{ii} is the diagonal value

x_{i+} is the marginal row total (row *i*)

x_{+i}) is the marginal column total (column *i*)

N : is the total number of observations.

2.4 *Habitat diversity assessment*

Areal and linear habitats were analysed at Fossitt habitat classification level two. A set of 30 2.5 X 1.5 km tiles were overlaid onto the photo interpreted habitat map to create a framework of habitat cover data (Fig. 4). Habitat percent cover and total linear density (km) were calculated for both areal and linear habitats within each tile. Shannons's diversity index H was selected for its sensitivity to less frequent habitat types (Nagendra 2002) and calculated for all semi-natural habitats occurring within each tile in PC-ORD v. 7.1 (McCune & Mefford 2016). Finally, semi-natural habitat diversity interquartile ranges of the 30 tiles were used to classify low, medium and high semi-natural habitat diversity groups: group one 0-Q1; group two Q1- Q3 and group three Q3-100, and significant semi-natural habitat differences were explored between the three diversity groups.

3 Results

3.1 The railway ballast and corridor

The railway ballast width is approximately four to five meters and where it remains it is typically 300 mm in depth of crushed limestone material, beneath which the remainder of the embankments is made up of fill, slag and ash mixture. Through abandonment, a layer of soil has formed over most of the infrastructure. The rail corridor structure takes the form of bench cuts along steep hillsides (Fig. 5 (a)), small or high embankments (Fig. 5 (b)) and cut (Fig. 5 (c)) sections through transverse raised inclines. While most of

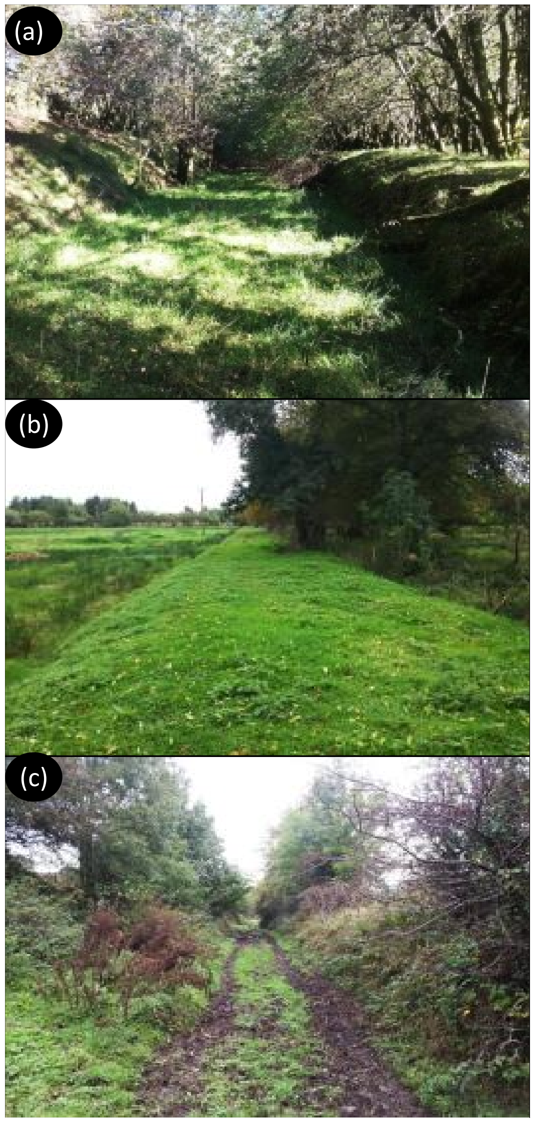

Figure 5: (a) Railway bench- cut section with overgrown hedgerows bounding both sides and semi-natural grassland blanketing the ballast; (b) Grazed railway embankment with mature and overgrown hedgerow bounding one side; (c) Railway cut section with remnant gappy hedgerows and poaching of ballast surface by livestock.

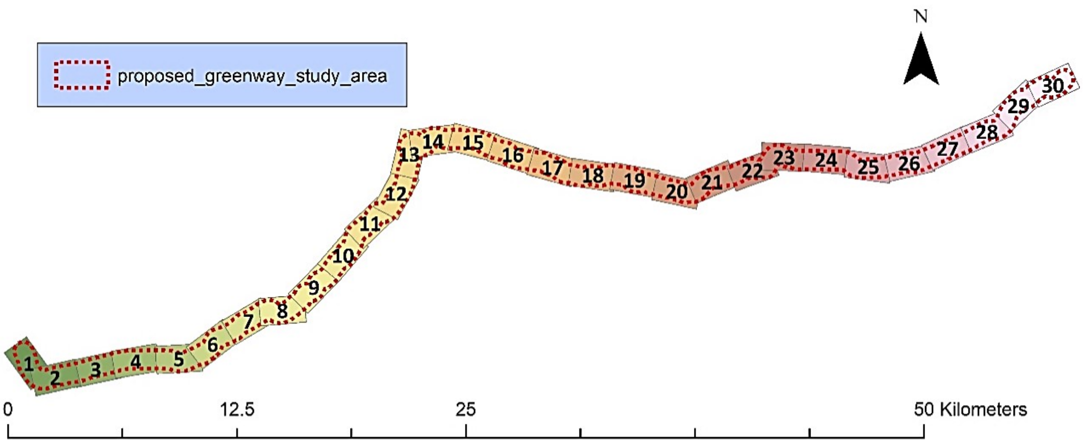

Figure 4: Set of 30 tiles overlaid onto the study area corridor

the corridor is returning to semi-naturalness, it is occasionally used for grazing, farm access or silage bale storage.

Both sides of the ballast are usually drained by means of open ditches, however many of these are overgrown and blocked- especially any cut sections, resulting in waterlogged conditions. Many of the bench cut sections of the route are also very overgrown making access near impossible. Any raised embankments are generally free draining. Hedgerows and treelines typically flank the rail ballast, though many are now overgrown. Under current conditions, the corridor resembles closely the'green lanes' descriptions in Walker et al. (2005), Croxton et al. (2005), providing high species diversity and linear corridors for birds and pollinators. Many small pockets of semi- natural woodlands (principally wet- willow alder ash woodland) and mixed broadleaf woodlands often interact with the railway corridor, either growing on it or linked by flanking or adjacent hedgerows or treelines (Carlier & Moran 2019a).

3.2 Study area photointerpreted habitat composition

A habitat database and map were generated providing habitat type, spatial and morphological characteristics of the proposed Greenway corridor. A full book of tile maps is available in Carlier and Moran (2018); Fig. 6 illustrates example tile maps 12, 21, and 26. Table 2 provides a breakdown of habitat cover (Fossitt level 2 & 3) and respective classification accuracies within the corridor.

Photointerpreted habitat cover and distance were extracted and summarised from the habitat database using 'summary statistics' tool in ArcGIS. Individual habitat proportions are listed under different land-use categories in Table 2. A major proportion (53%) of the study area was un-intensified semi-natural habitat cover. The most abundant habitat was wet grassland covering 41% of the study area, followed by improved agricultural grassland at 31% coverage of the study area.

Table 2: Inventory of a real habitat proportions, linear habitat lengths and respective ground truthed classification accuracies within the study area under various land- use categories using Fossitt habitat classification levels 3 & 2.

Category	Fossitt Habitat Classification Level 3	% Cover	Accuracy	Fossitt Habitat Classification Level 2	% Cover	Accuracy
Natural/ Semi-natural / non-productive /marginal agricultural habitat	Wet Grassland (GS4)	41.18%	87%	Semi-natural grassland (GS)	41.88%	93%
	Dry Calcareous and Neutral Grassland (GS1)	0.47%	No data			
	Dry Meadows and Grassy Verges (GS2)	0.15%	100%			
	Marsh (GM1)	0.08%	100%			
				Freshwater lakes and ponds (FL)	2.78%	100%
	Depositing Lowland Rivers (FW2)	1.11%	100%	Freshwater watercourses (FW)	1.11%	100%
	Oak Ash Hazel Woodland (WN2)	0.31%	No data	Semi-natural woodland (WN)	2.35%	99%
	Riparian Woodland (WN5)	0.05%	100%			
	Wet Willow Alder Ash Woodland (WN6)	1.40%	31%			
	Bog Woodland (WN7)	0.59%	100%			
	Cutover Bog (PB4)	1.19%	100%	Bogs (PB)	1.19%	100%
	Scrub (WS1)	0.63%	100%	Scrub/transitional woodland (WS)	0.64%	100%
Highly modified non-built habitat	Short rotation Coppice (WS4)	0.01%	No data			
	Improved Agricultural Grassland (GA1)	31.21%	89%	Improved grassland (GA)	32.84%	78%
	Amenity Grassland (GA2)	1.63%	14%			
	Conifer Plantations (WD4)	6.06%	100%	Highly modified/non-native woodland	7.12%	100%
	Mixed Conifer Woodland (WD3)	0.04%	No data			
	Broadleaf/Conifer Mix (WD2)	0.55%	11%			
	Broadleaf Woodland (WD1)	0.38%	2%			
	Scattered Trees and Parkland (WD5)	0.09%	No data			
Highly modified built land	Buildings and Artificial Surfaces (BL3)	5.55%	100%	Built land (BL)	5.55%	100%
	Active Quarries and Mines (ED4)	0.14%	No data	Disturbed ground (ED)	0.28	No data
	Spoil and Bare Ground (ED2)	0.03%	No data			
	Recolonising Bare Ground(ED3)	0.11%	No data			
	Artificial Lakes (FL8)	0.02%	No data			No data
	Unknown (unclassified)	0.58%	No data			No data
Fossitt Level 3 Classification Overall Accuracy: 83%; kappa: 0.82				*Fossitt Level 2 Classification Overall Accuracy: 89%; Kappa: 0.88*		

Category	Fossitt Habitat Classification Level 3	Length (km)	Accuracy	Fossitt Habitat Classification Level 2	Length (km)	Accuracy
Linear Built boundaries & rural tracks	Stone walls (BL1)	28.434	100%	Built land (BL)*	56.938	92%
	Earth banks (BL2)	18.641	83%			
	Buildings and artificial surfaces (BL3)	9.863	100%			
Linear water courses	Eroding / upland rivers (FW1)	36.090	100%	Freshwater watercourses (FW)	204.005	100%
	Drainage ditches (FW4)	173.915	100%			
Linear woodland	Hedgerows (WL1)	630.846	98%	Linear woodland/scrub (WL)	727.941	100%
	Treelines (WL2)	97.095	100%			
Fossitt Level 3 Classification Overall Accuracy: 98%; Kappa: 0.98				*Fossitt Level 2 Classification Overall Accuracy: 99%; Kappa: 0.99*		

*Built Land (linear) was composed of green lanes, bounded by hedgerows and grassy verges.

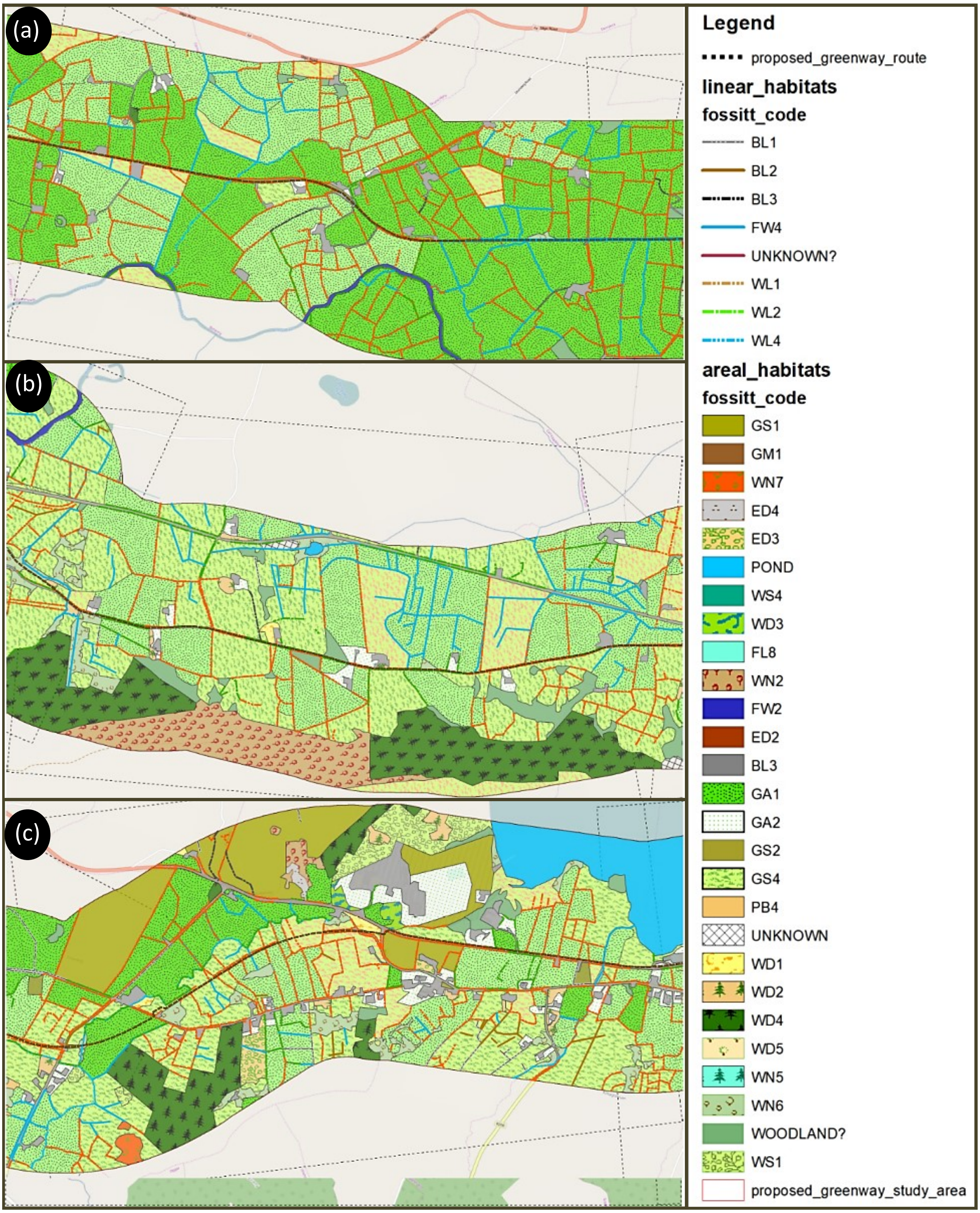

Figure 6: Example tiles from the habitat photointerpretation book of maps in Carlier and Moran (2018). Tile 26 (a) illustrates an intensified grassland section of the Greenway corridor with low habitat diversity (Shannon's diversity: 0.9); tile 12 (b) illustrates the Greenway corridor with mixed intensive and extensive land use and medium habitat diversity (Shannon's diversity: 1.3); tile 21 (c) illustrates the Greenway corridor with high habitat diversity (Shannon's diversity: 1.5).

The third most abundant habitat in the study area was conifer plantations, covering 6%. The most common semi- natural woodland was wet willow- alder- ash, frequently co-occurring with scrub in extensively managed lands dominated by wet grassland. Bog woodland occurred in localised areas, covering 0.6% of the study area and principally within proximity to cutover bog habitat. Some interpretation of woodlands as semi-natural woodlands (WN) (Fossitt level 2) habitat occurred due to limitations associated with photointerpretation of woodland broadleaf species composition and an absence of Google Street View imagery. Cutover bog was the only type of peatland present within study area; this habitat was mostly undergoing succession to heath. Extensive networks of hedgerows and treelines of 631 km and 97 km respectively were mapped. Depositing lowland rivers (mapped as polygons) covered 1.1% of the study area. A further 36 km of eroding upland river was mapped as linear habitat. 174 km of drainage ditches were mapped. It was not possible to interpret lakes and ponds to level three classification, these were interpreted as 'Freshwater- Lakes and Ponds' – level two. Disturbed ground habitats were mapped, mostly near towns, comprising spoil and bare ground, recolonizing bare ground and active quarries and mines. Buildings and artificial surfaces covered 5.6% of the study area with 10 km also mapped as linear built habitat. 28 km of stone walls and 19 km of earth banks were also mapped.

Certain areal habitats were not present within any sampling sites, due to their very low occurrence and area. Habitats unrepresented in sampling were GS1, ED2, ED3, ED4, FL8, WD3, WD5, WN2 and WS4. These habitats comprise a combined area of 191777 m^2 or 1.6% of the Study Area. Areal habitat overall accuracies observed were 83.34% (*Kappa 0.82*) and 88.76% (*Kappa 0.88*) for Fossitt habitat classification level 3 and 2 respectively. Linear habitat overall accuracies observed were 98% (*Kappa 0.98*) and 99% (*Kappa 0.99*) for Fossitt habitat classification level 3 and 2 respectively. Individual habitat classification accuracies for areal and linear features are included in Table 2.

3.3 Habitat diversity

Semi-natural habitats within each tile were analysed at Fossitt level two classification and included a real semi-natural habitats: Semi-natural Grassland (GS), Semi-natural Woodland (WN), Woodland Scrub (WS), Freshwater Lakes (FL), Freshwater Watercourses (FW), Peatland Bogs (PB) and linear semi-natural habitats: Linear Woodland (WL), Freshwater Watercourses (FW), Built Land (BL). Linear BL habitat was included due to its green lane composition. Semi-natural habitat Shannon diversity index ranged from 0.999 to 1.541 per tile.

Three groups of tiles were determined based on interquartile ranges of diversity index values. Group one (low diversity) ranged from the lowest value to the first quartile (1.174), group two (medium diversity) contained the interquartile range and group three contained the last quartile (1.420) range of diversity index values. Two diversity group distributions deviated from normality (Shapiro-Wilk normality test: group 1 $P = 0.003$; group 2 $P = 0.044$; group 3 $P = 0.284$). Kruskal-Wallis tests determined significant differences in freshwater lakes (FL) habitat cover (H= 8.91; $P=0.012$) and linear woodlands (WL) length ($H= 8.270$; $P= 0.016$) within the three

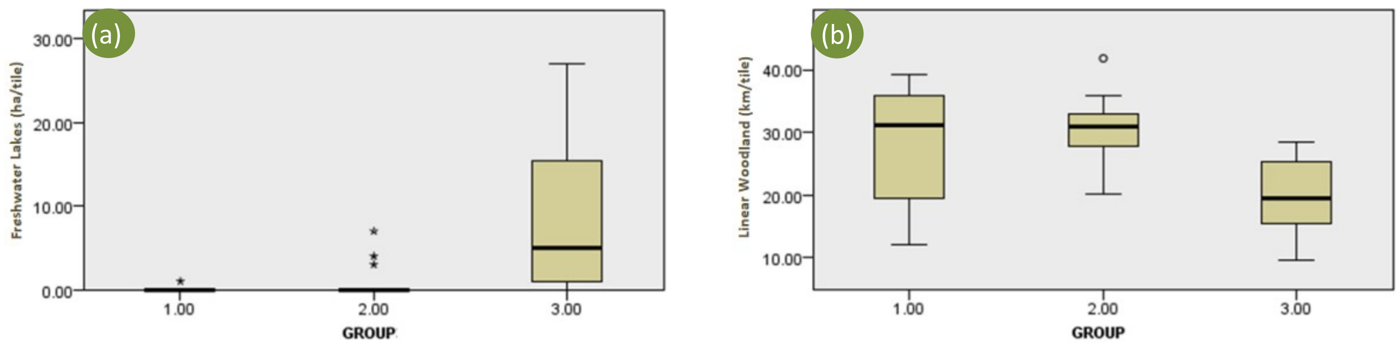

Figure 7: Effects of freshwater lakes habitat cover (a) and linear woodland length (b) on semi-natural diversity groups of tiles: 1 (low), 2 (medium) and 3 (high) along the Greenway.

semi-natural diversity groups. Bonferroni post-hoc tests indicated a difference between groups 1 & 3 (*P= 0.028*) and 2 & 3 (*P= 0.02*) for freshwater lakes habitat cover, and a difference in groups 3 & 2 (*P= 0.013*) only for linear woodland length (Fig. 7) due to excess variation in group one.

4 Discussion

Opportunities to preserve and enhance natural heritage can emerge from the development of a Greenway (Fabos 1995; Ryan et al. 2004), including targeted actions to maintain and increase ecosystem connectivity (Carlier & Moran 2019a; Carlier et al. 2019). The present paper highlights the semi-natural habitat diversity that exists within the immediate landscape following a former railway currently proposed for Greenway development. The results characterise this proposed Greenway corridor traversing a range of extensive regions of relatively high semi-natural habitat diversity and other regions composed of more intensified land use with proportionately less semi-natural habitat diversity. The development of Greenway infrastructure can potentially impose new and additional pressures to existing semi-natural habitat corridor conditions, but can also present favourable circumstances. With further analysis of remotely sensed aerial imagery, proposed European Greenway corridors can provide initiative towards potential preservation and enhancement of semi-natural habitats, with potential for international interconnectivity opportunities. Using Google Street View imagery to assist remote sensing exercises as presented in this study provides a highly accurate, cost-effective approach, ultimately contributing towards rapid assessment of image data interpretation, virtual groundtruthing procedures and the feasibility of future Greenway landscape dynamic analyses.

Although high accuracies were obtained for the interpretation of linear features in this study, it was observed during ground truthing exercises that overlap of linear habitats occurred leading to potential underestimation of remotely sensed linear habitat data. This is particularly the case for treelines overshadowing hedgerows, and for both treelines and hedgerows that can host ditches, earth banks and stone walls underneath. Habitats not sampled for accuracy were highly modified with the exception of woodland scrub and oak- ash- hazel woodland. With a collective coverage within the study area of 1.6%, their omission from accuracy analysis was considered insignificant. Overall, the accuracies for areal and linear photointerpretation of habitats came close to and exceeded that of the generally recommended remote sensing accuracy target of 85% (Comber et al. 2012; European Environment Agency 2006; Thomlinson et al. 1999; Anderson 1971). Foody (2002) notes in a review of land-cover classification that most articles observed accuracies below the recommended accuracy target. When assessing overall accuracy in remote sensing, accurate classification by chance can occur (Congalton 1991; Smits et al. 1999; Foody 2002) and a Kappa coefficient tvalue is widely recommended to measure this effect (Stehman 1996; Smits et al, 1999; Congalton & Green 2008). With high Kappa estimation and a close agreement observed between overall accuracy and Kappa estimation, this results in an 'Almost Perfect' measure of agreement between habitat classification and ground truth results (Landis & Koch 1977). Improved accuracy results could have been observed through comparison analysis of aerial imagery of summer and winter seasons- assisting in the identification of land uses such as crop cycles (Morton et al. 2011). Also, as noted in Fealy et al. (2009), the use of current field data to compare and accurately assess remotely sensed data based on older imagery can present inconsistencies due to temporal variations. This became evident during fieldwork where changes had accrued due to land management intensification since aerial imagery capture (four years previous), and where sections of railway ballast had been subsumed into larger improved agricultural grassland. Although useful for land use change predictions through change analyses, such rapid temporal changemay pose challenges to accuracy assessment in future remote sensing of fast changing landscapes.

It is likely that the combination use of Google Street View and orthophotographic analysis was a determining factor for the accuracies observed, providing a preliminary ‘virtual’ ground truthing technique further informing imagery interpretation. The use of Street View has been recommended for its low cost and extent of access from urban to rural areas for tree surveying (Berland & Lange 2017), farm scheme compliance and planning (Verhoeve et al. 2015; Erickson et al. 2013) and water quality assessment (McGarrigle 2014). The use of Street View imagery could be applied in ground-truthing to provide faster results than in-field surveying. Further use of Google Street View for remote sensing accuracy assessmentis highly recommended where Street View imagery is compatible with the study area extent. Railway corridors (including former corridors) are typically located within valley lowlands to follow routes of least inclination, and thus such corridors can often interact with substantial road infrastructure networks recorded by Google Street View interactive panoramic imagery. As European Greenways typically upcycle railway corridors, this highlights the further potential use of Google Street View imagery to survey numerous existing and future Greenway corridors. However, seasonal variation of imagery capture date along Street View routes (e.g. October, April and August 2011 during this study) can cause inconsistencies and potential misclassifications. Grassland photointerpretation using Street View Imagery can be subjective; for example, grassland habitat may appear less managed with semi- natural characteristics during winter seasons, be recently heavily grazed or be an image of grassland prior to silage mowing during the summer season.The combination of amenity (GA2) and improved agricultural grasslands (GA1) reduced improved grasslands (GA) classification accuracy due to large misclassification errors of GA2. In addition, distinction between types of semi-natural woodlands (particularly wet willow-alder-ash woodland (WN6)) and non-native woodlands proved difficult to photointerpret to Fossitt level three, as precise classification is subject to identification of specific indicator species. Nonetheless, full accuracy was achieved for non-native and 99% for semi-natural and woodland Fossitt level two classes.

Semi- natural habitat is often considered essential to maintaining biodiversity within agricultural and rural landscape contexts (Billeter et al. 2008; Tscharntke et al. 2005). Semi- natural habitat associated with less productive, marginal lands also provides a range of beneficial regulatory ecosystem services (García-Feced et al. 2015). Half (50%) of the Greenway corridor contained semi-natural vegetation cover within a wider grassland agricultural landscape setting. This is significantly higher in comparison to 14.3% average of semi- natural habitat coverage in farmlands in the South East of Ireland (Sheridan et al. 2011) where field boundaries, scrub and woodlands are most frequently recorded as habitats contributing to biodiversity. The semi-natural vegetation observed is consistent with the occurrence of semi- natural vegetation within general European agricultural settings (García-Feced et al. 2015), occurring principally within areas of extensive farming and often consisting of semi- natural grasslands and associated linear features such as hedgerows and field margins (as depicted in Fig. 8). Hedgerows comprised the most extensive of all semi- natural linear habitats, with 631 km mapped resulting in a high density of 9 km/km^2. This is considerably higher than the UK average of 2.9 km/km^2 (Barr et al. 1993), but remaining lower than ‘Bocage’- style landscapes of Brittany averaging 27.3 km/km^2 (Baudrey et al. 2000). Most Irish hedgerows were established during the 18th century for similar reasons to those in the rest of Western Europe (common land division, parcel boundaries, farm provisions etc.) and are now considered semi- natural habitat, providing extensive connectivity within the country’s landscape (Foulkes et al. 2013). European hedgerows in general are considered of high ecological and cultural value (Baudry et al. 2000; Burel et al. 1998). Threats to this extensive Greenway corridor were observed as the removal of hedgerows, improvement of grasslands and non-native conifer afforestation of marginal farmland, as identified in Sullivan et al. (2017) and Carlier and Moran (2019b). The loss of semi-natural grasslands due to land-use intensification (both for food and fibre) is increasing across Europe (European Commission 2015). A multifunctional role to preserve cultural and natural heritage therefore exists for European Greenway infrastructures, retaining extensive semi-natural grasslands where these occur (e.g. calcareous rail ballast banks, grassy verges along hedgerows and treelines, and wet grasslands in waterlogged railway cut sections in

Figure 8: Fly-over map displaying the proposed Greenway route (purple) and surrounding extensive drumlin farmland with patchwork of hedgerows, depositing rivers and small field parcels.

hills). In doing so, Greenway corridors can provide habitat diversity and refuge for associated species within wider, highly modified landscapes.

Ranges of semi-natural habitat diversities observed within the set of tiles indicates the presence of areas of predominantly intensified land use, contrasted by more extensive regions with larger proportions of semi-natural habitats. The ‘high’ diversity group of tiles differed significantly from ‘low’ and ‘medium’ diversity groups solely with an increase of lake habitat and decreasing linear woodland. The absence of other significant group interactions with habitats suggests that the semi-natural habitat composition of the surrounding landscape is relatively homogenous, principally because of dominating semi-natural grasslands, with the exception of lakelands where these occur. Despite potentially being attributed to low semi-natural habitat diversity, landscapes dominated by semi-natural grasslands provide diverse ecosystem services including cultural landscape provision, biodiversity and aesthetics (Rollett et al. 2008; Bullock et al. 2011), and as such are naturally complementary to Greenway multi-functionality. The observed reduction of linear woodland in the high diversity group of tiles may relate to a land use undergoing intensification, causing an intermediate disturbance effect and thus impacting semi-natural habitat diversity. With respect to Greenway development, this intermediate disturbance relationship highlights the potential sensitivity of such areas undergoing land-use change, with insensitive route development potentially negatively influencing previously optimal diversity-disturbance dynamics. Through applying the tile methodology approach, localised focus can be targeted to maintain particular tiles approaching maximum semi-natural habitat diversity. Where an observed loss of diversity due to intensification exists, primary Greenway objectives should focus on ecological connectivity functions to create bridging functions across such tiles - e.g. applying recommendations for the maintenance and enhancement of ecosystem connectivity (e.g. Carlier & Moran 2019a; Carlier et al. 2019).

Understanding landscape spatial characteristics is crucial to maintaining landscape connectivity and achieving sustainable development (Vogiatzakis et al. 2006). Landscape analyses identifying connectivity features typically require fine-scale data (Estreguil et al. 2016) and are usually remotely sensed to accurately identify semi-natural habitat data (e.g. Garcia-Feced 2015). Methods used in this study provided a highly- detailed classified map, and data from this study can be further analysed to determine landscape ecosystem connectivity features. This can help derive future strategic conservation actions and management protocols (Bischoff & Jongman 1993). Maintaining landscape permeability by identifying and preserving natural corridors and stepping stones can be crucial to species and ecosystems function (Jongman 2003; European Environment Agency 2011), and although significant ecosystem corridor functions can occur along European Greenways (Fig. 9), these are often undetected and unrecognised in Europe. Data gathered in this study provide an important baseline dataset that can be further analysed using landscape connectivity indices. These can be further interpreted to help quantify structural and functional connectivity of important ecosystems, informing Greenway developments to maintain and enhance important habitat patch and corridor features. Applying the habitat data in a landscape characterisation and integrating such connectivity indexes can help inform decision makers to determine appropriate actions and mitigation measures that are locally relevant in specific landscape contexts (e.g. Carlier & Moran 2019a).

6 Conclusions

The expanding European Greenway network presents opportunities to safeguard and interconnect semi-natural habitat that exists along disused transport infrastructure. This study presents remote sensing techniques enabling a detailed and effective approach to mapping Greenway corridors assisted through Google Street View imagery interpretation. Resulting high accuracies in detailed habitat classification mapping for both areal and linear habitats provided spatial data that can be further interpreted, such as in landscape connectivity and change analysis. Further research is recommended to evaluate accuracies resulting from Street View imagery photointerpretation in comparison to that of in-field groundtruthing. In this particular study area, large proportions of semi-natural habitat cover were observed to be interspersed by land-use intensification predominantly of improved

Figure 9: Aerial map of Jodoigne to Namur Greenway, Wallonia, Belgium: example of Greenway with bounding linear woodland traversing a highly intensified landscape, providing woodland habitat and potential corridor function to nearby woodland patches.

agricultural grasslands and built surfaces. These increases in intensification are consistent with trends in rural agricultural landscapes in Europe. This highlights the need for new infrastructural developments in such regions to incorporate sensitive ecological design and connectivity initiatives in order to mitigate further negative fragmentation effects of semi-natural habitat. Through informed design, development and management, Greenways can be developed as green infrastructure, ensuring continuity of disused corridors that traverse such landscapes and preserving semi-natural habitats that can exist within.

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