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Urban Green and Blue Space in Cork City and its importance to bird diversity

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Contents

Declaration

“This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism”.

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Abstract

Urban green and blue spaces are well known for providing ecosystem services in built up areas but they are also becoming increasingly important as these spaces are becoming unique ecosystems for bird diversity. The aims of this study was to investigate the importance of green and blue space in Cork City to bird diversity, through the generation of a satellite image that captures the landscape configuration of Cork City and green and blue space it contains, examine the relationships between bird diversity (richness and abundance) and landscape metrics generated using FRAGSATS and by conducting field surveys. The impact of spatial scales and how they affect species-landscape relationships was also investigated through regression analysis. Using Sentinel-2 satellite data and a maximum likelihood classification, a comprehensive landcover map of Cork City was produced with reliable accuracy. The map revealed that two thirds of the city is composed of green and blue space. The field surveys recorded 62 species in the city. The statistical analysis gathered revealed that green space was the main driver in increasing species richness and abundance, while blue space produced mixed results. The edge effect phenomenon was also found to play a key role in increasing bird diversity. The regression models produced results that revealed a diversified and varied landscape was preferable to bird diversity as the scale was increased. The impact of scale also affected how important blue space is as a connective network within the city. Overall, this study has demonstrated that urban green and blue space is intrinsically linked to bird diversity in Cork City. 40% of the species that were recorded in the field surveys are listed as species of conservation concern in Ireland, with five of these species listed on the Red list. This finding has shown how urban spaces can provide habitats for vulnerable species, and provides precedence for implementing conservation initiatives within urban areas.

1. Introduction

Urban expansion is a continuously occurring environmental issue that has replaced and fragmented natural landscapes across the world. As a result, researchers have begun to study urban green and blue space to investigate the unique ecosystems that urban areas can support, such as species that are endemic or of conservation concern that may reside in urban areas (Mortberg & Wallentinus 2000; Rudd et al 2002; Dearborn & Kark 2010; Kong et al 2010; Lepczyk et al 2017). Urban green spaces also provide the opportunity for citizens to connect with nature, witness ecological processes in action, and potentially become scientifically literate citizens who make informed decisions regarding conservation initiatives and policy (Lepczyk et al, 2017).

It is important to first define urban green and blue space (UGBS). Urban green space has been broadly defined as any public open space in an urban setting where vegetation is present (Lee et al 2015). Green spaces range from small plots of private gardens within a city to large public parks. Playing pitches, cemeteries, hedgerows and any open piece of land with vegetation can be classed as green space. Blue space is classed as anything that is visible water, which can range from a decorative pond in a public park to a river running through a city (Gledhill & James, 2008).

Throughout the literature it is well documented that both blue and green space provide benefits to urban areas, specifically ecosystem services (Fuller et al 2007; Tzoulas et al 2007; Haq 2011; Jennings et al 2016). Humans can profit from the natural environment when ecosystems function sufficiently. Dragos et al (2017), Hedblom & Mörtberg (2011) and Qian et al (2015) all mention that green spaces provide ecosystem services such as air and water purification, the regulation of climate and water cycles, noise reduction and the mitigation of the urban heat island effect. Many studies prove that UGBS also provides social, economic, recreational and mental health benefits to urban areas. Barton & Rogerson (2017) states that research has shown the potential mechanisms underpinning the positive relationship between green space and health are likely to include sensory, perceptual and immunological processes, air quality, physical activity, stress and social integration. A study by Völker et al (2017) suggested that there is a relationship between blue spaces in urban areas and an increased well-being and positive mental health. Dean et al (2011) undertook a study to see whether biodiversity improved mental health in urban areas. The results led to the conclusion that contact with biodiversity is beneficial to humans and improves quality of life. While this provides evidence that biodiversity can be beneficial to people living in urban areas, a study should be conducted to examine how important UGBS is to biodiversity itself.

The risks to biodiversity are ever increasing. A report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) found that around 1 million animal and plant species are now threatened with extinction, many within decades, more than ever before in human history (IPBES, 2019). The average abundance of native species in most major land-based habitats have fallen by at least 20% since 1900. This deterioration of life and ecosystems is directly linked to human activity, which also directly affects human well-being in all regions of the world. Urban areas have been identified as one of the main culprits in land use changes globally, which is ranked in the IPBES report as the number one driver in the changing of nature with the largest global impact. It is highlighted that urban areas have more than doubled since 1992. To help reduce the impact of urban expansion on biodiversity, the report outlines a number of nature-based solutions, such as:

- Improving access to green spaces.
- Sustainable production and consumption in urban areas
- Ecological connectivity within urban areas, particularly for native species.

This shows that in an ever-expanding urban world, UGBS can provide vital habitats and create quality ecosystems for the earth's relentlessly diminishing biodiversity.

Urban areas provide a unique set of habitats that have been created through human interactions on the landscape which can support a wide variety of flora and fauna within a city. It can be argued that human influences in urban habitats can be beneficial to bird diversity. Bird feeding is a common practise in urban areas that is of profound importance to urban bird populations (Jones & Reynolds, 2008). Tree species preferences in parks and gardens that are grown for their aesthetics, particularly flowering and berry-bearing species, also provide important food sources for wild birds. Trees species preferences have shown to be a key food resource through influxes of certain bird species to urban areas in harsh weather conditions. During the severe European winter of 2012, there was a major influx of Waxwings (*Bombycilla garrulus*) into Ireland, the UK and western continental Europe. Most sightings were recorded in suburban areas, feeding on berries off Cotoneaster (*Rosaceae* spp), Firethorn (*Pyracantha coccinea*) and Rowan trees (*Sorbus* spp) (Birdwatch Ireland, 2012). These birds are an uncommon winter visitor to these regions, particularly in Southern England, Wales and Ireland, and will arrive en masse if winter conditions are too harsh in their normal mainland European and Scandinavian wintering areas. In early 2018, there were many sightings of these species in Ireland once more, with the records coming from mainly urban areas due to the wealth of berry bearing bushes present in locations such as Dublin and Dundalk (Irish Birding, 2018). Large flocks of Redwing (*Turdus illacus*) and Fieldfare (*Turdus pilaris*) in Cork City were also reported during the snow period in early March 2018 (Irish Birding 2018). Similarly, these species migrated in search of berries for food which were readily available in the city. This shows that urban areas can be vital resources for food and shelter that is not readily available in the surrounding countryside. In this study, the focus will be centred on breeding species and summer migrants, where there is the potential to show that UGBS is important to bird diversity in the breeding season and not just during harsh weather conditions.

Dragos et. al (2017) notes that vegetation within urban areas provides nesting sites for birds while also supporting a variety of insects which in turn become a food source for many bird species. A number of bird species have also been known to adapt to the urban environment and use artificial structures for nesting sites. Peregrines (*Falco peregrinus*) are one of the main species that have swapped their natural nesting environments of cliff faces for high-rise buildings, cathedrals and churches. This bird of prey has been found to nest in cities worldwide, from smaller cities such as Cork to major global cities such as New York in the USA. The abundance of prey species such as pigeons is another major reason for Peregrines choosing cities as suitable habitat, as Caballero (2016) noted during his studies of Peregrine nesting behaviour in the cities of the Midwestern United States. Other species that have swapped coastal cliffs for urban structures include gulls, particularly in Western Europe. Studies show certain gull species have begun nesting in urban areas, such as Bristol in the UK, where Spelt

(2019) examined the use of urban habitats as nesting sites for Lesser Black-backed Gulls (*Larus fuscus*). Walls and pipes can also replace natural nesting sites such as holes in trees and river banks for woodland species such as Blue Tits (*Cyanistes caeruleus*) and Great Tits (*Parus major*) and freshwater species such as Grey Wagtail (*Motacilla cinera*) and Sand Martin (*Riparia riparia*) (Wilson & Carmody, 2011). This shows that UGBS provides food sources and suitable nesting for bird diversity.

Cork City was chosen as the area of study as it supports a wide and varied array of plants and animals. The green spaces of the city such as parks and gardens and blue spaces such as the ponds, lakes, rivers and Cork Harbour provide havens for many species more usually found in rural areas (Cork City Council, 2009). There are a number of policies that have been drawn up to help protect and manage the natural heritage and biodiversity that is present in the city. Policies such as the Cork City Development Plan 2015-2021 contains a number of suggestions or the protection of natural heritage such as identifying measures to protect and enhance the biodiversity of Cork City, to research and disseminate information on the biodiversity of the city, to promote interest, knowledge and to raise awareness of Cork City's biodiversity to the wider public. There are also policies in place to create landscape protection zones, river corridors, nature conservation designations, tree preservation orders and tree planting. The Cork City Heritage Plan 2015-2020 is another initiative to protect the city's natural heritage including bird diversity, where the plan intends to incorporate policies such as establishing a biodiversity plan working group, identification of gaps in the research and make recommendations for further research, carrying out habitat and species surveys of the city and establishing priorities and targets for biodiversity (Table 1). However, it was noted in the Cork City Development Plan that there is an issue with the lack of habitat surveys for non-designated sites and insufficient data on habitats and species to allow for ongoing monitoring (Cork City Council, 2015). This research aims to address these issues, by surveying bird diversity in Cork City across UGBS, generating current data and knowledge of the different bird species present across different habitats, which could further influence the policies that are in place for the city's natural heritage and help protect the bird diversity in the city. The information from this study could also inform the policies set out by Ireland's third National Biodiversity Action Plan 2017-2021, such as the policy of strengthening the knowledge base underpinning work on biodiversity issues, in this case, the knowledge of bird diversity in the second largest city in Ireland.

Table 1: Some of the policies and objectives in place adapted from the Cork City Heritage Plan 2015-2020 to help protect and raise awareness of the local natural heritage.

	Objective	Biodiversity Action Plan: actions to be incorporated into Heritage Plan
1	Ensure care and management of Heritage is incorporated into new plans, policies and projects as appropriate	(a) Review priorities and set targets for biodiversity in Cork City. (b) Implement the recommendations of the current research project 'Cork Lough Integrated Management Study' with regards the management and improvement of water quality and environmental conditions at Cork Lough for fauna, flora and recreation users. (c) Promote special and unique areas of local biodiversity such as Cork Lough, Blackrock Harbour and Douglas Estuary.
2	Investigate methods and resources to implement existing Heritage related plans	(a) Continue the Biodiversity Working Group and encourage participation from non-governmental bodies, private industry and other sectors.
3	Develop and implement a communication strategy for Heritage in the city	(a) Continue to update and maintain the biodiversity page on the City Heritage website: www.corkcityheritage.ie. (b) Create a slogan and identify flagship species to raise awareness of Cork City's unique biodiversity.
4	Promote and distribute existing information on Heritage.	(a) Indentifying gaps in biodiversity information through reviewing and analysing existing data. (b) Prepare a series of high quality publications on biodiversity e.g. 'A guide to enjoying the wildlife and wild places of Cork City'.

Therefore, the aims of this research can be broken down into three research questions:

- Can areas of green and blue space be identified in Cork City from satellite imagery?
- Are there relationships between bird diversity (richness and abundance) and the landscape metrics of UGBS?
- How does spatial scale impact these species-landscape relationships?

These three research questions will be answered through these following objectives:

- Classifying remotely sensed imagery collected through satellite data on Cork City.
- The conduction of field surveys of bird biodiversity within the landcover classes found through the remotely sensed imagery.
- Creating landscape metrics using FRAGSTATS at multiple scales, and combining these with the field survey data
- Performing regression analysis using this dataset to interpret the relationships between bird diversity and UGBS and how spatial scale impacts these relationships.

2. Literature Review

This literature review will cover the different elements involved in studying UGBS and bird diversity in urban areas. The review will begin by examining the use of remote sensing in urban green and blue space studies, then explore how bird surveying has been undertaken within urban areas, and finally investigate the role of connectivity and how GIS and statistical methods can analyse UGBS and bird diversity.

2.1 The use of remote sensing in UGBS studies

Remote sensing is a common tool used in the identification and classification of UGBS. It has been used as a method of uncovering 'invisible' green space patches in the urban framework which can be important for ecological aspects such as connectivity. For example, a study carried out by Feltynowski et al (2018) compared the land cover data acquired for Lodz, Poland between four different datasets. These datasets consisted of Open Street Map, the Urban Atlas, a local landcover/land-use dataset created exclusively for Poland (BDOT) and Landsat satellite imagery. The landcover maps created by each dataset were then adjusted into green space categories in order to compare them using QGIS. The resulting maps from the four datasets revealed that the local BDOT dataset had the highest area of green space with 61%. The Open Street Map yielded the lowest result, with a share of 32.3% green space. The Landsat satellite imagery had a lower green space share result of 52%. Despite the lower green space percentage, Feltynowski et al (2018) noted that while the BDOT dataset was the most comprehensive for total urban green space in the city, the 30m spatial resolution acquired from Landsat satellite imagery included the aforementioned 'invisible green space' that the BDOT data did not depict, particularly the smaller green space patches in the city centre of Lodz. The identification of invisible green space was an improvement on other datasets, but in respect to the satellite imagery used, it was concluded that a finer spatial resolution image would create a more quality and accurate image.

Landsat data generally ranges from medium (30m) to low (60m) resolution and has been used by many researchers in classifying UGBS. Dragos et al (2017) used Landsat to detect vegetation in Bucharest and compare changes in vegetation cover within the city for the years of 1991 and 2006. The results from comparing the two images revealed the rapid urban expansion of Bucharest. Their analysis of a combination of the 321 spectral bands revealed that there was more vegetation, particularly of agricultural land, in 1991 and an increase in built up surfaces in 2006. Furthermore, the authors believed that the satellite imagery represented a viable resource for information in evaluating and comparing changes to urban landscape pattern over time. Similarly, Rafiee et al (2009) also used 30m resolution Landsat data to assess green space changes in Mashad City, Iran from 1987 against 30m resolution data acquired from the Indian Remote Sensing (IRS) satellite in 2006. Upon comparing the results from both satellite images, they found that urban green space had decreased significantly over the time period with a total decrease of 30.8km^2 of green space lost for the study area. The extent of temporal Landsat data, running since 1972, makes it a key product for detecting long term changes in vegetation, in this case, proving that rapid urban expansion has occurred in the Mashad City area from 1987-2006. The fine spatial scale of Landsat data (30m), coupled with the long temporal series means that the data is useful for detecting fine scale changes in highly heterogeneous and complex structures of urban areas (Kabisch et al 2019).

Despite the potential of Landsat, there are conflicting opinions on the accuracy levels of Landsat data compared to other high-resolution satellites. Van et al (2017) used ALOS (Advanced Land Observation Satellite) of 10m spatial resolution and Landsat data to determine land cover distribution changes between 2007 and 2017 in Nha Trang, Vietnam. While both sensors highlighted the increase in built up areas and the decrease of green space over the ten years, with both sensors attaining high accuracy values upon conducting accuracy assessments on the maximum likelihood classifications images, with a total accuracy of 90.43% for the ALOS image and 91.21% for Landsat and kappa coefficients of 0.89, showing that both sensors performed as well as the other in displaying the city's landcover composition. Conversely, Zhou et al (2018) stated that Landsat data underestimated the cover of green space in their studies of nine cities in China. The results showed that the percent cover of urban greenspace mapped from the Landsat TM and the Spot-5 data (2.5m spatial resolution) was very different. According to the Landsat data, the mean percent cover of urban greenspace for the nine Chinese cities stood at 20.44% in 2005. In contrast, the mean percent cover of urban greenspace derived from the SPOT-5 data was much higher than that revealed by the 30m resolution Landsat data for all the nine cities, with a mean of 34.48% in 2005. Haas & Ban (2018) also noted that Sentinel-2 had 5 to 6% higher accuracy then that of the lower resolution data of Landsat when measuring the landcover percentage of Beijing, China. This shows why Landsat is often avoided as a sensor for urban green space studies as the resolution is not fine enough to produce accurate findings.

It also shows why accuracy assessments are an important tool for validating classified maps and images. The overall accuracy of a classified image compares how each of the pixels is classified versus the definite land cover conditions obtained from their corresponding ground truth data. Producer's accuracy measures errors of omission, which is a measure of how well real-world land cover types can be classified (Rwanga & Ndambuki, 2017). The kappa coefficient has become one of the standard means of assessment of image classification accuracy. KAPPA analysis yields a Khat statistic (an estimate of KAPPA) that is a measure of agreement or accuracy (Congalton, 2001). A classified image can determined as fit for further research depending on its kappa coefficient result from an accuracy assessment (Table 2).

Table 2: The strength of a classified images accuracy can be based off its kappa coefficient value in an accuracy assessment. (Source: Rwanga & Ndambuki, 2017)

Kappa coefficient	Strength of agreement
<0.00	Poor
0.00 - 0.20	Slight
0.21 - 0.40	Fair
0.41 - 0.60	Moderate
0.61 - 0.80	Substantial
0.81 - 1.00	Almost perfect

ALOS and SPOT-5 sensors were used by Wang et al (2018) when mapping green space change between 2005 and 2009 in the core city area of Beijing. The fine spatial resolutions of 5-2.5m obtained from both sensors in panchromatic mode produced detailed information on the landscape change of the city over time at a patch level. The results showed that 24.20% of green space patches in 2005 were totally lost. However, most of these patches were very small, with mean patch size of only 0.03 ha, accounting for 0.91% (or 607 ha) of the total area. The results also revealed 36.63% of the green space patches in 2009 were newly created, with a total area of 821 ha and the mean patch size of 0.06 ha. Similar to the lost green space patches, newly created patches tended to be very small. Qian et al, (2015) conducted a similar study when detecting landcover change between 2005 and 2009 with the same sensors but included the whole city of Beijing as the study area. The results revealed that there was an increase in the spatial pattern of green space from 2005 to 2009, with an increase of 5.45% from 22.57% to 28,01%, indicating the usefulness of ALOS and SPOT-5 as an adequate resource for evaluating the dynamics of green space changes in rapidly expanding urban areas like Beijing.

Subsequently, sensors such as ALOS and SPOT are preferential due to their increased accuracy primarily driven by their finer spatial resolutions. However, these are commercial satellites, and so they are not freely available, unlike Landsat data. Furthermore, the ALOS satellite only ran for 5 years since its launch in 2006, meaning there is only data available from those years. ALOS-2 replaced it in 2014, but there is still a temporal gap of three years between both satellites.

Other fine-resolution satellite data that have been used in urban green space mapping include Worldview 2 and Quickbird. For example, Giezen et al (2018) used these sensors when mapping net land use change in Amsterdam from 2003 to 2016. The results from this study showed that Amsterdam had lost 11% of its green space over the time period. This was a particularly interesting find as it was pointed out in the study that a policy in the city's Green Agenda programme was to increase green space in the area in efforts to prevent flooding, when in reality, the efforts were not able to keep up with the rapid urban expansion. Worldview-2 has the highest spatial resolution available at 0.43m, however, it is intended for commercial use and is not freely available. Quickbird also has a high resolution of 0.64m but does not offer any current data as it was de-commissioned in 2015. While these are commercial products, Chen et al (2018) used a civilian satellite, Gao-fen 2, to successfully create social functioning maps of urban green spaces in Beijing. While it has a high spatial resolution, and is freely available, Gao-fen 2 is only available to Chinese citizens, limiting the use of its data at an international scale.

Given the spatial, temporal, and commercial limitations of the previous satellites, a fine-resolution satellite that is freely available in Europe is Sentinel-2. This satellite has been used in multiple studies in evaluating green space (Rosina & Kopecka 2016; Kopecka et al 2017; and Kabisch et al 2019). Kopecka et al (2017) used Sentinel-2A data to analyse urban green spaces in three cities in Slovakia. The results demonstrated the value of Sentinel-2A data for mapping built up areas in the context of ecosystem assessment and mapping, by allowing the authors to compare and contrast the green space patterns in the three cities of Bratislava, Trnava and Zilina. Similarly, Vatseva et al (2016) also used Sentinel 2-A data in mapping urban green spaces in Bulgari and Slovakia. The Sentinel-2 imagery for the cities of Sofia and Bratislava allowed the study to compare the green and blue space types in each city, where it was found that Sofia had the higher percentage of water bodies and green space in residential areas, while Bratislava had a significantly higher amount of pastures and cropland. It was concluded that the use of Sentinel-2 imagery provided reliable geoinformation and produced quality high-resolution maps for UGBS. Both Vatseva et al (2016) and Kopecka et al (2017) utilized the maximum likelihood classification method to characterise the different landcover types in each of the studied cities. Sentinel-2 was also one of the multiple sensors used by Kabisch et al (2019) to detect landcover change in Leipzig, Germany. The study combined the data collected from Landsat, Sentinel-2 and Rapid Eye to detect land cover change through a normalized urban greenness algorithm based on the Normalised Difference Vegetation Index (NDVI). NDVI was used to create maps on the changes in the "greenness" of Leipzig's districts between 2005-2017.The Sentinel-2 data used in the study was praised for delivering valuable data to detect urban greenness state and development over seamless periods of more than ten years.

Rosina & Kopecka (2016) noted the positives of using Sentinel-2 data included the wide swath, frequent revisit time, spectral richness and the free availability data. The authors believed that Sentinel-2 was an adequate satellite for use in investigating urban green space mapping for future researchers. Haas & Ban (2018) also highlighted the free data accessibility of the Sentinel family and commended the high temporal and spatial resolutions of up to 10m. However, Rosina & Kopecka (2016) also found an issue with cross-pixel spectral contamination in Sentinel-2 data. This occurs when a class has a higher reflectance value than another class (e.g. woodland has a higher reflectance than water) dominates a particular area where it is overestimated in the classification process. This issue occurred with the Sentinel-2 data due to its spatial resolution of 10m, where there may be multiple surfaces in 10×10 pixel sizes such as along river edges. This issue can lead to more fragmented green spaces in urban areas being underestimated and also leads to less overall accuracy when classifying urban green space. This loss in accuracy can then affect the results in the statistical analysis in aspects of landscape ecology such as connectivity of green space.

There are other forms of remote sensing that have been used in urban green space studies. One such technique is LiDAR imagery. Casalegno et al (2017), used waveform LiDAR imagery in his studies of improving models of urban green space when studying the three towns of Bedford, Luton and Milton Keynes in England. A LiDAR instrument with waveform capabilities was placed under a low flying aircraft and a standard digital camera. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges of variable distances to the Earth. The LiDAR data for the three towns found overall underestimation biases in green cover increased as the spatial resolution of the land cover product was coarsened. The three datasets also allowed for the creation of tree cover maps, where Milton Keynes was found to have the highest percentage of tree cover over the two other towns. The study concluded that waveform LiDAR has a key role to play in estimating important quantitative metrics of urban green infrastructure. This type of remote sensing is becoming more recognised as a form of geospatial surveying, particularly with NASA's Global Ecosystems Dynamics Investigation (GEDI) mission becoming operational in 2019. However, Casalegno et al (2017) warn that there are computational challenges in translating the waveform signal into voxel data due to the complex issues of multiple scattering with waveform LiDAR from scattering and signal attenuation. There are also high economic costs in attaining and processing data, particularly with the availability and cost of low flying aircraft.

Unmanned Aerial Vehicles (UAV) are a recent addition to the techniques for UGBS mapping. Liang et al (2017) used UAV's to assess the three-dimension green quantity of urban green space in the PWP park in eastern Shanghai, China. A mosaic of the images collected from the UAV created an orthophoto map of the park. A detailed landcover map of the park was then created in ESRI ArcGIS by interpreting the UAV images with the PWP greening reformation project in 2009 and field surveys from 2013. The use of the UAV was instrumental in creating a detailed high-quality image at such a localised scale. Feng et al (2017) used a small UAV for urban vegetation mapping in Lishui, China. This paper attempted to propose an accurate hybrid method by combining the Random Forest classifier and texture analysis for mapping vegetation on a heterogeneous urban landscape based on UAV remote sensing. The ultra-high- resolution images of 7 cm acquired by the UAV provided excellent detail for urban vegetation extraction and highly detailed maps of the landcover in different parts of the city. Feng et al (2017) concluded that UAV's are an outstanding resource for detailed vegetation monitoring in urban areas. Mozgeris et al (2016) simultaneously acquired hyperspectral and colour-infrared (CIR) images and then tested for their potential to identify deciduous tree species and estimate tree health in Kaunas, Lithuania. Six urban deciduous tree species were derived in the results using tree crown level statistics, extracted from 16 visible-near infrared spectral band hyperspectral images. The accuracy in identifying the tree health condition classes using fused hyperspectral and CIR crown level image characteristics ranged from poor to moderate. Horse chestnut (*Aesculus hippocastanum*) and Small-leaved lime (*Tillia cordata*) were identified with overall classification accuracies of 74.5 and 71.9% respectively. It was concluded that the hyperspectral images attained from the UAV resulted in excellent tree species identification over the CIR images and have the potential to increase in performance if integrated into other studies on the city of Kaunas.

UAV's have great potential for providing ultra-high spatial resolution as outlined in these respective studies. However, they can be financially costly and permission must be sought for the use of UAV's, especially in urban areas. A license is also needed for the use of UAV's in most cases around the world. In Ireland, a UAV must be registered with the Irish aviation authority and an exam must be taken before a license will be granted. UAVs are also banned from flying within 5km of an airport, restricting the use of a UAV in some parts of Dublin and Cork City, the two largest cities in Ireland.

Another method that has been used in the literature is the use of Google street maps in assessing street-level urban vegetation. Li et al (2015) used the street maps to assess street-level vegetation in Manhattan, New York where it was possible to identify and locate tree species within the study area at ground-level. This is a great way of assessing a study area at a very local level which offers great ground-level detail of vegetation along streets and roadways. However, this can be time consuming when looking at a larger urban scale and Google street view is limited to roads and so cannot be used to accurately assess a full classification of urban green space in an urban area (e.g. private gardens).

A common theme in this review is of the lack of blue space being mentioned in studies of UGBS in urban areas. The term 'green space' has been commonly applied to all open natural and semi-natural areas in urban environments, including blue spaces (Gledhill and James 2008). This term can be misleading, as blue spaces are often considered as a proportion of urban green spaces. There have been very few studies focusing on blue spaces in urban areas, but studies have used remote sensing when studying blue spaces such as rivers. Langat et al

(2019) monitored river dynamics using Landsat data on the Tana River, Kenya. Using Landsat images from 1975, 1986, 2000 and 2017, manual and automatic digital processing procedures using GIS were applied to visualize and quantify the spatial and temporal changes on the Tana River. The results exhibited dynamic behaviour in terms of erosion, deposition and anthropogenic activities. They revealed that meandering, straightening, and abandonment had characterised erosion and deposition of the river channel at lower reaches in more recent years. The information gathered from this research was seen as crucial for understanding river evolution characteristics and aiding in planning and management at the lower reaches of the river network which had remained poorly understood.

Luck et al (2010) also used Landsat data to examine the physical complexity of North Pacific Rim rivers to assist wild salmon conservation. The Landsat data used in this study were assembled from a database of 1990s-era Landsat 4 and Landsat 5 acquisitions. The data was used to classify open water and vegetated areas, which were then used to delineate the main and side channels of river flow. The results from this were then used to create a database of landscape metrics that ranked the rivers in relation to potential salmon productivity. The resulting database was then systematically ranked by performing a PCA model on 1509 catchments. It was concluded that the resulting database aided the objective of providing a technique to efficiently prioritize the allocation of funding and resources towards salmon management and conservation across Alaska, North-western USA and the Kamchatka region of Russia. Both of these studies show that remote sensing can be useful in studies regarding spatial and temporal patterns of rivers. However, these studies focused on rivers at a coarse scale.

The literature shows that there are many different options for using remote sensing technologies in UGBS mapping. Many studies have been undertaken in urban areas using remote sensing to examine landscape changes over time, and to characterise the different landcover types in a study area. A fine spatial resolution is essential for UGBS mapping and Sentinel-2 is seen as the best option due to its free availability. While green space has been extensively covered in urban studies, the species-landscape relationships from urban green and blue spaces has often been overlooked. Scale has also regularly been neglected as a potential factor in determining the true importance of green space to biodiversity. There are also very few studies that have truly examined the potential importance of blue spaces on biodiversity in urban areas in terms of connectivity and conservation.

2.2 Habitat connectivity in urban areas

Connectivity is a key issue in the overall heterogeneity of urban ecosystems and species diversities. Connectivity is the degree to which habitat for a species is continuous or traversable across a spatial extent (Andersson, 2006), allowing individuals to move freely between habitats. Andersson (2006) believes that connectivity can be seen from two aspects, structural connectivity, such as the continuity of habitats, and functional connectivity, where organisms can move between patches. Due to the patchy nature of green and blue space in urban areas, the availability of green corridors can be seen as an essential connective link in both structural and functional connectivity. Lepczyk (2017) notes that networks of urban green spaces such as corridors may provide passage through the urban matrix, and when they are plentiful and in close proximity to one another, these corridors have the potential to lessen the risk of sink habitats in urban areas. Cases that support the importance of green space corridors can be found in New York where a narrow linear patch of green space of 40m width at Long island Motor Parkway helped to increase the gene flow between White-Footed Mouse (*Peromyscus leucopus*) populations (Munshi-South, 2012).

The importance of green space corridors as an aspect of connectivity was investigated by Mörtberg & Wallentinus (2000) in their study of red-listed forest bird species in Sweden. The forest remnants and network of green space corridors of Stockholm and its surrounding suburbs were assessed for their presence of red-listed forest species, which would show that the urban green space network provided habitat quality that could support these target species. Field surveys were undertaken at 67 sample sites within natural vegetation, both within and outside of green space corridors. Seven of the national Red-listed forest bird species were recorded in the sample sites (Honey Buzzard (*Pernis apivorus*), Goshawk (*Accipter gentillis*), Stock Dove (*Columba oenas*), Black Woodpecker (*Dryocopus martius*), Lesser Spotted Woodpecker (*Dryobates minor*), Nutcracker (*Nucifraga caryocatactes*) and Hawfinch (*Coccothraustes coccothraustes*)). Species placed on a national Red-list represent species of the highest conservation concern in a country. The green space corridors were seen as key to the connectivity and quality of habitats in the area. The results showed that conservation efforts for these species in urban areas can be developed through the design of urban green space corridors where treating mature and decaying trees along with damp forests (habitats preferred by these species according to the study) as valuable resources for these species. Through this, guidelines to assist the necessary stakeholders in urban green space corridor planning and management can be developed.

Bierwagen (2006) investigated how urbanization interacts with the initial amount and aggregation of habitat to change dispersal potential, restoration potential, and the risk of spatially extensive disturbances. This was examined through the simulation of natural landscapes using a multi-fractal neutral landscape model (NLM). A neutral landscape model states that in the absence of specific landscape processes that affect the distribution of landcover, the number, size, and shape of patches will change as a function of the fraction of landscape occupied by the landcover type of interest (Gardner et al, 1987). The factorial set of simulated landscapes were then subjected to habitat loss through the overlaying of 66 different urban areas in the USA, using data from the National Land Cover Database (NLCD). The landscape metric of CONNECT was used, as it measures the percentage of all habitat patches by calculating all possible connections between patches given a distance less than or equal to the dispersal distance that is being measured. CONNECT assessed the magnitude and direction of changes in the range of dispersal distances, illustrating that the relationship between habitat loss and connectivity loss is non-linear and subject to interactions between the spatial patterns of urban morphology, dispersal capabilities and habitat distribution. While the results showed that more aggregated or continuous habitats are more vulnerable to habitat loss, the approach could be used conversely to identify where connectivity could be restored to particular habitats through the placement of green space corridors or stepping stone habitats. There is also the implication that any conservation planning in urban areas regarding connectivity should consider the historical habitat distribution when evaluating the changes that have occurred through urban expansion and subsequent habitat loss.

Another method that is often used to investigate connectivity is the use of landscape metrics (Table 3). Landscape metrics are measurable units of landscape composition and act as a surrogate for change, thus allowing for the description and quantification of spatial patterns and ecological processes over time and space (Turner et al 2001). For example, Li et al (2015) used landscape metrics to analyse the 2005 green space system against the planned system in 2020 in Nanchang, China. A green space distribution map, urban green space system planning map, present layout of urban traffic, and an urban traffic map of Nanchang from 2003-2020 was used in the study. To analyse the landscape pattern of the city, the landscape metrics such as total class area (CA), landscape shape index (LSI), Shannon's diversity index (SHDI), Euclidean nearest neighbour distance (ENN) and connectivity (CONNECT) were implemented in FRAGSTATS software. The results showed an expected increase in the LSI, SHDI and CONNECT landscape metrics between the 2005 and 2020 green space systems. While these are positive signs for the planned green space system in 2020, the patch density (PD) was also analysed and the results demonstrated an increase in patch density at a landscape level, which means the landscape would become highly fragmented and reduce the health of urban ecosystems. The study concluded that a robust ecological network would help to enhance the connectivity in the Nanchang area and should be considered in the green space planning process for 2020 and beyond. This study also highlights that it's important to consider multiple landscape metrics, and that while certain metrics may have a positive relationship on variables such as species richness or connectivity, others may also create a negative relationship. Scale can also play a part in influencing the positive and negative relationships between landscape metrics and the dependent variables.

There are many different ways that researchers have assessed connectivity in ecological studies. NLM's are an option for exploring connectivity. Graph theory has also been used to study connectivity (Minor & Urban, 2008) but is a complex procedure that can be difficult to understand. Landscape metrics are a clear favourite that is used throughout the literature. For connectivity in particular, the CONNECT function from FRAGSTATS is a reliable metric that can be run in models against habitat variables to assess connectivity in urban areas and at a multiple scale level.

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Table 3: The landscape metrics that were used in this study.

Metric	Description	Equation	Notes
Total Area (CA)	equals the sum of the areas (m^2) of all patches of the corresponding patch type.	$CA = \sum_{j=1}^{n} a_{ij} \left(\frac{1}{10,000}\right)$	aij = area (m2) of patch ij.
Percentage of landscape (PLAND)	equals the percentage of the landscape comprised of the corresponding patch type.	$PLAND = Pi = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$	P_i = proportion of the landscape occupied by patch type (class) i. a_{ij} = area (m^2) of patch ij.
Total Area (TA)	equals the sum of the areas (m^2) of the landscape.	$TA = A\left(\frac{1}{10,000}\right)$	aij = area (m^2) of patch ij.
Connectance Index (CONNECT)	equals the number of functional joining's between all patches of the corresponding patch type.	$CONNECT = \left[\frac{\sum_{i=1}^{m} \sum_{j \neq k}^{n} c_{ijk}}{\sum_{i=1}^{m}\left(\frac{n_i(ni-1)}{2}\right)}\right]$	A = total landscape area (m^2).
Contagion (CONTAG)	is minus the sum of the proportional abundance of each patch type multiplied by the proportion of adjacencies between cells of that patch type.	$CONTAG = \left[1 + \frac{\sum_{i=1}^{m} \sum_{k=1}^{m}\left[(Pi)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right] * \left[\ln(Pi)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)}\right](100)$	P_i = proportion of the landscape occupied by patch type (class) i. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the double-count method. m = number of patch types (classes) present in the landscape, including the landscape border if present.
Proportion of Like Adjacencies (PLADJ)	equals the number of like adjacencies involving the focal class, divided by the total number of cell adjacencies involving the focal class; multiplied by 100 (to convert to a percentage).	$PLADJ = \left(\frac{\sum_{i=1}^{m}(gii)}{\sum_{i=1}^{m} \sum_{k=1}^{m}(gik)}\right)$	g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the double-count method. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the double-count method.
Patch Cohesion Index (COHESION)	equals 1 minus the sum of patch perimeter (in terms of number of cell surfaces) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage.	$COHESION = \left[1 - \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{n} p_{ij} \sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1}(100)$	p_{ij} = perimeter of patch ij in terms of number of cell surfaces. a_{ij} = area of patch ij in terms of number of cells. A = total number of cells in the landscape.
Shannon's Diversity Index (SHDI)	equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.	$SHDI = -\sum_{i=1}^{m}(P_i * lnP_i)$	P_i = proportion of the landscape occupied by patch type (class) i.
Simpson's Diversity Index (SIDI)	equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared.	$SIDI = 1 - \sum_{i=1}^{m} P_i^2$	P_i = proportion of the landscape occupied by patch type (class) i.

2.3 Ecological surveying in urban areas

Biodiversity is the variety and variability of life on Earth. One of the best ways to evaluate the health of biodiversity in an urban area is by assessing its bird diversity. Birds are a good indicator as they are sensitive to habitat change. Birds are easier to survey than most animals, and a high or low bird diversity in an urban area provides an insight to how healthy or poor its biodiversity is. There are two distinct different approaches to bird surveying in urban areas. Firstly, there is the methods of citizen science (or crowd-sourced data) and secondly, there is the standardised method of surveys in multiple locations in a study area.

Citizen science has been known to be a successful approach in collecting data of bird species. For example, McCaffrey (2005) notes several large-scale bird-monitoring projects in the United States of America, such as the Breeding Bird Survey (BBS), Christmas Bird Count (CBC), and Project FeederWatch (PFW), where the involvement of citizen scientists in these projects provided agencies with data that allowed them to generate detailed distribution maps for species throughout the study region and monitor changes in bird populations over time (Root, 1988; Sauer, 2003).

Snäll et al (2011) evaluated the potential of a nationwide citizen-based bird survey against the standardised national bird survey in Sweden. The Swedish Bird survey which was conducted from 2001-2009, was a standardised survey undertaken across the country where species were recorded once a year at chosen sites in the months of May and June during the breeding season. The participants were skilled amateurs at bird identification and professional ornithologists. They compared this data from the Species Gateway, a citizen-based survey that began in 2000 where anyone could submit their sightings. This report would include the species type, location, number of individuals and their behaviour. Upon comparing both sets of data, it was noted that there was a positive relationship between the datasets of the Swedish Bird Survey and Species Gateway, leading Snäll et al (2011) to believe citizen-based surveys should not be disregarded as a potential avenue for monitoring population changes and long-term trends. However, a potential weakness was seen that citizens may neglect to submit reports of certain species ('everyday' common species like pigeons) or may lack the necessary knowledge of where or when to observe certain species which can skew and limit data gathered.

Other benefits of incorporating citizen science into ecological research are not limited to the quantity of data that can be collected. Citizen science projects can also benefit the volunteers themselves. The results of Snäll et al (2011) study showed that citizens participating in these surveys can gain experience in making observations, identifying different species and participating in a scientific study. It could also inspire and provoke citizens to act and try to help conservation initiatives in their own local areas. A key limitation in bird surveying in urban areas is the restrictions of private land where surveys cannot be conducted such as in gardens and disused sites with no permitted access. This is where citizen science offers a solution for this issue, where, for example, members of the public can partake in surveys in their own garden or private land where a researcher would be unable to enter.

Another example of a successful citizen science project which positively impacted the studied area in the long term can be found with Turner (2003) who organised a citizen-driven bird survey in Tucson, Arizona (known as the Tucson Bird Count). Skilled observers in bird identification were recruited through the Tucson Audubon Society newsletter, a regional birding e-mail server, and through personal communication. Participants used the bird counts website to view the study area map, adopt a route and register. Each participant received a detailed roadmap (letter size) of their route(s), GPS co-ordinates of each site, and survey forms. The results were submitted via mail or an online version of the survey form. Participants would follow a survey protocol (5-minute time period, all birds seen or heard recorded, surveys take place 30 minutes before sunrise and 4 hours after sunrise). Eighty-one citizens participated in the first year of the survey, with 78 undertaking the survey in the second year. The results of the survey allowed the author to create distribution maps of the different species and species richness and abundance was calculated. Since its inception, the Tucson Bird Count has had a high recognition in the Tucson community. As Turner explains, that with large sections of urban areas being private, successful efforts to sustain nature in urban areas will require communication of results and recommendations to the public.

The Garden Bird Survey is another popular citizen-based survey that takes place nationwide in Ireland. The survey is an ongoing project hosted by Birdwatch Ireland and takes place annually for thirteen weeks between December and February since 1994/95 (Crowe, 2005). The main aim of the survey is to monitor the number and diversity of birds in rural and urban gardens of Ireland. The participants in the survey are required to record the peak count of each species present in their gardens in each of the thirteen weeks. The submitted results from the entire country help track large-scale movements of wintering garden birds in Ireland (Crowe, 2005). The survey has increased in participants over the years, with individuals coming from a wide range of backgrounds including schoolchildren as well as amateur and professional birdwatchers, reflecting a growing popularity in the programme and an increase in environmental awareness (Crowe, 2005). In recent years, the surveys have collected significant data during winters that experience a period of harsh weather such as in the winter of 2017/18. Ninety-one species were recorded during the survey, a joint highest for the year of any survey (Burke, 2018). Many species not normally associated with gardens such as Meadow Pipit (*Anthus pratensis*) and Lapwing (*Vanellus vanellus*) were recorded due to the heavy snow period which forced these species out of their normal habitats in search of food. There was also an increase in the number of thrushes recorded during the week of the snow with five times as many Redwing and Fieldfares recorded during the period and a 50% increase in the number of Song Thrushes (*Turdus philomelos*) recorded in gardens. As these species are ground-feeders, they took advantage of gardens that may have been cleared of snow or from participants leaving food out such as apples (Burke, 2018). Citizen science projects like this one and Turner's (2003) present opportunities for community-based conservation and other collaborative efforts. This shows that researchers can work together with the public and gather vital information that can be passed on to the necessary stakeholders that, in turn, can help in conservation efforts of bird diversity in urban areas.

A limitation of citizen-based surveys is the potential issues of participants not having the required knowledge in the necessary field. For instance, Turner (2003) had to discard 18 sites in the first year of the Tucson Bird Count as the surveyors had not met the requirements of the survey protocol or were not as skilled at bird identification as first believed, resulting in a loss of data. Snäll et al (2011) also indicated a potential weakness in the Species Gateway surveys where citizens may have neglected to submit reports of certain species ('everyday' common species like pigeons) or may have lacked the necessary knowledge of where or when to observe certain species which can skew and limit the data gathered.

An alternative to citizen science surveys is the point count method. Melles et al (2003) carried out 285 bird surveys across the city of Vancouver, Canada to evaluate the association of urban bird diversity with landscape complexity in the city. The results from the surveys identified 48 species that were then grouped into their respective habitats types in which they were detected. This allowed for the analysis of bird species-habitat relationships. Other studies that have used the point count method include Fuller et al (2008) when surveying bird abundance and richness in the English city of Sheffield to predict whether garden bird feeders were affecting the structure of bird assemblages in the study area. The bird surveys, combined with their predicted distribution of bird feeding in different neighbourhood types through questionnaires, were key to their findings that bird feeders have little influence in the overall assemblages of avian species in Sheffield. A single-visit point count method was used by Jokimaki & Suhonen (1998) where the authors visited multiple town and cities across Finland to monitor the distribution and habitat selection of wintering birds in urban environments. The surveys helped the authors to deduce that human factors such as putting out feed were as important as natural factors in the distribution of bird species in the urban areas studied. The point count method is a widely used technique, as evident by the large number of studies that have adopted it (Marsden, 1999; Hostetler & Main, 2001; Alldredge et al, 2007; Volpato et al, 2009; Nalwanga et al, 2012)

Both citizen science and standardised point count surveys are viable methods for bird surveying in urban areas. Citizen science surveys provide an opportunity for local people to participate and interact with studies that affect their local area while also raising awareness of the local natural heritage and the potential conservation efforts that are required. However, an individual can be weighed down by the management of excessive data collection and the potential issue of finding citizens with the required knowledge to participate and contribute positively to the surveys. While the point count method will create less data than from citizen-based surveys, it offers a potentially cleaner sampling structure and a more robust and manageable form of data collection than collecting survey results from multiple participants at different times and days. It also allows for the monitoring of specific habitats which is a key part of this study. After these surveys are completed, the next step is to perform the correct analysis to evaluate the impact of UGBS on bird diversity.

2.4 Ecological Modelling Methods

2.4.1 Statistical Analysis

Ecological modelling is often needed when evaluating or examining landscape and ecological patterns and processes. Three components are needed for statistical modelling, an ecological model concerning the ecological theory to be used or tested such as connectivity, a data model concerning the collection and measurement of the data, and a statistical model concerning the statistical theory and methods used (Austin, 2002).

To evaluate patterns of bird diversity and habitat use in mixed-vineyard matorral landscapes in Central Chile, Steel et al (2017) employed a boosted regression tree (BRT) analysis with point count data and landscape metrics. BRT models consist of regression trees where simple models build relationships between predictive and response variables using recursive binary splits and ignoring non-informative predictors. Boosting combines regression trees based on residual deviance to improve the predictive performance (Elith et al, 2008). BRT models were constructed for each individual species in the dataset and were run using a binomial error structure with presence/non-detection of a species at a point as the response variable. The models were successfully run for 15 species present in the study. The results showed associations between certain species and landcover types, with most species occurring in remnant habitats and ecotones rather than in the large vineyards that occurred in the study area. The models also help identify that landscape composition and patch shape, which were some of the landscape metrics analysed in FRAGSTATS earlier in the study, as being important factors in species habitat use.

There are many different statistical methods that have been implemented into ecological studies. Another model type used by Geary et al (2013) involved principal component analysis (PCA) modelling. This method of modelling uses orthogonal transformations to convert a set of observations of possibly correlated variables into a set of values of uncorrelated values or principal components. Maxent models were also implemented into this research. This method expresses the probability distributions where each grid cell has a predicted suitability of conditions for a particular species of interest, and is a helpful tool for measuring species distributions. Both of these model techniques were used in a study investigating the relationship between habitat and Black Grouse lek size and growth within two scales, 0.2km and 2km. Habitat metrics around leks were condensed into two composite axes using PCA modelling. These consisted of proportions of improved grassland, grazed moorland, wet moorland, scrub moorland, developed areas and roads/deciduous woodland, grouse moor and open canopy/ mixed woodland habitat types along with habitat richness, elevation and slope. Relationships were assessed by relating PCA axis scores to lek size and growth using Spearman's rank correlation analysis. Scatterplots were then used from the PCA axes and converted to 4×4 grids displaying lek size at each of the 16 combinations of the two PCA axes. The results showed a complex relationship between habitat and lek size and growth. Landscapes with large or productive leks were found to be a result of more than one combination of habitats. The results from the maxent and PCA models demonstrated that there is flexibility for designing landscapes in Black grouse conservation which can aid the landowners in prioritizing habitat combinations that are economical and practical while still being beneficial to the Black Grouse population in Scotland (Geary et al, 2013).

Another study that utilized PCA models can be seen in the assessment of the landscape and ecological quality of urban green spaces in the compact city of Hong Kong (Tian et al, 2013). A PCA analysis was carried out with varimax rotation to convert a set of possibly correlated landscape indices which were characterized and analysed previously using FRAGSTATS, into a set of values of linearly uncorrelated variables (principal components) and then quantifying the weight of each variable using SPSS software. The green spaces in the study area were simulated by summarising the multiplication of the eigenvalue (weight) of each component by the loading values (S) of the corresponding variables. The most notable component extracted consisted of 49.4% variance in initial eigenvalues. Edge Depth (ED) and Patch Density (PD) played negative significant roles to Area-weighted mean patch size (AWMPS), while Area-weighted mean patch fractal dimension (AWMPFD) played a positive role. This represented the quality of large green spaces in the non-built landscape class type. Other components proved that there was positive ecological quality in large and small green spaces in built-up areas, while also indicating the success of using PCA modelling for this urban green space study. PCA models are useful in studies such as those involving multiscale simulation frameworks for studying natural systems or large interconnected network structures (Fernandez et al, 2018).

Models using regression analysis have been used in the literature when analysing diversity and species richness. Regression analysis is a modelling technique which is used to investigate dependent and independent variables and the relationships between them and are a tool for helping to understand environments. Rogerson (2015) believes that regression analysis is beneficial for evaluating the importance of variables, the correctness of the model chosen and creating a simplified version of relationships between variables. Gledhill & James (2008) used a linear regression model to test the nature of any relationships found in species richness between taxa in a study of urban ponds in the Halton district in Northwest England. The results showed that the relationship between richness of different taxa varied according to scale, becoming more significant within clusters of ponds than within a single site. The analysis, conducted using Minitab software, found that connectivity between the ponds that were closer together caused a significant increase in species richness compared to ponds that were dispersed across the study area.

2.4.2 Scale

One major factor that should be considered in ecological modelling is scale. Scale refers to an extent of a study area, primarily its extent in space but also to some degree its extent in other dimensions including time. It also refers to spatial and temporal resolution, also known as grain (Goodchild, 2003). The extent and grain are key components in landscape ecology studies, and many researchers have harnessed the power of scale in their research.

An example of scale being used in ecological studies can be found with Gallardo-Cruz et al (2018) in their study of relationships between species richness and continuous landscapes. Multiple regression and variance partitioning methods were used to analyse the effects of the two landscape descriptors of moving window metrics and surface metrics at two different scales of 200m and 400m and space (based on the extraction of principal co-ordinates of neighbour matrices' vectors) on species richness in Nizanda, Mexico. Multiple regression models were fitted to the six sets of plant species-diversity variables against one set of landscape data of 12 surface metrics and one set of 12 moving-window metrics. The moving window metric provides a continuous representation of the landscape starting from a classified image, which is expected to reflect the species' perception of landscape structure, emulating local landscape patterns. The surface metrics approach allows one to analyse local patterns in the spatial variation of pixels. Another multiple regression model was developed using the selected set of PCNM models from the previous model and fitting it against dependent variables. Both models were then combined into a global regression model using significant variables only. The results of the models showed that some of the variables had differing relationships with scale. Moving window metrics were highly sensitive to spatial scale, while the surface metrics were found to be more independent from scale.

The relationships between bird species richness and environmental factors in New York State at multiple scales was explored by Holloway & Miller (2015). The study looked at how four spatial scales of 30, 60, 90 and 120km would affect relationships with autocorrelation using Getis-Ord Gi* spatial statistics. A geographically weighted regression (GWR) was also used to explore scale dependencies and nonstationarity in the relationships between richness and environmental variables such as climate and plant productivity. There were considerable local differences in relationships between enhanced vegetation index, precipitation, elevation, temperature and bird species richness at different scales. The use of localized spatial statistics allowed for more detailed environmental analysis, and offered a chance to explore species richness patterns at varying spatial scales in a variety of visualizations.

Geary et al (2013) also examined scale when designing mosaic landscapes for Black Grouse in Perthshire, Scotland. Scales between several radii of 0.2–3 km were implemented to assess how the importance of different habitats changed with proximity to lek and scale. Habitat features or combinations of features that were associated with large leks or positive lek growth were then examined. Maxent models were used for this study. This model suited Geary's work, as the study focused on a single species and was solely concerned with lek presence (groups of male Grouse performing mating displays) in the study area. Models at all radii generated satisfactory predictive power. At the 2-km radius, suitability was found to be highest with around 20% each of three moorland types and open/mixed forestry, whereas close to the leks (0.2 km), higher proportions of grouse moor and lower proportions of closed-canopy woodland were optimal. The relationships between habitat and lek size or direction of lek growth was complex, indicating that a landscape containing large or productive leks can be the result of more than one combination of habitats. This outcome of using scale in the study demonstrated a level of flexibility in designing landscapes for Black Grouse conservation, so landowners can prioritize combinations of habitats that are the most practical and/or economical, while still serving the requirements of the target species.

Kumar et al (2009) also used multiple regression analysis in the study of heterogeneity of butterfly species richness in the Rocky Mountains National Park, USA at a multiple scale level. From butterfly surveys that were conducted in the study area previously, species richness was chosen as the response variable and the plot-level characteristics of plant species richness, vegetation height, and range in NDVI and spatial heterogeneity in topography were chosen as predictor variables along with the landscape patterns of composition and configuration. Separate models were developed for each of the eight spatial extents between radii of 300m to 2,400m. Pearson correlation coefficient (r) was used to investigate associations between butterfly species richness and measures of spatial heterogeneity at each of the spatial extents. Cross-correlation was implemented into the predictors through multicollinearity between the predictor variables and the landscape metrics that were produced prior using FRAGSTATS. High cross-correlation was found in landscape metrics such as cohesion, edge density, mean patch size and the Shannon and Simpson's diversity indexes. Stepwise forward multiple regression was then carried out to eliminate any insignificant predictors (where p is greater than 0.05). Akaike's Information Criteria (AIC) was then used to evaluate the models and to select the best model for butterfly species richness from the models developed. The best model explained 62% of the variation in butterfly species richness at a spatial extent of 2,100m. The three best predictors for butterfly species richness were also found at this scale. No continuous trend in the variation of butterfly species was found across the eight spatial extents.

The results of the multiple regression models showed that spatial heterogeneity at different scales can greatly influence patterns in butterfly species richness. The results further illustrated the need for land managers to recognise the importance of spatial heterogeneity of species at a wider landscape context aspect. Multiple regression is clearly a useful tool when evaluating ecological aspects such as species richness against different variables and spatial scales and when successful, the results can end up being key to conservation management and planning.

From the literature studied, many different statistical models have been used in quantitative analysis in ecological and UGBS studies. Different forms of regression analysis have been used to develop models that analyse variables to quantify and measure the quality of species richness, diversity and heterogeneity in ecological studies in both urban and non-urban areas. Other more advanced models like PCA models have been helpful in finding relationships between different ecological and landscape variables. These models have been conducted using software such as SAS, Minitab, SPSS and R. FRAGSTATS has also been key in the build-up to the statistical analysis of many of the studies mentioned, with the software allowing for the configuration of landscape patterns that can then be implemented into models later in the research. Scale is also an influential factor in ecological studies. Spatial scales can impact and change patterns and processes in the landscape. Relationships between variables can also change depending on the spatial scales used in a study. Ecological variables such as species richness and abundance can be scale dependent or independent, whereas a variable like connectivity could be greatly influenced by spatial scale, particularly in the urban environment.

3. Methodology

3.1 Study Area

Cork City was chosen as the urban area for this study. Cork City is situated in the southwest of Ireland. As of the 2016 census, the city has a population of 125,657 within an area of 187km^2, making it the second largest city behind Dublin in the Republic of Ireland. The climate of Cork City is that of a temperate climate, with cool summers and relatively mild winters. According to the thirty-year averages from Cork Airport, the city does not experience any temperature extremes, with a mean yearly temperature of 9.9°C, mean highs of 18°C in the summer months and mean lows of 3.3°C in December, January and February. The city experiences high levels of precipitation, with averages of 1,227.9 millimetres (48.34 in) annually. Due to its low altitude of 15m (49 ft), most of Cork City's precipitation falls as rain, with snow being a rare occurrence in the winter months. The high rainfall levels in the region causes Cork to expect an average of 73 days a year of 'heavy rain'. Cork is, however, one of the sunniest cities in Ireland, with an average of 3.9 hours of sunshine every day (Met Eireann, 2019).

The main river in Cork City is the River Lee (Fig.1), which splits into two channels at the western end and divides the city centre into an island. The channels re-converge at the eastern end of the city where the quays and docks along the river banks lead outwards towards Lough Mahon and Cork Harbour, which is known to be the second largest natural harbour in the world. Other rivers that also flow through the city include the TwoPot, Curraheen and Glasheen rivers in the south of the city, and the Bride and Glen rivers which flow through the northside. Other waterbodies in the city include two lakes, Cork Lough (Fig.2) and the Atlantic Pond (Fig.3). Cork has many parks and recreational areas ranging from small local green areas to large city parks, the most notable being Fitzgerald Park, Tory Top Park, the Lee Fields and Glen Park (Fig.4). There are many trees within the city parks and along the river banks, however, there are only a few small patches of true woodland in the city, with the largest patches found at Curraheen Wood, along the Marina and the woodland at Beale's Hill/Lover's Walk (Fig.5).

Fig.1: The River Lee is the main river that runs through Cork City.

Fig.2: Cork Lough is an important area for both bird and bat diversity. The wooded island is an important roosting area for all kind of bird species in the city.

Fig.3: Atlantic Pond is another important blue space for bird diversity, but is also an important green space due to its surrounding woodland for many woodland bird species too.

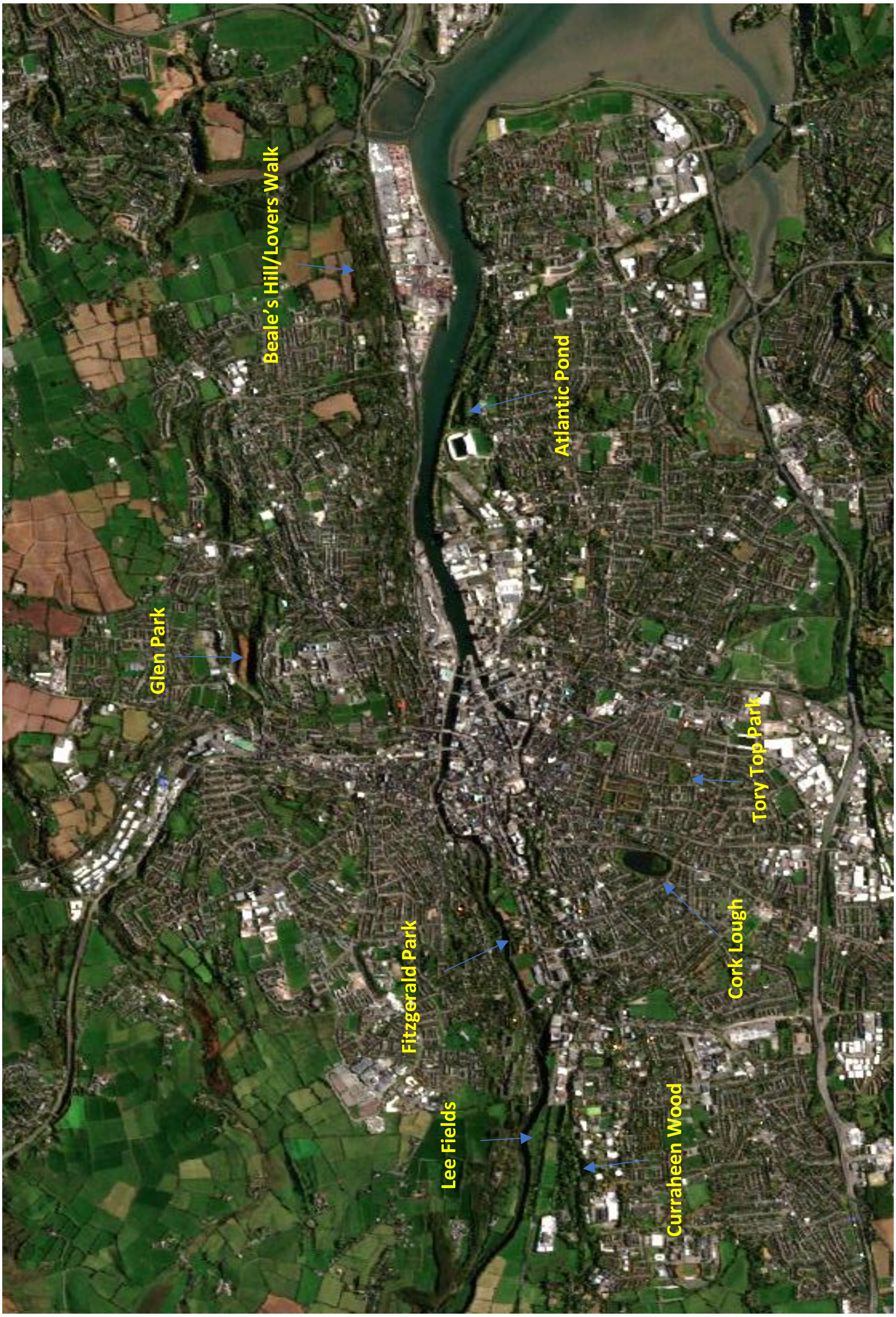


Fig.4: A map showing some of the main parks and woodland that are found in Cork City.

Fig.5: Beale's Hill and Lovers Walk in the eastern side of Cork is one of the only small patches of natural woodland present in the city.

Coinciding with the green and blue spaces of Cork City is a relatively rich level of biodiversity. The blue spaces of the city in particular are of significant ecological importance for an urban area. It's well known that there is a healthy bat population in the city, with six of the ten Irish bat species present in the city. This is thanks to the abundance of insect food along the River Lee and Cork Lough (also referred to as The Lough) and the wide availability of buildings for roosting (Cork City Council, 2009). A number of bat boxes are also placed around Cork Lough to accommodate the bats. One bat species of particular interest, the Daubenton's Bat (*Myotis daubentonil*), is a great indicator for the significance of Cork City's blue space, as this species lives near freshwater habitats. They are often seen along the River Lee, particularly around UCC and the Lee Fields, and are also found at Cork Lough. In fact, Cork City has one of the largest populations of this species in the whole country. Other mammal species that occur in the city's blue spaces include Otters and Seals. European Otters (*Lutra lutra*) are not often associated with urban areas, but there is a healthy population of them that live along the Lee and around Douglas Estuary and Lough Mahon. Common (*Phoca vitulina*) and Grey Seals (*Halichoerus grypus*) occasionally swim upstream of the Lee in chase of Salmon (*Salmo salar*) and Mullet (*Chelon labrosus*) and can be seen as far up as the Lee Fields in the western part of the city. The presence alone of Salmon and Mullet gives a sense of the healthy ecosystem within the blue space in Cork. The Lee is an important route for salmon who migrate from the sea and up-river. However, the construction of a dam at Inishcarra to the west of Cork city is a severe obstacle in the migration route and has led to the alarming depletion in the numbers of Salmon in the river. Foxes (*Vulpes vulpes)*, Hedgehogs (*Erinaceus europaeus*) and Rabbits (*Oryctolagus cuniculus*) are also found in the city, and there is a small population of Irish Hare (*Lepus timidus*) also present in the city, particularly by the Apple Headquarters in northwest part of the city.

In terms of bird diversity, Cork is also an important area for birds, particularly shorebirds and wildfowl as a wintering destination. Sites such as Cork Lough, Lough Mahon (Fig.6) and the Douglas Estuary are favoured wintering areas for many ducks and waders. The latter two are both part of a larger special protection area (SPA) for the whole Cork Harbour area. Over 30,000 waders and 5,000 wildfowl winter in the harbour area (Dempsey & O'Clery, 2007), with nationally important numbers in the 1000's of Lapwing and Black-tailed Godwits (*Limosa limosa*) (Fig.7), and internationally important numbers of Redshank (*Tringa tetanus*). Other species that winter there with nationally important numbers include Curlew (*Numenius arquata*), Greenshank (*Tringa nebularia*), Dunlin (*Calidris alpine*) and 9.6% of the total Irish population of Shelduck (*Tadorna tadorna*). Cork Lough too (which is declared as a Public Wildlife Refuge), has important numbers of wintering Shoveler (*Spatula clypeata*) (Fig.8) and occasionally Pochard (*Aythya farina*) too. Other species of note that can be found in Cork City include birds of prey such as the Peregrine, Kestrel (*Falco tinnunculus*) and Buzzard (*Buteo buteo*). The Stock Dove, a species mainly found in mature woodland areas, has been known to nest in the holes of a large wall behind the Distillery Fields at the north channel of the River Lee (Cork City Council, 2009). Large numbers of Pied Wagtails (*Motacilla yarreli*) have also been known to roost in the very core of the city centre at Grand Parade, taking advantage of the few trees along the street and of the warmth created by the urban heat island effect (Fig.9). The species mentioned show that Cork City has an important role to play in bird diversity during the winter months. This study, however, will be focusing on the bird diversity present in the summer months, where the vast numbers of wildfowl and waders of Cork Harbour and Cork Lough will have returned to their breeding grounds in Northern Europe and the Arctic, and so, less species will be present in the city. The summer months can still be an important time for bird diversity however, particularly with the addition of summer migrants such as Willow Warblers (*Phylloscopus trochilus*), Barn Swallows (*Hirundo rustica*), Swifts (*Apus apus*), Spotted Flycatchers (*Muscicapa striata*) and Common Sandpipers (*Actitus hypoleucos*). The species recorded during this study will be also be a potential indicator of them breeding in the city, if not through direct observation during the field survey process.

Fig.6: Lough Mahon is part of the Cork Harbour special protected area (SPA), with thousands of wildfowl and waders wintering here.

Fig.7: Black-Tailed Godwits winter in their thousands at Lough Mahon such as these five feeding on the food-rich mudflats.

Fig.8: Shovelers winter in small flocks at Cork Lough. Sometimes these flocks can reach nationally important numbers on the lough.

Fig.9: Pied Wagtails roosting in the trees of Grand Parade in the heart of the city centre in Cork. The Wagtails roost here every winter from the extra warmth created by the city centre.

The study area consists of Cork City Council's boundary for the city (Fig.10). In July 2018, there was a proposal for the city boundary to be extended out and encompass the satellite towns of Ballincollig, Douglas, Glanmire and Blarney (Fig.11). In January 2019, the legislation was passed and Cork City's boundary was officially extended in May 2019. The extension process occurred after this study started, so the original boundary remained as the study area. This is because the original boundary includes the core city area and the surrounding suburbs. The new extended boundary would be a much greater task to extensively cover and would also include rural areas in between the core city area and satellite towns which would change the overall objective at looking at solely urban green and blue space.

Fig.10: The orange dotted line represents the study area, based off of Cork City Council's original boundary of the city.

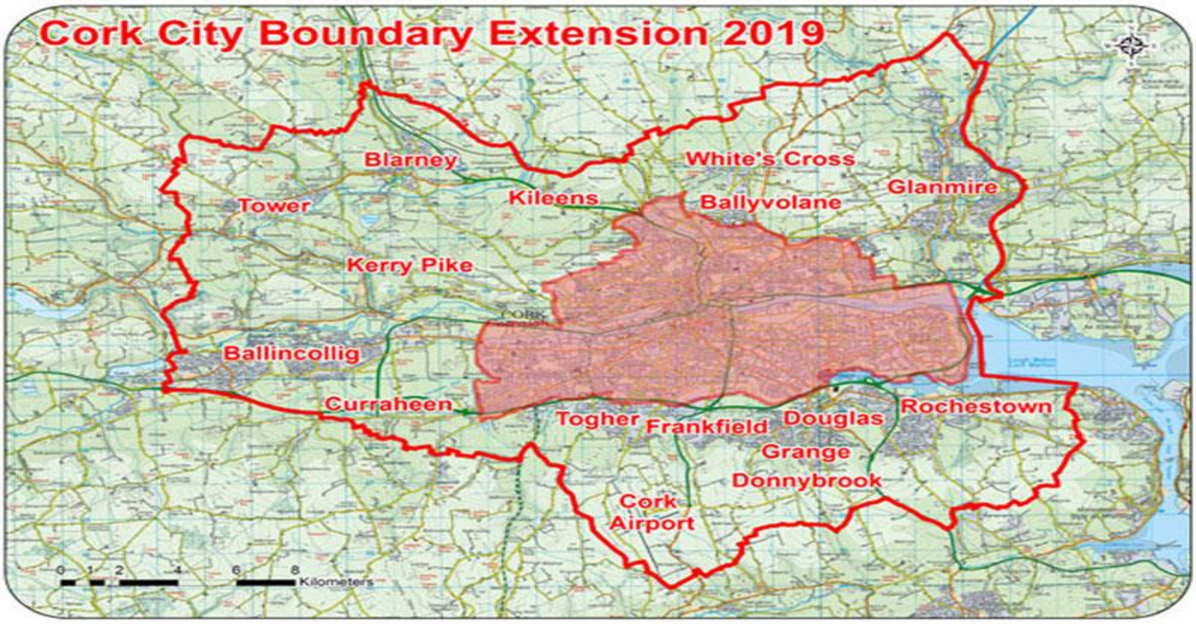


Fig.11: The official boundary extension that occurred in 2019 (the red area in the map is original boundary and the one that will be used in this study). The new extension includes a large amount of rural area which would cause for a different approach when looking at bird diversity from an urban perspective. (Source: corkcity.ie)

3.2 UGBS mapping using remote sensing

3.2.1 Data Acquisition

To improve classifications of UGBS in Cork City, the use of Sentinel-2 imagery was employed. Sentinel-2 was chosen as it is provided free of charge and part of the European Copernicus Earth observation program. The sensor records data in 13 spectral bands, with a swath width of 290 km and a spatial resolution of up to 10m (for the three visible and one near-infrared band). The mission was launched to monitor variability in land surface conditions, operational land monitoring, emergency response and security services. The short revisit time of Sentinel-2 of five days and the fine spatial resolution can support and deliver more timely and accurate information on UGBS in Cork City than that of the Urban Atlas data.

Sentinel-2 images of Cork City were viewed on the USGS Earth Explorer geoportal and seven cloud-free images were downloaded from different months in 2018 with the true colour bands of blue (B2), green (B3), red (B4) and near infrared (B8). The cloud-free data was acquired from the months of February, April, May, June, July, September and October. An attempt was made to acquire images from across all seasons, however, cloud-free data for Cork City was unavailable for the winter months of November, December and January. The images were then added to the ENVI 5.5 program, where they were subset to fit the study area of Cork City. The seven images were atmospherically corrected using a linear percent stretch which trims the minimum and maximum histogram values which define the dynamic range of the image. A 2% linear stretch was applied where the lowest 2% of histogram values were assigned a value of 0 and the highest 2% of histogram values were assigned a value 255. Pixel values less than the minimum histogram value are assigned a value of 0. The pixel values between these points are then linearly stretched where they are distributed across the entire histogram range, causing the image to become brighter and more contrasted. The images were then stacked to create a time-series for Cork City.

3.2.2 Landcover Classification

Drawing from the literature, the methods adopted by Vatseva et al (2016), Kopecka et al (2017) and Rosina & Kopecka (2016) were adopted for this project. These authors used an impervious-water-vegetation classification scheme in their respective studies, but for this region the vegetation classification was further sub-divided into woody and non-woody classes. The impervious class, which represents any feature that is solid, was renamed as a built class. A mudflat class was also assigned to the classification scheme to capture the presence of mudflats on the eastern side of Cork City at Lough Mahon and the Douglas estuary due the importance of mudflats as a habitat for bird diversity.

An automatic land cover classification was implemented to perform per-pixel classification of the study area. The widely used supervised maximum likelihood classifier was chosen as the classifier for this research (Vatseva et al 2016; Kopecka et al 2017; Dragos et al 2017). This method assumes that the values for each class in each of the bands are normally distributed and calculates the probability that a given pixel belongs to a specific class defined by training areas. Unless a probability threshold is assigned, all pixels are assigned to the class that has the highest probability, or the maximum likelihood, to be that specific class. If the highest probability is smaller than the threshold specified, the pixel remains unclassified. This was performed in ENVI 5.5. Ten training areas were assigned to each class and equally distributed across the study area in order for the computer to determine the spectral signature of the pixels within each training area. This number of training areas was chosen due to the small size of the study area and to keep a consistent number of training areas for each class regardless of their varying sizes. The information is then used to define the values, including the mean and variance of each of the classes. Only pure pixels were chosen for each class to avoid any cross-contamination during classification, so sizes of training areas varied depending on the class type (e.g. training areas for the water class tended to be long and narrow in tandem with the river system). After the completion of the classification process, a per-pixel classification image was generated to be discussed in greater detail in results (Fig. 12).

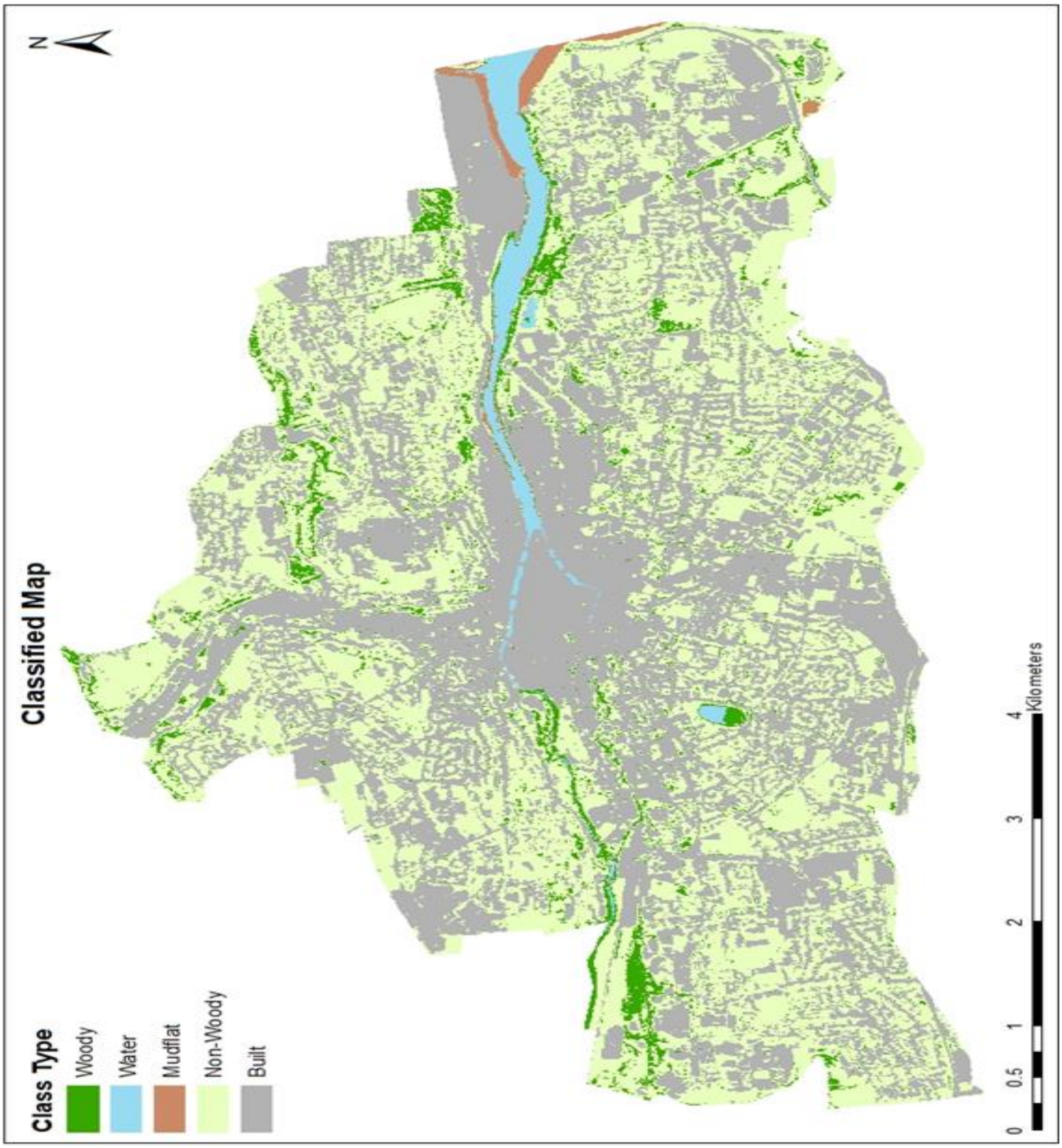


Fig.12: The classified map generated from the maximum likelihood classifier.

3.3 Field Surveys

3.3.1 Field survey methods

There are a number of field survey methods that have been used concerning bird diversity, for example to determine the species abundance, richness and distribution of bird communities. The main methods that are discussed in the literature are line transect counts and point counts Line (also known as belt or strip) transects involve the surveyor walking slowly along the centreline of a transect, counting all birds seen or heard on either side of a given distance (Adams et al, 2005) and have been used in several studies involving bird surveys. (Edgar & Kershaw, 1994; Fernandez-Juricic, 2000; Khera et al, 2009). The point count method has also been employed for bird surveys in multiple studies (Volpato et al, 2009; Nalwanga et al, 2012; Saskatchewan Breeding Bird Atlas, 2017). Point counts differ to line transects in that the surveyor remains stationary and counts birds seen or heard within a specified distance from the point (Bibby et al, 2000).

For this research, the point count method was seen as the most suitable method. Remaining stationary at a point in each location was preferable, especially when the easiest way to identify species is through calls and songs, particularly during the early morning light. As in the literature reviewed, the surveys for Cork City would also take place in the morning, from sunrise (around 5am) and for the following four hours. Adverse conditions such as rain and wind would be avoided during the studies. The surveys were planned to take place in June, when all summer migrants were predicted to be in the city according to a defined sampling strategy.

3.3.2 Sampling strategy for field surveys

There are three main approaches to sampling which are used for data collection: random, stratified and systematic. These sampling techniques all have their advantages and disadvantages. The best sampling strategy concerning field surveys will be discussed here through the literature read for this topic.

The point count method was employed for this research project, and according to Rogerson (2015), a number of spatial sampling methods can be utilised. One way is where x and y co-ordinates are chosen at random and in an unbiased way. Alternatively, the study area could be broken down to ensure coverage of all the different habitats. This can be done by dividing the study area into sub-regions with a grid system. A stratified or systematic spatial sample can be then identified within the different sub regions (or strata). Coe (2008) also mentions the use of the grid system, where diagrams (Fig.13) help to illustrate their usefulness for sampling sites. The approach where boundaries of another category were recognised was used for this study. This was chosen as a site might be assigned a particular class (e.g. water) for a survey, but the boundaries of another category (e.g. woodland) may be present nearby and can affect the potential survey results with an increase or decrease in the amount of birds seen or heard. By recognising these boundaries, the edge effect theory can be identified as a catalyst for the richness and abundance numbers recorded at a site.

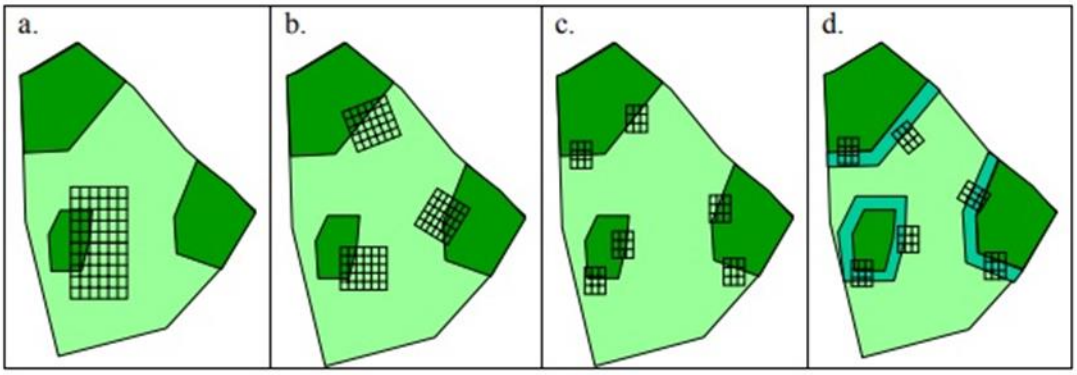


Fig.13: Four approaches in grid sampling: (a) a single grid that includes a wooded patch, (b) three grids sampling three different woody patches, (c) increasing the replication, (d) recognising the boundaries as another category, which was the approach taken in this study. Source: Coe (2008).

The spatial characteristics for this research project dictated a stratified sampling of the data worked best. The grid sampling approach where boundaries of another category (class) were recognised was also implemented (Fig.13(d)) into the sampling sites. Five classes were sampled, comprising of woody, water, mudflat, non-woody and built habitats. These classes were sampled throughout Cork City and sub regions were integrated into the study to stratify the sampling of data. It was decided that the city would be divided up into different zones (sub regions) to allow for a complete spatial coverage of the study area. The constituency zones for Cork City were used as a reference for creating each zone (Cork City Development Plan, 2019). However, some of these zones were quite large and were further subdivided again (for example the southeast region could be divided up into the Mahon and Blackrock areas) using major road lines or natural landscapes such as rivers and streams as borders for the zones. The zone borders were modified so each habitat class could be sampled in each of the zones using a stratified random technique, with the exception of the mudflats class as this habitat only occurred in the zones found in the eastern and south-eastern part of the city. The grid system was employed within these zones for the four different habitat classes, where each class was surveyed twice in each zone.

3.3.3 Field surveys of Cork City

Nine zones were created in ArcPro using the Trace tool. (Fig.14) It was decided that the four main habitat classes would be surveyed twice in each zone (water, built, woody and non woody), to bring the total number of sites to 72. This was done to create a larger database for analysis that would be more statistically robust and less sensitive to outliers during the statistical analysis of the surveys and habitat classes. The zones created were altered in their boundaries to accommodate the presence of the four classes in each zone, where two sites for each class could be surveyed. Upon completing the zone boundaries, the 72 sites were randomly chosen, with 8 sites in each zone (Fig.15).

For the water classes, the co-ordinates for sites on parts of the River Lee and the smaller rivers of the city that were not classified by the maximum likelihood classifier, which will be discussed later on, were taken from the river network dataset that was downloaded from the EPA Geoportal (EPA, 2017). This allowed for the water class to be included in each zone, and allowed for the blue spaces of the city to be extensively surveyed. Each sites co-ordinates, class type and site name were noted. Two sites within Z5 were assigned as mudflats due to the habitat class' presence in that zone. It was decided that they would replace the water class in this particular zone, but they still represented a blue space area. The lack of mudflats across the rest of the zones influenced this decision and will be discussed further in a later section.

The field surveys were undertaken from the 4th until the 23rd of June 2019. By starting in June, all migrants that would be settled in the city would almost certainly be present by this time. The surveys were completed between 5-8am with 10 minutes spent at each site. The date, time, species names and counts were taken down in a field notebook and were identified through sight and sound. Species that could not be identified through poorly-lit light were discounted, but there were only two incidences of this occurring during the 72 survey sites. Chicks were also discounted as some nests where nestlings were heard could not be accurately counted without observing the actual nest itself. This occurred at a few sites and the method followed in this study dictated to remain stationary. It is also advised not to disturb nest sites during the breeding season, particularly when chicks are present, as this could cause the parents to abandon the nest if it is disturbed.

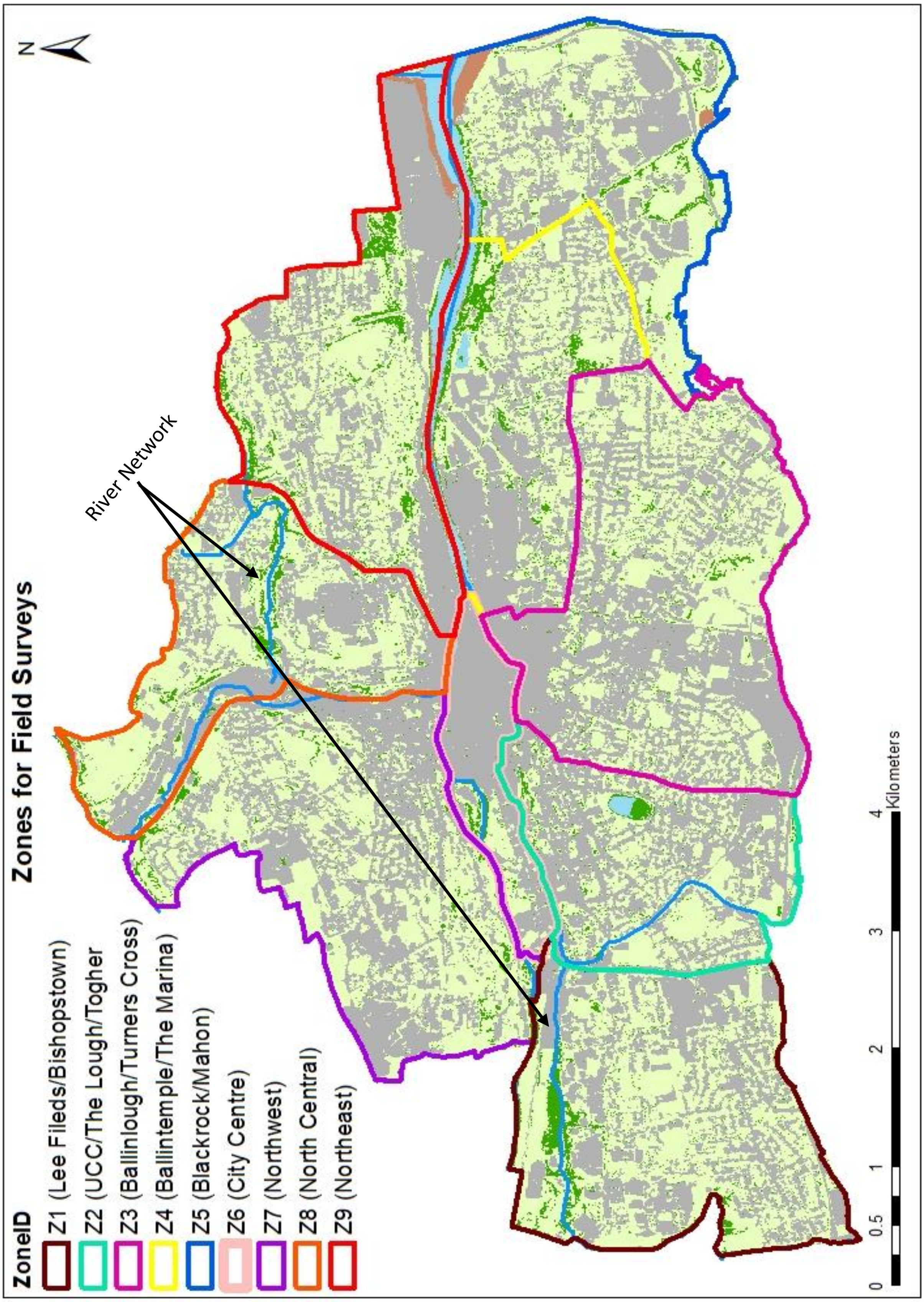


Fig.14: The nine zones created for the field surveys.

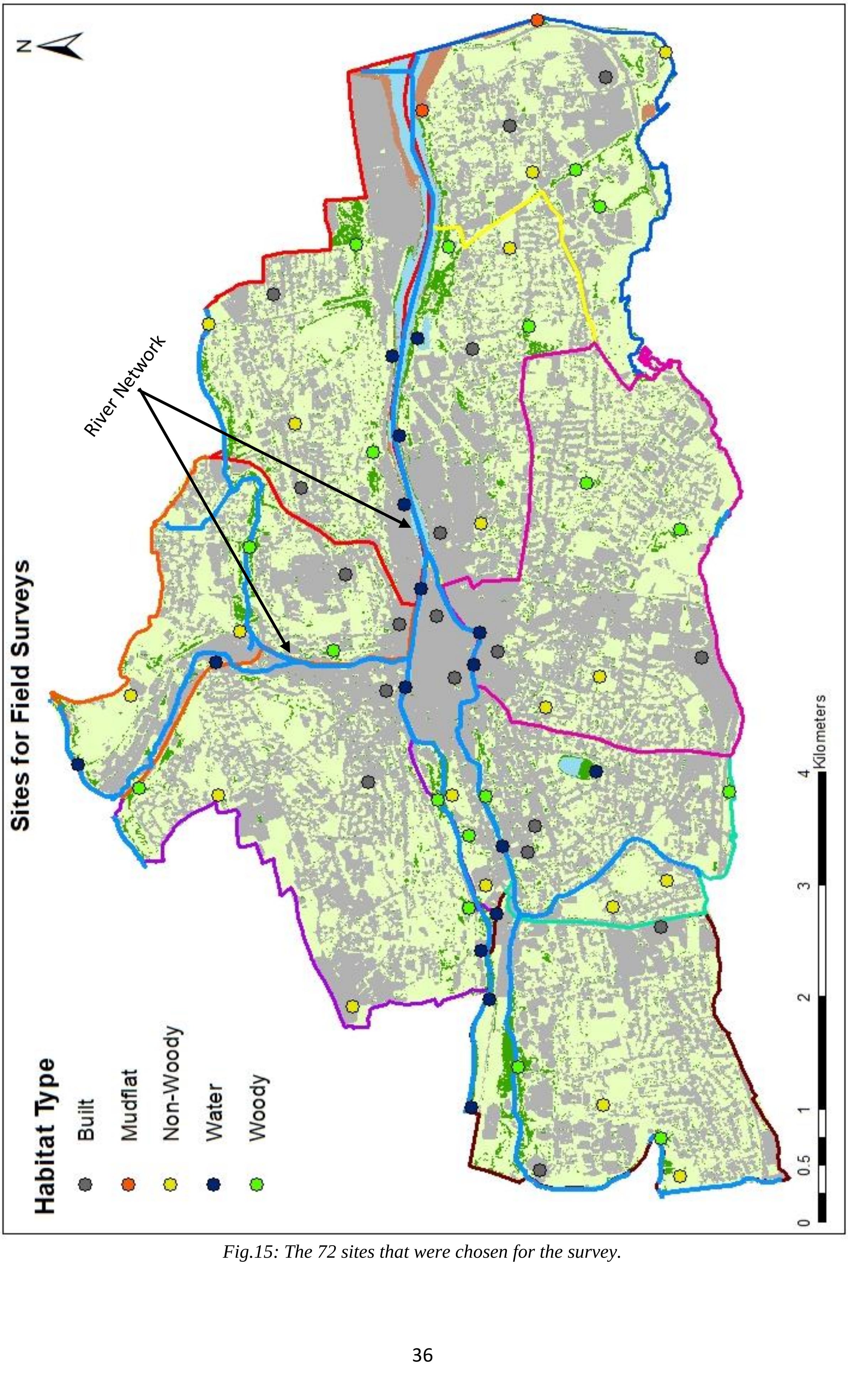


Fig.15: The 72 sites that were chosen for the survey.

3.4 GIS and Statistical Analysis

Upon completion of the field surveys, the next process involved preparing the data gathered from the landcover classification and the field surveys for conducting statistical analysis. This involved the parametrising of statistical models to explore species-landscape relationships. The significant relationships between bird species richness and abundance with the landscape metrics of UGBS was explored, together with the assessment of the spatial scale impact of the species-landscape relationships. This was carried out using FRAGSTATS v.4.2.1 (McGarigal et al, 2012) and R v.3.6.1 software (R Core Team, 2019).

3.4.1 Geoprocessing of Data

The first step in the statistical analysis process was to manipulate the data from the classified map to fit the FRAGSTATS software and to create the three different scales for analysing the UGBS data. Using ArcPro, each of the 72 sites were first buffered with a circle of radius 50m, 100m and 200m. Once each site was buffered three times, the classified map was then clipped to each individual buffer. Extract by mask was then applied to extract the cells of the raster data that corresponded to the areas defined by the mask, in this case, the clipped buffers at each scale. This was done so that the extracted data could then be converted into a GeoTIFF format, which could then be imported into FRAGSTATS software for analysis.

3.4.2 Scale for species-landscape relationships

Scale, as described by Turner et al (2001), is the spatial or temporal dimension of an object or process, characterized by both grain and extent. The grain represents the finest level of spatial resolution possible within a given data set. In the context of this study, the grain refers to the cell sizes for the minimum mapping units drawn with raster grids gathered from classified remote sensing imagery. The Sentinel-2 imagery used in this study has a spatial resolution of 10m, giving a grain size of 10m × 10m. The extent refers to the size of the study area or the duration of time under consideration. For this study, the extent was defined by the multiple sites which were surveyed during the field surveys, where the focus of scale would be in investigating how it affects species-landscape relationships at a fine-scale level. The term fine-scale refers to small areas with high resolution and is regularly used in ecological studies (Turner et al, 2001).

No one scale is correct when studying landscape or ecological processes, and the scale of interest is dictated by the question or phenomenon studied (Turner et al. 2001). Bird diversity and its relationship to landscape pattern is the focus in this study, and three scales were identified to compare and contrast these species-landscape relationships, particularly related to connectivity, which can be a scale dependent phenomenon. Three scales of 50m, 100m and 200m were chosen for this study These scales were also seen as an appropriate measure for bird diversity in an urban landscape. A site may have little to no connectivity at 50m, but at 100m to 200m, there may be signs or features of connectivity. Likewise, there may be little connectivity at 200m, but scaling down to 100m or 50m may reveal connective networks that are significant in increasing bird species richness and abundance. The focal points of each scale were implemented based on the fixed points of the 72 survey sites. Despite the fine-scales used in this study, they can serve as relative scales, as two points may be close together linearly (e.g. 100-200m) but are in fact far apart as they are separated by a large peak or ravine, or in this instance, a street or industrial area, which requires much more energy to traverse; whereas two points that are further away from each other but connected by level ground that is easier to traverse will have a closer relative distance (Turner et al, 2001). This relative scale is of particular interest in this study as it's an important factor of connectivity within Cork City, where a river channel or greenway requires less energy for a bird to move between green spaces than a series of busy city streets, particularly for smaller bird species who need to conserve as much energy as possible to prevent exhaustion.

3.4.3 FRAGSTATS Analysis

Once all of the landcover data was created and exported as TIFFs, they were inputted into FRAGSTATS v.4.2.1. This software is a spatial pattern analysis program for quantifying the composition and configuration of landscape. There are a variety of landscape metrics available to use in FRAGSTATS, divided into three categories, Patch metrics, Class metrics and Landscape metrics, which are further sub divided into Area-edge, Shape, Core Area, Contrast and Aggregation groups. These metrics provide different measures of landscape structure (Table 3). For the purpose of this study, metrics were chosen to analyse connectivity and diversity in order to evaluate species-landscape relationships of Cork City. Two Class metrics and seven Landscape metrics were chosen to fit this criterion as follows (as defined by McGarigal et al, 2012):

Class Metrics

- **Total Area (CA):** equals the sum of the areas (m^2) of all patches of the corresponding patch type.
- **Percentage of landscape (PLAND):** equals the percentage of the landscape comprised of the corresponding patch type.

Landscape Metrics

- **Total Area (TA):** equals the sum of the areas (m^2) of the landscape.
- **Connectance Index (CONNECT):** equals the number of functional joinings between all patches of the corresponding patch type.
- **Contagion (CONTAG):** is minus the sum of the proportional abundance of each patch type multiplied by the proportion of adjacencies between cells of that patch type and another patch type, multiplied by the logarithm of the same quantity, summed over each unique adjacency type and each patch type; divided by 2 times the logarithm of the number of patch types; multiplied by 100 (to convert to a percentage).
- **Proportion of Like Adjacencies (PLADJ):** equals the number of like adjacencies involving the focal class, divided by the total number of cell adjacencies involving the focal class; multiplied by 100 (to convert to a percentage).
- **Patch Cohesion Index (COHESION):** equals 1 minus the sum of patch perimeter (in terms of number of cell surfaces) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage.

- **Shannon's Diversity Index (SHDI):** equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion (sum_i - p_i log(p_i)).
- **Simpson's Diversity Index (SIDI):** equals 1 minus the sum, across all patch types, of the proportional abundance of each patch type squared.

The class metrics were chosen as they provide information on the landscape make-up of each site. The landscape metrics were chosen as they represent various ecological functions. For example, the PLAND metric measures landscape composition which can be an important characteristic in identifying fragmentation or habitat loss. Therefore, it is important to know how much of a target patch type (e.g. woodland) exists within the landscape. CONTAG is a measure of dispersion and interspersion of patch types, which provides information on habitat variability and is inversely related to edge densities in a landscape. COHESION and CONNECT are both metrics that measure connectivity, the former measures the physical connectedness of the corresponding patch type and the latter defines the number of functional joining between patches of the corresponding patch type, where each pair of patches is either connected or not. The SHDI and SIDI metrics are diversity metrics, and both measure the high or low landcover diversity present in the landscape. All of these metrics may be important for bird diversity, and as shown in the literature review, allow for the description and quantification of spatial patterns and ecological processes of the study area (Turner et al, 2001).

3.4.4 Multiple Regression Analysis

After running the selected metrics in FRAGSTATS for all 72 sites for each scale, the results were collated into three separate tables representing the data for each scale. The results for the richness and abundance for each site from the field surveys were then added to these tables. The next step of analysis was to perform multiple regression to evaluate the species-landscape relationships with the landscape metrics of UGBS, in addition to the impact of spatial scale on these species-landscape relationships.

For this study of bird diversity and UGBS in Cork City, a stepwise multiple regression approach was taken to examine the species-landscape relationships through landscape metrics at multiple scales. Using R version 3.6.1, the first step was to create QQ plots of the species richness and abundance numbers collected during the field surveys to test for normal distribution This was done using the "car" package (Fox & Weisberg. 2019). The QQ plots of species richness (Fig.15) and species abundance (Fig.16) both represented Gaussian distributions. The species richness histogram shows a normally distributed graph with a slight positive skew to the maximum species richness of 25. The species abundance histogram is also of Gaussian distribution, albeit with a much longer tail than the richness histogram. Before performing multiple regression analysis, three sites were removed from the data due to outliers creating skewed distributions. The two sites representing mudflats (S33 and S37) were removed due to the small sample size of mudflat habitat and the high abundance counts due to one particular species (Black Tailed Godwit). The other site removed was Cork Lough (S9), due to the very high abundance count of over a hundred, created by the flock of feral Greylag Geese fed daily at the site which also attracted large numbers of Feral Pigeon. Spatial autocorrelation was tested for using morans I where no significant relationships were found in the residuals (see Appendix). Homogeneity of variance was also tested using Bartlett's and Levene's tests. The results also showed no significant relationships (see Appendix).

These functions were then applied in R, with species richness and abundance serving as the dependent variables to the independent variables of class and landscape metrics created in FRAGSTATS (Table 3). A generalized linear model (GLM) was first performed:

$$\hat{Y} = \beta_0 + \beta_1 X$$

Stepwise multiple regression involves a step selection of both forward and backward procedures. Variables are first added in a manner of forward selection. However, as each variable is added, variables entered on earlier steps are re-checked to see if they are still significant. If they are not still significant, they are removed. The procedure ends when the addition of any variable not already in the equation would result in it being insignificant (Rogerson, 2015). The specified criterion used for this study was the Akaike Information Criteria, also known as AIC. This provides a method for assessing the quality of a model through a comparison of other models, and through step selection it removes irrelevant predictors. These models were created by using the stepAIC function in R, from the "MASS" package (Venables & Ripley, 2002). A function to display significant interactions between metrics was also added into the code:

stepAIC('GLM model', scope = .~.^2, direction = "both")

Models were created for 50m, 100m and 200m with the dependent variables of richness and abundance. Of these models, half were based off the class metrics (PLAND) for each habitat, and the other half included the landscape metrics, with the exception of total area (TA), as area was already accounted for with the PLAND metrics in the regression process. Interactions were also added to test for any relevant interactions in the multi scale model selections. All model results were recorded when they reached their lowest respective AIC values.

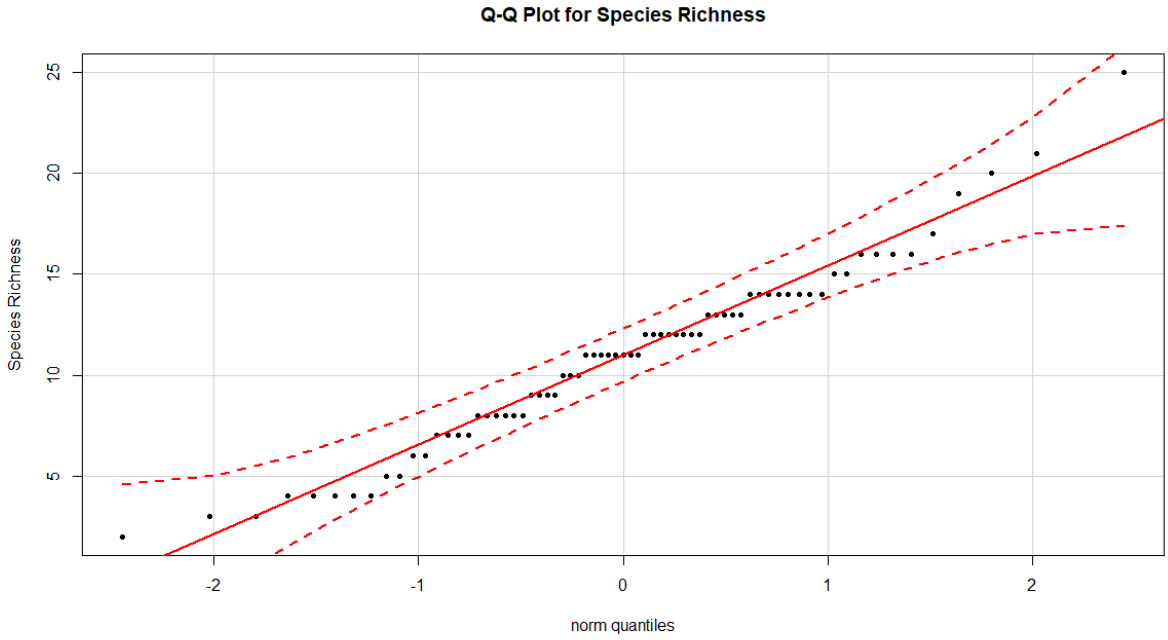


Fig.15: The species richness QQ plot, displaying a Gaussian distribution.

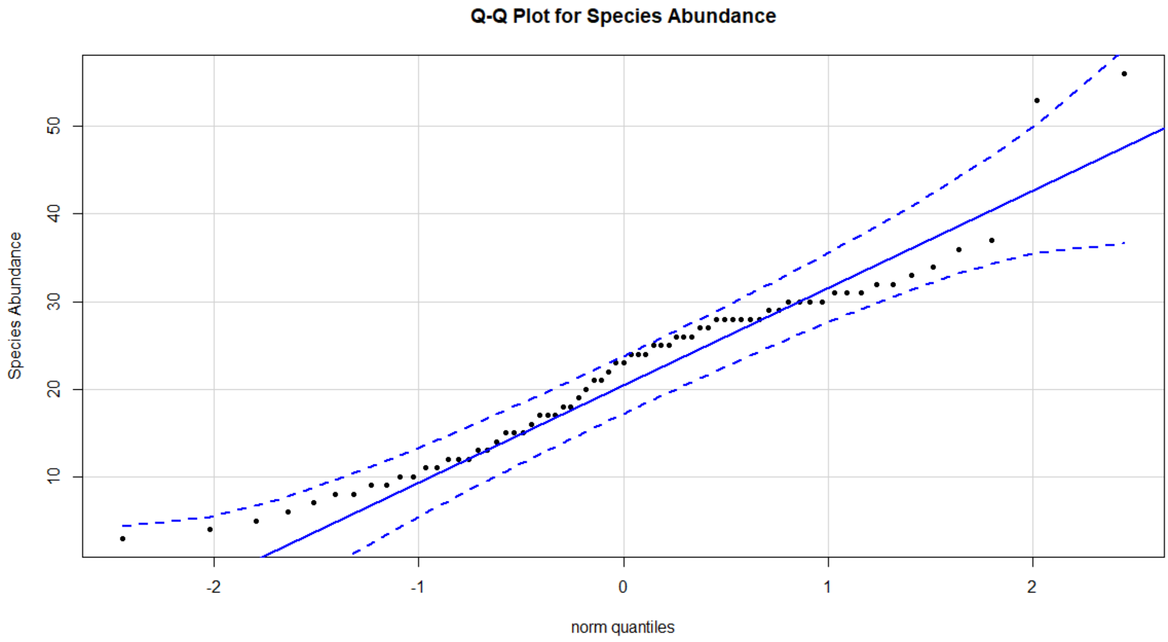


Fig.16: The species abundance QQ plot, showing a relatively Gaussian distribution.

4. Results

4.1 UGBS mapping results

Before moving on to the next step, an accuracy assessment was performed on the classified product (Fig.12). Using a Geohive map as a reference for Cork City, 40 sites were identified for the larger classes of non-woody and built, 30 for the water and woody classes, and 10 for the smallest class which was mudflats. Using these sites as ground truth points, an accuracy assessment was generated. The overall accuracy for this product was 87.85%, with a kappa coefficient of 0.8421, indicating a relatively accurate landcover classification of Cork City (Table 2). The results (Table 4) revealed two thirds of Cork City's landscape is made up of green and blue space, suggesting that Cork is a relatively green city. Green space accounted for 51.4% of the landscape composition, while blue space made up 14.96% of the classified image. The built class had the highest percentage of all classes, comprising of 32.71% of the whole classified image.

A producer/user accuracy table (Table 5) displayed how accurately each class was classified in the final product. The producer accuracy indicates how well a given class has been classified (Banko, 1998), while the user accuracy denotes the reliability of the map and how well it represents what is really there (Story & Congalton, 1986). The built, mudflat and woody classes were the most accurately classified classes with a 100% producer accuracy. The water class was the least accurately classed habitat, with only a third of it classed accurately according to the producer accuracy. However, the water class was the most reliably represented class along with mudflat according to the user accuracy results, with both classes garnering 100% reliability. The woody class had the lowest user accuracy score with a percentage of 83.33%.

Table 4: The ground truth table, displaying the total landscape composition of Cork City.

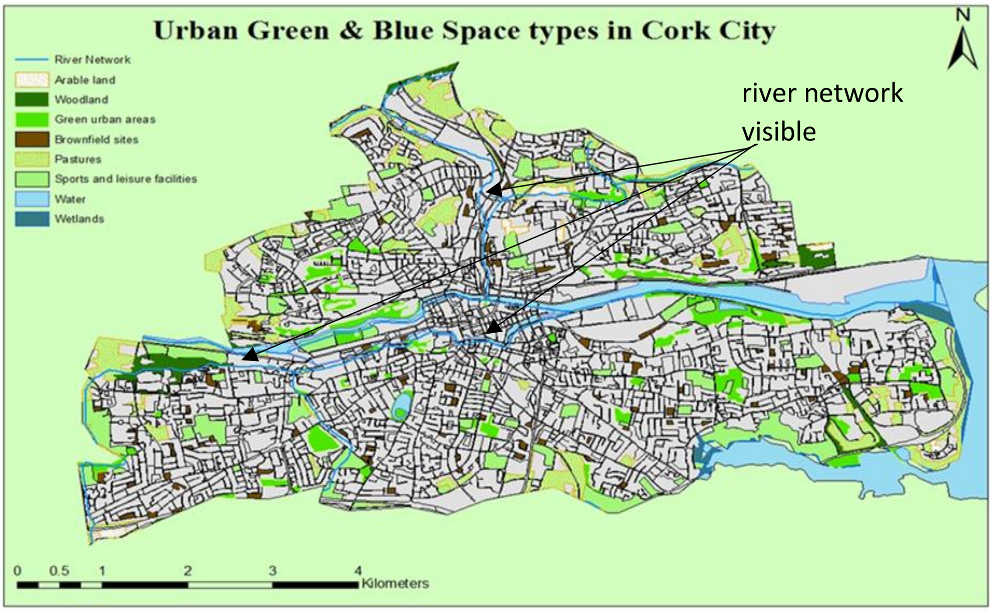
Class	Ground Truth (%)
Unclassified	0.93
Built	32.71
Mudflat	9.35
Non-Woody	28.97
Water	5.61
Woody	22.43

Table 5: The producer and user accuracy results for each class from the accuracy assessment of the classified image.

Class	Producer accuracy (%)	User accuracy (%)
Built	100	85.71
Mudflat	100	100
Non-Woody	96.55	90.32
Water	33.33	100
Woody	100	83.33

When comparing the classified map to an Urban Atlas (UA) map, the advantages and disadvantages of both products are clear to see (Fig.17). The classified map displays much more green space within Cork City compared to the UA map. The gardens are clearly displayed across the classified map, and there is much better representation of the wooded areas found in the city. The urban core of the city centre is also well represented, along with the industrial areas in the north, south and the Cork Harbour area. In comparison, the UA map has a much better representations of the river networks in the city. Aside from the issues with the water class, the classified map has much more advantages over the UA map, hence why it was chosen as the map that the field surveys and data analysis would be based off.

(A)



(B)

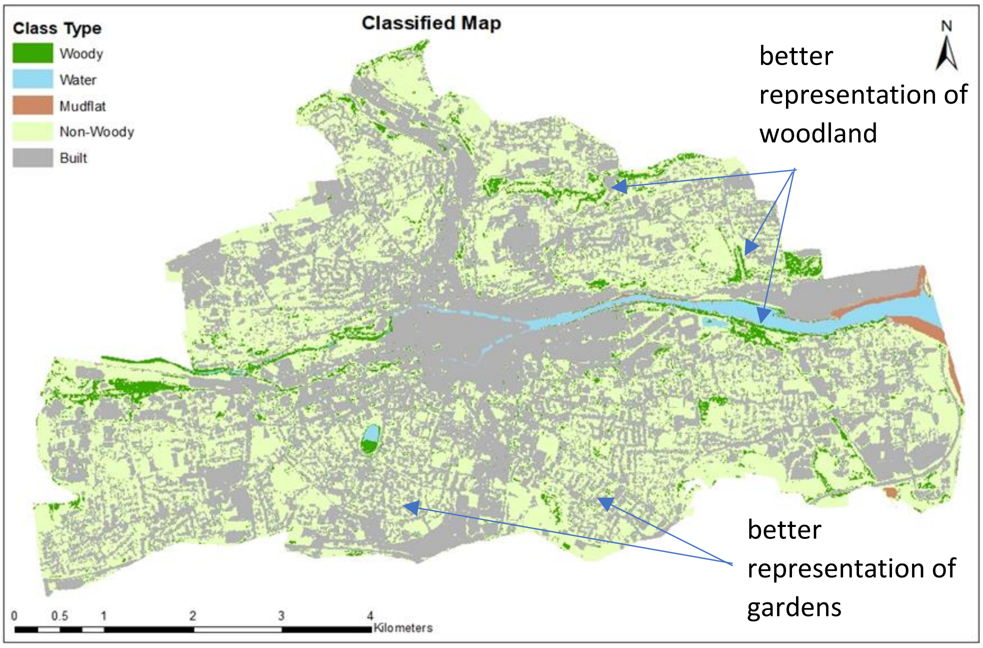


Fig 17: Urban Atlas map (A) vs Classified image (B). The classified map has a much better representation of the green spaces while the Urban Atlas map has the full river network of Cork City, unlike the classified image.

4.2 Field Survey Results

A total of 62 species were recorded across the 72 sites. The Wren (*Troglodytes troglodytes*) was the most frequent bird species present over the 72 sites, with an 81% frequency rate across all study sites, followed by Wood Pigeon (*Columba palumbus*) with 76% and Blackbird (*Turdus merula*) with a 69% frequency rate. Six species had a frequency rate higher than 50%, with the majority of species having a frequency of 2-10% (18 species) or 1% (17 species) (Fig.18). The average species richness equated to 11 species per site, with the highest average species richness for the zones found at the Z2 (UCC, The Lough, Togher) zone with an average of 12.75 species, with the lowest average richness present at the Z6 (City Centre) zone with an average of 8.5. The site with the highest species richness count was S62 (Glen Park), with a richness count of 25, with the lowest richness count of two species occurring at S48 (Parnell Place).

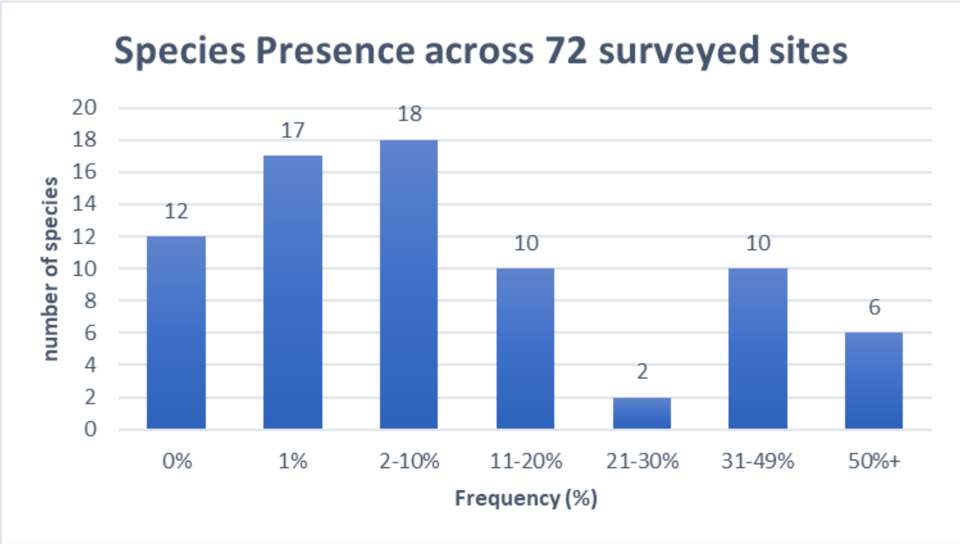


Fig.18: Frequency numbers of each bird species recorded across all study sites.

The Wren (*Troglodytes troglodytes*) was the most frequent bird species present over the 72 sites (Fig.19), with an 81% frequency rate across all study sites (Table 6 A-B). This result corroborates with existing knowledge, as this species is the most widespread in Ireland (Birdwatch Ireland, 2019). The 11% frequency of Feral Pigeons was an interesting outcome in comparison to Wood Pigeon and Collared Dove (*Streptophelia decaocto*), with Wood Pigeon having the second highest frequency of any species with 76%, while Collared Dove had 15%. This suggests that the smaller size of Cork and the high presence of green and blue space in the city is linked to the much higher presence of Wood Pigeon compared to Feral Pigeon. Studies have shown that the Wood Pigeon has been taking advantage of urban food sources, and in some cases, have a higher breeding density in urban areas then they do in neighbouring rural areas (Bea et al 2011; Fey et al 2015). If similar surveys were to be taken in Dublin for example, the frequency of Feral Pigeons would be expected to be much higher and likely greater than that of the Wood Pigeon due to the city's larger size and greater volume of urban structures where this species is associated with.

Fig 19: The Wren is the most widespread species in Ireland. It was also the most widespread species across the 72 sites surveyed.

There was a slight variation in the most abundant species across all sites compared to species presence (Table 6 A-B) with Wood Pigeon having the highest average abundance of 2.375 across sites, followed by Rook (*Corvus frugilegus*) with an average of 1.986, Jackdaw (*Corvus monedula*) and Wren (both have an average abundance of 1.83). Six species had a higher average abundance of one or more a site, with the majority of species having an average abundance of 0.1-0.5 (Fig.20). An average abundance of 24 individuals was deduced for all sites, with the highest abundance count of 35 birds found at the Z5 (Blackrock and Mahon) zone. The lowest average abundance counts were recorded from the Z6 (City Centre) zone with an average of 19 birds counted across the sites in that zone. The site with the highest abundance count of 103 was surveyed at S9 (The Lough), and the lowest abundance of 3 birds was documented at S65 (Horgans Quay). Mudflats had the highest average abundance count of 75 in regard to habitat classes, albeit with a smaller sample size of two sites compared to the other habitat classes. Like with average species richness, the built class had the lowest average abundance counts with an average of 15 birds across built classed sites (Fig.21). The woody habitat class was found to be responsible for the highest average richness counts, with an average of 14 species recorded at each woody site, with the lowest average richness counts coming from the mudflat and built classes (Fig.21).

Table 6: (A) Top ten species for highest species presence across the 72 surveyed sites, and (B) Top ten species for highest average abundance across all sites.

(A)

Rank	Species name	Frequency (%)
1	Wren	81%
2	Woodpigeon	76%
3	Blackbird	69%
4	Rook	58%
5	Jackdaw	53%
6	Robin	51%
7	Magpie	42%
8	Blue Tit	42%
9	Chaffinch	42%
10	Dunnock	40%

(B)

Rank	Species Name	Average Abundance
1	Woodpigeon	2.375
2	Rook	1.986
3	Wren	1.83
4	Jackdaw	1.83
5	Black-tailed Godwit	1.597
6	Blackbird	1.583
7	Starling	0.819
8	Mallard	0.764
9	Robin	0.708
10	Magpie	0.638

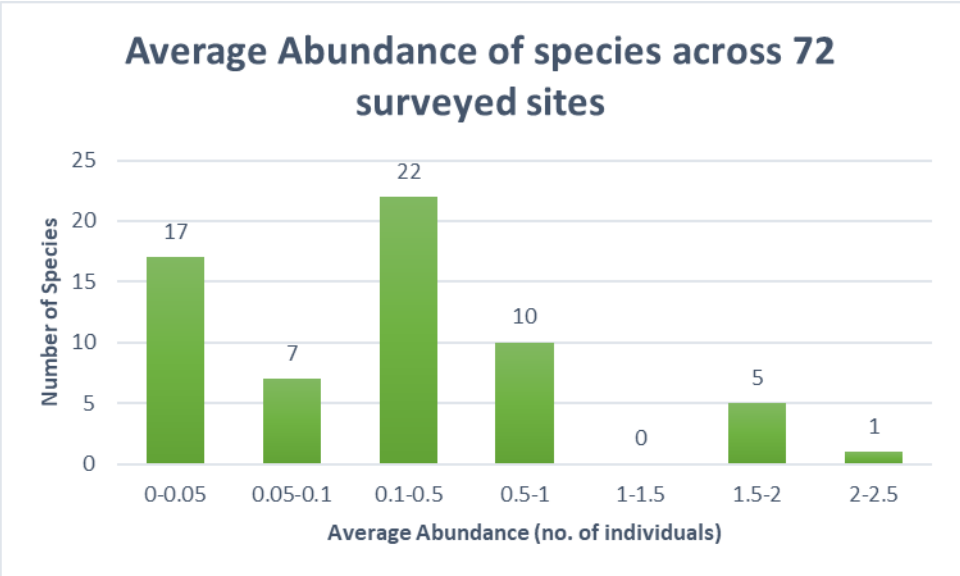


Fig.20: The average abundance of bird species recorded across all 72 surveyed sites.

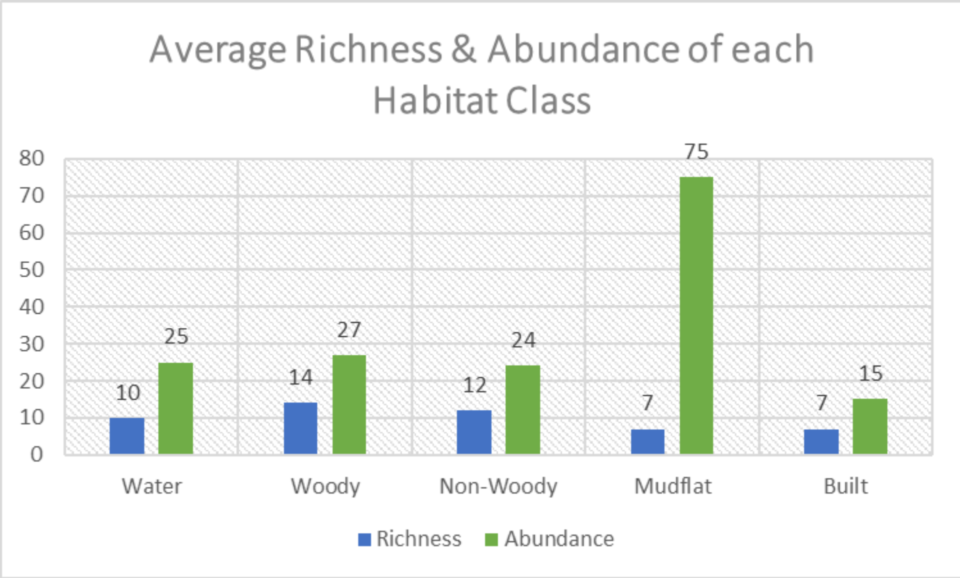


Fig.21: Average bird species richness and abundance recorded from each habitat class.

The lowest numbers of species richness were found in the city centre, with the lowest count of two species recorded at Parnell Place (S48). Surprisingly, Grand Parade (S44), the heart of the city centre, had a species richness count of seven. It was expected to have a similar richness to Parnell Place, where a gull or corvid species were the only species recorded, but a total of seven species was highly unusual. A possible explanation is that the survey took place on a Sunday morning just after 5am. As a result of this, a larger amount of food waste was strewn along both sides of the street from the Saturday night prior. This food waste surprisingly attracted a pair of Mallards (*Anas platyrhynchos*) and four Grey Herons (*Ardea cinera*) onto the street (Fig.22). This is also proof of how a survey taken on a particular day can have an impact on the results compared to if the survey took place on a different day of the week. However, it should also be noted that the herons are regular visitors to the city centre as the fishmongers of the English Market will feed them fish early in the morning, meaning the impact of the day on the results was not greatly affected. However, these results suggest that species such as herons, corvids, and gull species have adapted to taking advantage of the food waste left on the street.

The three highest species abundance counts were predictably found at The Lough (S9), with an abundance count of 103, and the mudflat sites of Blackrock Castle (S33) and Lough Mahon (S37), with abundance counts of 78 and 73 respectively. The Lough was expected to have a high abundance count, due to the presence of the feral Greylag Goose (*Anser anser*) flock and the high volume of Feral Pigeons (*Columba livia*) that flock to the site to take advantage of the food left out for the ducks and geese. The wooded island situated on the lake is also a popular roost site for various species, particularly corvid species such as Jackdaws and Magpies (*Pica pica)*. The mudflats also accumulated high abundance counts, primarily due to the flocks of Black-tailed Godwit present at both sites. This species does not breed in Ireland, and flocks such as the two seen at both mudflat sites are mainly composed of immature non-breeding individuals. Due to the high abundance counts of these sites compared to the rest of the surveyed sites, they were removed from the statistical analysis to maintain a more Gaussian distribution for species abundance.

Fig.22: One of the Grey Herons perched on the fountain on Grand Parade in the city centre during the survey. Some of the food waste can be seen across the street.

In terms of freshwater species, the surveys displayed the wide variety present in the city. Fourteen species regularly associated with freshwater were recorded in the surveys, with Mallard having the highest frequency of 15% across all sites, with a 45% frequency at sites where freshwater was present (Table 7). The presence of species such as Kingfisher and Grey Wagtail on the River Lee suggests that there is a healthy water quality in the city (Wilson & Carmody, 2011). Atlantic Pond and Cork Lough proved to possess the widest variety of freshwater species, with Tufted Duck (*Aythya fuligula*), Little Egret (*Egretta garzetta*), Little Grebe (*Tachybaptus ruficollis*), Coot (*Fulica atra*), Moorhen (*Gallinula chloropus*), Mallard and Grey Heron all recorded at these sites. In addition, the wooded island at Atlantic Pond is home to a group of breeding Grey Herons (Fig.23), and a small number of Little Egrets. Single

Sedge Warblers (*Acrocephalus schoenobaenus*) and Reed Buntings (*Emberzia schoeniclus*) were unexpectedly recorded at Tramore Valley Park. Both of these species are associated with freshwater due to their preferred breeding habitat of reedbed, where a small patch of this habitat is found next to the woodland at that site. Both these species, while not recorded during the survey of the site, can also potentially be found at Glen Park (*personal observation)*, where there are other patches of reedbed present. The presence of these species is another positive sign for the health of the freshwater ecosystems in Cork City.

Table 7: This table represents the frequency that each freshwater species was recorded at a site that contained any freshwater habitat.

Species	Frequency (%)
Mallard	45%
Grey Heron	30%
Grey Wagtail	30%
Moorhen	20%
Sand Martin	20%
Mute Swan	10%
Little Grebe	10%
Coot	5%
Great Cormorant	5%
Kingfisher	5%
Little Egret	5%
Sedge Warbler	5%
Tufted Duck	5%
Sedge Warbler	5%

Fig.23: A group of Grey Herons breed every year on the island at Atlantic Pond.

Ten of Ireland's summer migrants were recorded during the surveys, with the most frequently recorded species composed of the warbler family (Fig.24). Blackcaps (*Sylvia atricapilla*) were the most frequent summer migrant, owing to its expansion in population in recent years which is noted in the recently published countryside bird survey report 1998-2016 (Lewis et al, 2019). Unsurprisingly, the Swift was more frequent than the swallows and martins due to the urban setting where Swifts readily breed (Birdwatch Ireland, 2019). The Sand Martin was the more abundant species compared to the House Martin (*Delichon urbicum)* and Barn Swallow. This was due to the presence of the River Lee, where Sand Martins are known to breed in the holes of the walls along the river as it flows through the city. It was a surprise to record a Whitethroat (*Sylvia communis*) in the survey, as this species of warbler prefers upland habitat or scrubland with gorse (Birdwatch Ireland, 2019). However, a small stand of non-woody scrubland, as shown in the landscape configuration for that site (see Appendix) was present at Upper Fairhill (S55) in the north of city, where a male was heard singing.

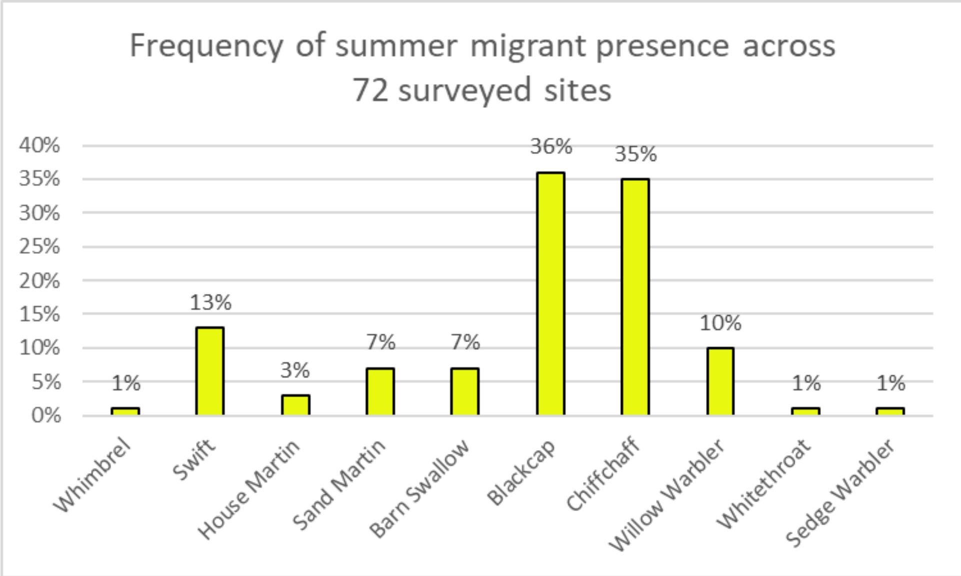


Fig.24: The frequency of summer migrants recorded during the field surveys.

One of the main results emanating from these field surveys is that 40% of the species recorded in Cork City are species of conservation in Ireland. According to Birdwatch Ireland's birds of conservation concern 2014-2019, 19 species recorded in the surveys are placed on the Amber list (medium conservation concern). Herring Gull (Larus argentatus), Black-headed Gull (Chroicocephalus ridibundus), Tufted Duck, Grey Wagtail and Meadow Pipit (Anthus palustris), which were all recorded in the surveys, are species placed on the Red list (Table 8) due to their declines in breeding numbers in Ireland, with the exception of the Tufted Duck, which is on the Red list for its declining wintering numbers. This information demonstrates how important an urban area such as Cork City can be for species monitoring and management.

Table 8: The list of species recorded during the field surveys that are on the Red and Amber lists according to Birdwatch Ireland's birds of conservation concern 2014-2019.

Species	Amber/Red listed
Mute Swan	Amber listed
Shelduck	Amber listed
Great Cormorant	Amber listed
Coot	Amber listed
Little Grebe	Amber listed
Great black backed Gull	Amber listed
Lesser black backed Gull	Amber listed
Swift	Amber listed
House Martin	Amber listed
Sand Martin	Amber listed
Barn Swallow	Amber listed
Kingfisher	Amber listed
Goldcrest	Amber listed
Robin	Amber listed
Mistle Thrush	Amber listed
Starling	Amber listed
Greenfinch	Amber listed
Linnet	Amber listed
House Sparrow	Amber listed
Tufted Duck	Red listed
Black headed Gull	Red listed
Herring Gull	Red listed
Meadow Pipit	Red listed
Grey Wagtail	Red listed

4.3 FRAGSTATS Results

The results from FRAGSTATS using the class metrics revealed the landscape configurations for each site at the three different scales. Naturally, the CA (Core Area) values increased for each class type as the scale was increased. The PLAND values were more variable depending on the class type with values increasing and decreasing with scale. A landscape composition table (Table 9) demonstrates the percentage of each class type and their respective roles in the overall landscape configuration of all sites at each scale. The woody and non-woody habitat classes decrease in the mosaic of Cork City's landscape with the increase in scale, while the built class increases and the water class experiences only a one percent increase.

Table 9: Landscape configuration of the 72 sites at multiple scales.

Class Type	50m	100m	200m
Woody	13%	10%	9%
Water	2%	2%	3%
Non-Woody	42%	42%	41%
Built	41%	44%	47%

There was also a similar pattern in the results with the increase in scale for each of the landscape metrics. The average values of TA, PLADJ, COHESION, SHDI and SIDI all increased with scale, with only the CONNECT values decreasing and CONTAG at 200m (Table 10). TA (Total Area) was expected to scale linearly with the increase of scale which is demonstrated by a t-test where the p values are very significant (Table 11). CONTAG displayed an increase from 50-100m and then a slight decrease from 100-200m. The full landscape metrics results for every site at each scale is included in the Appendix.

These increases in values express various characteristics of the landscape in Cork City. For instance, the increasing values of CONTAG (Contagion Index) when the extent is widened indicates that all patch types are increasingly aggregated (with a minor decrease at 200m). This means as the scale widens, CONTAG is expected to increase until the landscape is represented as one single patch (umass, 2019). However, the results (Table 10) show that the CONTAG value is less than 50 at 200m, indicating that there are different patch or habitat types interspersed across all sites. According to the t-tests, there was no significant difference in the CONTAG values (Table 11) suggesting that the landscape remained relatively unchanged in terms of landscape aggregation.

The PLADJ values for all three scales consisted of values between 70-80, suggesting a higher chance of single patch composition, where all adjacencies are between the same class (e.g. built or woody). The PLADJ metric experienced the most significant change between 50-200m (Table 11), meaning there was a notable change in single patch composition between the smallest and largest scale in the study.

The increase in COHESION values as the scale is increased suggests that the landscape of Cork City is highly cohesive and has high connectivity among patches. However, most of the built class sites garnered a value of 100, advocating a highly cohesive patch, which is true, but is a hindrance to bird diversity and connectivity as an impervious surface rather than an asset. The t-tests showed that there are significant differences in COHESION between all of the scales (Table 11).

The CONNECT metric decreased as the scale increased (Table 10), proving that there was less connectivity in the landscape the greater the scale. The t-test results revealed that the most significant differences in connectivity were found between 100-200m and 50-200m (Table 11). This can be linked with the COHESION and PLADJ metrics, where an increase in cohesive single patch landscape composition breaks up functional joinings and detriments connectance wholly.

Both diversity indexes also increase in value when scaling up albeit minimally. The closer value to 1 for SHDI (Shannon's Diversity Index) proposes a greater patch richness and higher diversity. An average value of 0.81 at 200m was calculated and indicates that the quality of diversity increases with scale. Similarly, the SIDI (Simpson's Diversity Index) metric represents the probability that any two cells selected at random would be different patch types, and thus, the higher the value the greater the likelihood that any two randomly drawn cells would be different patch types. Both metrics were found have the most significant differences between 50-200m (Table 11), showing that the landscape diversity quality deviated significantly between the smallest and largest scale.

Table 10: Mean landscape metrics from FRAGSTATS at each scale with 95% confidence intervals, displaying that each metric increased in scale with the exception of the CONNECT metric and CONTAG at 200m.

Metric	50m		100m		200m	
	mean	95% CI	mean	95% CI	mean	95% CI
TA	0.77	0.61-0.93	3.01	2.91-3.11	11.92	11.54-12.3
PLADJ	70.31	67.41-73.21	76.37	74.17-78.57	79.06	77.5-80.62
CONTAG	39.3	33.1-45.5	47.37	42.75-51.99	45.64	41.76-49.52
COHESION	91.86	90.44-93.28	94.65	94.05-95.25	96.14	95.78-96.5
CONNECT	14.49	8.97-20.01	11.93	8.15-15.71	3.96	3.14-4.78
SHDI	0.56	0.48-0.64	0.69	0.61-0.77	0.81	0.73-0.89
SIDI	0.34	0.28-0.4	0.4	0.38-0.42	0.47	0.43-0.51

Table 11: The p values from t-tests demonstrating significant or non-significant differences between metrics at each scale.

Metric	50-100m	50-200m	100-200m
TA	4.98E-56***	2.09E-59***	2.49E-56***
CONTAG	0.04$^{.}$	0.09^{ns}	0.6^{ns}
PLADJ	0.001**	6.67E-07***	0.04$^{.}$
COHESION	0.0004***	1.04E-07***	4.37E-05***
CONNECT	0.45^{ns}	0.0003***	9.98E-07***
SHDI	0.03$^{.}$	2.56E-05***	0.02$^{.}$
SIDI	0.08^{ns}	0.0002***	0.03$^{.}$

Significance	
0	***
0.001	**
0.01	*
0.05	.
> 0.05	ns

The FRAGSTATS metrics were also run with the classified image to create an overall assessment of the landscape at the city-wide scale. The results showed a high value of 0.97 for SHDI, indicating high diversity in the landscape for Cork City (Table 12) The connective metrics also showed varying results, with COHESION displaying a 98.90 value and CONNECT a zero value.

Table 12: Landscape metrics for the classified product of Cork City.

Metric	Value
TA	3974.34
CONTAG	46.48
PLADJ	67.75
CONNECT	0
COHESION	98.90
SHDI	0.97
SIDI	0.57

While the three scales were implemented into this study to investigate species-landscape relationships at different scales at each surveyed site, this study is concerned with the city as a whole. The values from the landscape metrics suggest there is a high diversity presence in the landscape configuration, with an SHDI value of 0.97. The SIDI value of 0.57 shows a more neutral diversity value that is neither high nor low. The diversity metrics suggest that Cork City has a high diversity of land covers for an urban area, further demonstrated by the accuracy assessment results where two thirds of the city are shown to be green or blue space. The CONTAG metric result of 46.48 indicates that there is a mix of aggregation and dispersion of patch types. The aggregated patch types tend to comprise of the built class as shown in the landscape metrics results for each site, while the green and blue spaces generally represent the more dispersed patch types across the city. The higher value of 67.75 for PLADJ proposes that there is more aggregation in the city than dispersion. Generally, the two metrics demonstrates a mixture of aggregation in the patch types overall. The connective metrics of COHESION and CONNECT produced differing values of 98.90 and zero respectively. This suggests that there is high cohesion between patch types but there is no connectivity. However, the threshold value of 20m was used again, and demonstrates that when the scale is extended out to the whole city, the coarser grain is unable to identify the functional joinings between patch types at such a small threshold value. This shows the importance of assessing the landscape at the finer scales to evaluate how high or low factors such as connectiveness truly are in the landscape.

4.4 Statistical Analysis results

For the class only models, the richness variable had lower AIC values than abundance, where the best performing model is found at the 100m scale (Table 13). The abundance variable shows a more linear pattern where the AIC values decreases as the scale is widened. When the landscape metrics were added into the GLMs, the best performing models were found at the 200m scale for both dependent variables (Table 14). However, the change in model performance when analysing richness and abundance was not very significant and suggests that they are both scale independent.

Table 13: AIC values for the final class models at all three scales.

Dependent variables	50m	100m	200m
Richness	368.36	364.35	368.09
Abundance	501.5	492.52	489.16

Table 14: AIC values for the final landscape metric models at all three scales.

Dependent variables	50m	100m	200m
Richness	368.26	360.52	350.78
Abundance	493.68	492.75	476.83

For the class only models at 50m, the built class was the only variable represented in both models which suggests that the built class has a negative effect on richness and abundance at a 50m scale (Table 15). Other habitat class variables that also formed a similar pattern included water at 100m, while non-woody and woody represented positive relationships at the 100m scale for both dependent variables (Table 15). Water was then found to have a positive relationship with species richness and abundance at 200m. Interactions in the class models did not play a significant role in their explanatory power, however, a significantly positive interaction between water and woody covers was included in the richness and abundance models at 100m. Three interactions were included in the models at the 200m scale, with water and built the only interaction that appeared across both models, where a significantly negative relationship was accounted for (Table 15).

With the landscape metrics added into the regression analysis, the final models produced a wider variety of variables and intercations. A negative relationship was found with the built class and SHDI at 50m for both richness and abundance (Table 16). The water class and the PLADJ metric appeared as a negative relationship in both metrics at the 100m extent (Table 16), with CONTAG and the connective metrics of COHESION and CONNECT exhibiting positive relationships between both dependent variables at the same scale. PLADJ was found to have a significantly negative relationship with both richness and abundance at 200m (Table 16), while significantly positive relationships were displayed in the 200m abundance model with woody, non-woody and COHESION. A total of 15 interactions were included in the coefficient tables of the final models, a significant increase compared to the class only models (Table 16). The interaction between the woody and water classes was once again included as a significant positive relationship in the 100m models, while the Built and CONTAG interaction had a significantly negative relationship with both models. The Water Built interaction appeared as a negative relationship once again in the 200m richness model, and Built and CONNECT also displayed a negative relationship in that model. Significant positive relationships were present in the 200m abundance model for Water and CONNECT and CONTAG and PLADJ.

Table 15: The coefficient tables of the class only models for richness and abundance across all three scales.

	50m								100m								200m							
	Richness				Abundance				Richness				Abundance				Richness				Abundance			
Variable	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)
Intercept	14.17	0.601	23.567	2E-16	27.944	1.573	17.768	2.00E-16	6.326	0.797	7.941	4.1E-11	13.743	2.016	6.816	3.91E-09	15.762	0.915	17.233	2E-16	-14.605	21.218	-0.688	0.494
Woody									0.08	0.03	2.85	0.006	0.12	0.08	1.69	0.96					0.52	0.19	2.68	0.009
Water									-0.19	0.09	-1.89	0.06	-0.58	0.25	-2.33	0.023	0.078	0.077	1.016	0.31	2.407	0.185	2.955	0.004
Non-Woody									0.09	0.02	5.71	3.09E-07	0.16	0.038	4.163	9.57E-05					0.515	0.23	2.239	0.028
Built	-0.08	0.01	-7.51	1.82E-10	-0.15	0.028	-5.313	1.32E-06									-0.096	0.177	-5.443	8.55E-07				
Woody:Water									0.018	0.006	2.99	0.004	0.05423	0.01501	3.613	0.0006								
Woody:Non-Woody																								
Woody:Built																								
Water:Non-Woody																					-0.039	0.019	-2.056	0.044
Water:Built																	-0.005	0.002	-2.3	0.025	-0.031	0.01	-3.003	0.004
Non-Woody:Built																					-0.003	0.002	-1.607	0.113

Table 16: The coefficient tables with the landscape metrics added for the richness and abundance models at the three scales.

	50m								100m								200m							
	Richness				Abundance				Richness				Abundance				Richness				Abundance			
Variable	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)	Estimate	Std.error	t value	Pr(>|t|)
Intercept	26.871	18.807	1.429	0.158	41.384	39.506	1.048	0.299	-89.54	36.34	-2.464	0.017	-36.546	64.899	-0.563	0.575	-0.3269	111.5	-2.931	0.005	-606.51	252.276	-2.404	0.019
Woody					-1.72	0.587	-2.938	0.005	0.03736	0.03925	0.952	0.345	0.041	0.041	0.103	0.689					0.296	0.087	3.384	0.001
Water					-6.57	3.044	-2.159	0.034	-0.3992	0.1064	-3.743	0.0004	-11.278	-11.278	-1.417	0.162	0.1398	699.5	1.999	0.05	-0.407	0.304	-1.336	0.187
Non-Woody																					0.254	0.054	4.624	2.15E-05
Built	-0.075	0.012	-6.472	1.75E-08	-0.11	0.032	-3.461	0.001	0.09062	0.05947	1.524	0.133	0.109	0.144	0.765	0.453	-5.73	0.02852	-1.308	0.196				
CONTAG									0.2764	0.08941	3.091	0.003	0.469	0.209	2.247	0.0284	8.096	2.91	2.782	0.007	14.094	6.506	2.166	0.034
COHESION	-0.257	0.242	-1.063	0.292	0.308	0.504	0.611	0.544	1.097	0.3795	2.891	0.005	1.104	0.8106	1.362	0.178	4.677	1.327	3.525	0.00008	8.593	2.989	2.875	0.006
CONNECT									0.04177	0.02624	1.592	0.117	0.106	0.068	1.553	0.125	0.7974	0.3974	2.127	0.038	-0.028	0.312	-0.09	0.929
PLADJ	0.13	0.096	1.352	0.181	-0.547	0.292	-1.875	0.066	-0.287	0.1181	-2.43	0.018	-0.852	0.309	-2.753	0.008	-1.418	0.3066	-4.626	2.14E-05	-2.762	0.717	-3.852	0.0003
SHDI	-29.232	15.523	-1.883	0.064	-21.08	10.858	-1.941	0.057	1.035	3.743+00	2.766	0.008												
SIDI	11.173	6.4	1.746	0.086	24.168	15.353	1.574	0.121																
Woody:Water									0.02456	0.005925	4.145	0.0001	0.078	0.0209	3.765	0.0004								
Woody:PLADJ					0.027	0.009	2.91	0.005																
Water:Built																	-0.006488	0.002216	-2.928	0.005				
Water:COHESION					0.093	0.038	2.433	0.018					0.114	0.085	1.334	0.187								
Water:CONNECT																					0.165	0.051	3.429	0.002
Built:CONTAG									-0.002596	0.0009386	-2.765	0.008	-0.004	0.002	-1.79	0.079								
Built:CONNECT																	-0.01018	0.004436	-2.294	0.025				
CONTAG:COHESION																	-0.1069	0.03482	-3.069	0.003	-0.189	0.077	-2.499	0.017
CONTAG:PLADJ																	0.02762	0.007058	3.912	0.0002	0.053	0.016	3.318	0.002
COHESION:SHDI	0.285	0.175	1.628	0.109																				

5. Discussion

This section will discuss the results gathered from this study and how they relate to the three aims that were outlined in the introduction: satellite imagery capabilities for UGBS mapping, relationships between bird diversity and landscape metrics and the impact of spatial scale on these species-landscape relationships. The limitations of the study and future work will also be discussed.

5.1 Satellite imagery and UGBS mapping

The Sentinel-2 imagery applied in this study demonstrated the sensors suitability for UGBS mapping. As discussed in the literature review, the wide swath width, frequent revisit time, spectral richness and free availability of Sentinel-2 make it a desirable choice for studying UGBS. After performing a maximum likelihood classification, the final product produced a clear and detailed image of the wide green space presence in Cork City. This outcome was expected as other studies have shown the capabilities of Sentinel-2 data in generating clear and concise UGBS maps with reliable accuracy (Vatseva et al, 2016; Kopecka et al, 2017; Kabisch et al, 2019).

In particular, the results showed that the use of remote sensing techniques revealed the 'invisible' green space of Cork City, urban gardens in this case, compared to existing products such as the Urban Atlas (Fig.17). This is echoed by Rosina & Kopecka (2016), where they found that the information gathered from Sentinel-2 exceeds the data available from the Urban Atlas project in terms of spatial and thematic detail. The Sentinel-2 data for Cork City not only improves on existing products, it generates a better landcover classification that is more suitable for biodiversity analysis.

The UGBS map generated in this study of Cork City provides a reliably accurate visualisation of the cities green spaces that can be a useful tool for initiatives and policy strategies implemented into the previously mentioned Cork City Heritage Plan 2015-2020. For example, the map provides comprehensive data on the green space types in the city, and is particularly useful for identifying the main woodlands present within the city limits. The identification of these woodlands, in tandem with the bird survey data, can be a key factor in determining and implementing sustainable management and conservation measures of these areas as potential areas of significant biodiversity value. The UGBS map can also aid in identifying green space corridors in the city. Mörtberg & Wallentinus (2000) demonstrated the importance of the green space corridors in Stockholm in providing key habitat quality and connectivity that could support endangered species in the region. The study provided information for the necessary stakeholders that could assist in developing guidelines for urban green space corridor planning and management. A similar outlook could be developed for Cork City. Green and blue space corridors can be identified within the city through the UGBS map generated through this research that could assist in the development of guidelines regarding connectivity and green space corridor management in Cork City for bird diversity and biodiversity as a whole.

However, the final product generated for this study is not a perfect representation of Cork City's UGBS. From the results of the accuracy assessment, the poor accuracy of the water class suggests that there is a limitation to using Sentinel-2 imagery. Water had a producer accuracy of only 33.33% where built, mudflat and woody had 100% accuracy and non-woody 96.55%.

One of the reasons for this issue is cross-pixel spectral contamination during the classification process, an issue that corroborates Rosina & Kopecka (2016). This contamination occurs when the mixed pixel signature is more representative of the higher reflecting classes, in this case the woody and built classes, over the lower reflecting water class. This mixed pixel error has led to these classes dominating the water class with their higher reflectance, causing lower accuracy in the classified map. The spatial resolution also causes issues in the poor accuracy of the water class as with lots of different surfaces congregating in a tightly-knit environment such as urban areas, the 10×10 pixel sizes of Sentinel-2 data leads to cross-pixel contamination, particularly along river edges (Fig.25).

Fig.25: A 10 ×10 square representing a pixel size from a Sentinel 2 image. This shows three separate classes in one pixel, part of the river Bride, a non-woody and a built section, demonstrating the difficulty in accurately classifying the water class in Cork City. Source: Google Earth

However, the issue of the poor classification accuracy of blue space was not found in similar studies using Sentinel-2 data. Kopecka et al (2017) had a 100% accuracy for the water class and Haas & Ban (2018) also had a high accuracy of 99.7%. This shows that Sentinel-2 data is not entirely responsible for poor blue space classification, but rather, the spatial scale of the blue space needs to be considered against the 10m spatial resolution. In the two studies mentioned, both were undertaken in the cities of Bratislava and Beijing where much larger water bodies are present compared Cork City. In Bratislava, the Danube, the longest river in Europe, offers few problems in classification due to its wide width. Similarly, the large lakes of Beijing are not affected by cross-pixel contamination. In the case of parts of River Lee and its tributaries, the rivers are sub-pixel in size that the 10m resolution cannot pick up (Fig.25). The narrow width of these rivers is the main reason for the low accuracy result, whereas the wider lakes of Cork Lough and the Atlantic Pond were accurately classified. This shows that this issue is a particular limitation of this study rather than an overall issue when using Sentinel-2 data for UGBS mapping.

Despite the poor classification of blue space, it is still possible to interpret the results with rigour. By using the landscape configuration metrics implemented in FRAGSTATS and including interactions in the regression analysis, it is possible to see what is immediately surrounding the rivers. Blue space was expected to have a mixed impact on bird diversity, and this is displayed in the positive blue-green and negative blue-urban interactions found in the regression tables (Table 15 & 16). This shows that despite the low accuracy of the blue space classification, the regression models appear to capture what was expected in the results, thus somewhat negating the issue.

5.2 Relationships between bird diversity and landscape metrics

The results from the regression models have shown that there are both positive and negative relationships between bird diversity and the landscape metrics implemented into FRAGSTATS (Table 15 & 16). Green space was shown to have a positive relationship in increasing bird diversity. Positive relationships were demonstrated for the woody and non woody classes in the class only models, where significant p values were present in the 100m richness models and the 200m richness and abundance models. By contrast, the built class exhibited negative relationships with bird diversity, with significantly negative relationships appearing in the 50m richness model and the 200m richness and abundance models. These relationships were expected as green space was projected to have a positive impact on bird diversity as was the case in other similar studies (Mortberg & Wallentinus 2000; Sandström et al, 2006; Dragos et al, 2017). By contrast, the negative results for built class were not surprising as urban infrastructure provides little suitable habitat for bird diversity to thrive. However, as mentioned in the introduction, it must be noted that the while the built class should not be totally discounted as it can aid bird diversity in the form of providing suitable nesting habitats as mentioned previously in the introduction (Wilson & Carmody, 2011; Caballero, 2016; Spelt, 2019).

There were mixed results for blue space and its relationship with bird diversity. The water class was found to have a negative relationship on richness and abundance at 100m and a positive relationship on richness and abundance at 200m in the class only models. These results are interesting, as they demonstrate how blue space can increase and also decrease bird diversity. This can be dependent on the blue space type and the habitats that surround it. The edge effect is one such phenomenon that can explain these positive and negative relationships. First defined by Odum (1958), the edge effect occurs where there is a tendency for an increase in species richness and abundance where there is a mixing between two communities. These combinations can explain the variations in richness and abundance at the surveyed sites along the River Lee, where richness increased when the river was flanked by woody riparian corridors (Fig.26), compared to low levels of richness where the river flowed through the city centre itself and into Cork Harbour, where the river was surrounded by buildings and industrial areas (Table 17).

This edge effect phenomenon is not exclusive to the River Lee however, as Glen Park (S62) and Atlantic Pond (S25), with the highest richness counts of 25 and 21 species respectively, both have a combination of woody and water habitats. The combination of these two habitats contain a wider variety of species than the rest of the sites in the city, with freshwater species and woodland species co-existing in a unique community. This shows that when green space and blue space are together, species richness and abundance increase. Alternatively, when green and urban are adjacent in the landscape configuration, biodiversity tends to decrease. This is further supported in the regression models, where a positive interaction with woody and water was present in the richness and abundance models at 100m in the class only models and the models with the landscape metrics added (Table 15 & 16). Conversely, a negative interaction was present in the 200m models for richness and abundance in the class only models and in the 200m abundance model with the landscape metrics added (Table 15 & 16). This demonstrates that green space is the most important factor in increasing species richness and abundance, and blue space, if not coupled with green space, is not as effective.

Fig.26: An example of the edge effect on the River Lee where the river is flanked on either side by woodland, where species diversity would be expected to increase with the presence of freshwater and woodland species coexisting together in one community.

Table 17: A table of the different sites on the River Lee with the adjacent habitat, showcasing the increase in richness when woodland is adjacent to the river.

Site name	Adjacent habitat	Richness
River Lee (Lee Fields Car Park)	Woody	15
River Lee (West end of Lee Fields)	Woody	13
River Lee (Kingsley Bridge)	Woody	12
River Lee (Castlewhite Apartments)	Woody/Built	11
River Lee (Weir)	Non-Woody/Built	11
River Lee (Port of Cork)	Non-Woody	11
River Lee (Union Quay)	Built	9
River Lee (Captain Frederick Monument)	Non-Woody	7
River Lee (Popes Quay)	Built	7
River Lee (Sullivans Quay)	Built	6
River Lee (Michael Collins Quay)	Built	4
River Lee (Horgans Quay)	Built	3

In terms of the landscape metrics, the regression models displayed positive relationships for CONTAG on richness and abundance at 100m and 200m (Table 16). This metric is concerned with dispersion and interspersion in the landscape, and the presence of these positive relationships in some of the models indicates that there is a level of disaggregated patch types that positively influence species richness and abundance. Other positive relationships that appeared in the models included a single significantly positive for the CONNECT metric (200m richness), SHDI (100m richness) and the interactions between water and CONNECT (200m abundance), woody and PLADJ (50m abundance) and CONTAG and PLADJ (200m richness and abundance). The interaction between water and CONNECT is a possible indication of how blue space can positively affect bird diversity from a connective standpoint.

Other studies have tested the potential for river systems as connective functions for bird diversities in urban areas (Tremblay & St.Clair, 2009; Dellimer et al, 2012). Species richness was found to decline as rivers entered the urban core (Dellimer et al, 2012) which corroborates with the survey results from this study (Table 12). Both studies found little difference between water and built surfaces for connectivity in terms of positively affecting bird diversity. Permeable surfaces such as railways were found to be better for connectivity than the river system (Tremblay & St.Clair, 2009) and the strategic placement of trees along transportation corridors played a key role in improving connectivity. These results go against the positive interaction between water and CONNECT found in this study. However, the study area of Calgary (Tremblay & St.Clair, 2009) is a much larger city to Cork with a differing urban infrastructure. The railway line in Cork City runs through a tunnel system for most of Cork City's urban core unlike the extensive railway network in Calgary, thus negating it as a potential connective function for bird diversity. There is also a lack of trees along many of Cork City's streets (Fig.27) in the city centre, where gaps of 30m or more between tree cover is a key detriment to bird movement (Tremblay & St.Clair, 2009). There are trees placed more strategically along most of the River Lee in the city centre, and the positive interaction between woody and water combined with the positive interaction between water and CONNECT suggest that the river plays an important role in connectivity for bird diversity within the urban core.

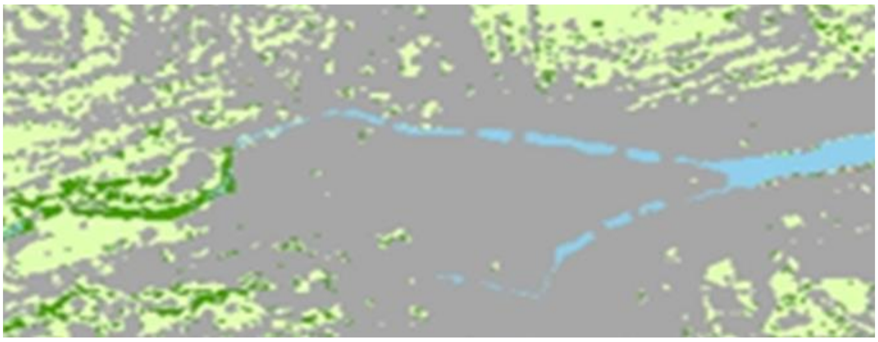


Fig.27: The classified image displaying how the river can act as a connective function between either side of the city centre. This also shows how the river has been fragmented (with the exception of the bridges) by cross-pixel contamination where it has been replaced by the built and woody classes on the south channel.

The positive interaction between woody and PLADJ suggests that bird diversity increases when the proportion of landscape is mainly comprised of woodland. CONTAG and PLADJ are inversely related to one another, where there are low levels of patch type dispersion (CONTAG) and a high proportion of like adjacencies (PLADJ) or low levels of patch type interspersion and inequitable distributions of pairwise adjacencies, resulting in high contagion and vice versa. A higher level of CONTAG over PLADJ would support the positive relationship on bird diversity when considering CONTAG has a positive relationship on bird diversity and PLADJ has a negative relationship (Table 16). This is an interesting outcome as other studies have produced mixed results from these metrics. In a study conducted by

Schindler et al (2008) found that certain biodiversity had positive relationships with each metric measured. CONTAG was found to have a positive effect on reptiles while PLADJ had a positive relationship with woody vegetation. Dos Santos Romeiro et al (2016) argued that a disaggregated landscape proved to be beneficial to bird diversity as it created a multitude of habitats which many bird species require during different stages of their respective life cycles. However, this study took place in a river valley in north Portugal with a variety of habitats such as scrubland, farmland and transitional forest areas which is hugely beneficial to bird diversity. In contrast, the impervious urban infrastructure of Cork City causes fragmentation in the landscape, which inhibits movement and negatively impacts bird diversity as shown in the models. Silva-Opps et al (2019) noted that species richness was influenced by the interspersion of wetlands with richness being the highest for both land birds and shorebirds in areas where wetlands were equally interspersed or adjacent to each other. This shows that depending on the landscape composition, the levels of CONTAG and PLADJ can vary in value and can both positively and negatively affect bird diversity.

The models also found many negative relationships between the landscape metrics and bird diversity. COHESION demonstrated negative relationships in the 100m and 200m models in richness and abundance (Table 16). High COHESION values are linked to human land use which is detrimental to spatial heterogeneity (Dallimer et al, 2012) so it is unsurprising that it displays negative relationships. As mentioned previously, PLADJ has a negative relationship at 100m and 200m for both richness and abundance. There were also negative relationships with SHDI (50m abundance) and the interactions between built and CONTAG (100m abundance), built and CONNECT (200m richness and abundance) and CONTAG and COHESION (200m richness and abundance). These negative relationships were also generally expected as the built class is generally seen as having a negative impact on bird diversity (Bierwagen, 2006; Tremblay & St.Clair, 2009; Dallimer et al, 2012) and the interactions between the built class and CONTAG and CONNECT are understandably negative as a contagion made up primarily of urban infrastructure would decrease bird diversity. Similarly, buildings and other impervious urban structures are a hindrance to connectivity in urban areas. The negative interaction between CONTAG and COHESION indicates that highly cohesive and interspersed patch types are also a negative influence on bird diversity in Cork City.

5.3 The impact of scale on species-landscape relationships

The results generated from FRAGSTATS displayed the landscape configuration of each surveyed site on a multiple scale level. As expected, the built class increased with scale, increasing from 41% at 50m, to 44% and 47% at 100 and 200m respectively. With this increase in the built class, the green space classes naturally decreased with scale, although blue space increased by 1% at 200m. After running all models, the results showed that the best performing models occurred at the 200m scale, and that there was only a marginal improvement in overall model performance with the models when the metrics were added (Table 15 & 16). However, there was no substantial change in the AIC values for richness or abundance in either the class only models or the landscape metrics models to suggest that the three scales play a significant role in increasing species richness and abundance. This is probably due to the scale size itself, as there are only 50 and 100m increases between each of the scales, whereas if the scales were to be increased to 300 or 500m, there would be a greater chance that the species richness and abundance would increase or decrease significantly depending on the landscape composition. The larger scales were avoided in this study however as the study area is small enough that a

500m for each site would encompass a large portion of the city and reduce the need for a large number of sites and would also minimise the variety in landscape values collected from said site points. The results of the models did show that there was an increase, mainly due to more habitat variation, in addition to the edge effect phenomenon, causing a greater number of species to be recorded. However, the increases are not significant enough to claim that an increase of scale benefits species richness and abundance, suggesting that both variables are independent from scale and are more dependent on the landscape composition itself in affecting bird diversity positively or negatively.

In the class only models, several significant species-landscape relationships were found at the 100m and 200m scales, with the exception of the built class which was has a negative relationship for both richness and abundance at 50m. This is not surprising as the landscape impact becomes more important as the scale increases with the potential for more habitat variation. The 50m scale is a relatively small spatial scale where landscape composition was generally made up of one habitat type at each site. It was expected that each habitat class other than the built class would increase bird diversity at that scale. This is also the case for the models with the landscape metrics. the SHDI metric has a negative relationship with abundance at 50m. The negative value for the Shannon's Index is not surprising at the 50m scale, as less diversity is expected in the landscape the smaller the scale. Diversity metrics such as SHDI tend to exhibit varying values when responding to different scales (Plexida et al, 2014). This can be seen in this study with a positive SHDI value present in the 100m richness model, although no more values for this metric appeared in the final models as the scale was increased. The positive interaction between the woody class and PLADJ at 50m (Table 16) displays that if a site is primarily composed of woodland at 50m, the abundance would be expected to increase compared to other habitat types. This is an interesting result, as Dallimer et al (2012) found woodland to be detrimental to species richness in the city of Sheffield. In the case for Cork City, the 50m scale suggests that a small patch of woodland would have more species abundance than the other habitat types at that scale. However, the woody and PLADJ metrics independently have negative values for 50m abundance, so the results can be interpreted both ways.

The increase in scale was also expected to impact species-landscape relationships for certain landscape metrics. The positive relationships at 100m and 200m for CONTAG were expected as the patch types diversified with the increase in scale, Conversely, the negative species-landscape relationships of COHESION and PLADJ demonstrate interspersion and how landscape composed of one core class, particularly the built class, can negatively affect species diversity, particularly the COHESION metric, which had the most significant changes between the scales according to the t-tests (Table 11). The built class in general presents a negative impact on bird diversity at the 100 and 200m scales which is expected as the larger the composition of the built class is at these scales, the more likely habitats are fragmented and disconnected, thus decreasing the bird diversity (Andersson, 2006; Sandström et al, 2006; Strohbach et al, 2009; Dallimer et al, 2012; Lepczyk, 2017). The water class also displayed negative relationships at certain scales. For example, the River Lee is at its widest as it reaches Cork Harbour, and very few bird species were expected to be recorded due to the wide-open nature of the water there. The bird survey results then supported this expectation as the species counts were low at sites on that area of the river, with seven species recorded at S29 (Captain Frederick Monument) and three species at S65 (Horgans Quay). S69 (Port of Cork) is an exception with 11 species recorded. However, this is due to the edge effect where the site was near a woodland and a non woody parkland, while the other two sites were surrounded predominantly by the built class, which links with the significantly negative interaction between water and built in the 200m class only models (Table 15).

The CONNECT metric has a positive relationship in the 200m richness model (Table 16). This corroborates with the studies by Bierwagen (2006) and Li et al (2015) where this metric was also found to increase biodiversity. One of the key interactions that included the CONNECT metric was the significantly positive relationship of CONNECT and water to abundance at 200m. This is an indication of the importance of blue space as a connective network in Cork City. Studies have shown that green corridors can influence and increase bird diversity in urban areas (Cox et al 2016). In this case, a blue corridor acts as a key connective network in Cork City. As discussed previously, the River Lee flows through the city centre, where the city core almost represents an "urban wall" where there is little to no green space, thus restricting movement of bird diversity (Fig.27). Due to the Lee splitting in two on the north and south side of the city centre, it offers two connective networks to freely move between either side of the city.

While it could be argued that birds could simply fly over the city centre, many birds would be reluctant to do so, particularly small passerines, where relative scales such as traversing high buildings would require more energy than simply traversing along the river with added threat of aerial predators such as birds of prey. These relative scales also impact how traversable a river is for bird diversity. According to Tremblay & St.Clair (2009), rivers can also be detrimental to bird movement, as wide rivers can leave birds just as exposed to predators as flying over high buildings. This too may explain why there is a low species richness where the river Lee is at its widest entering Cork Harbour. However, due to the river splitting either side of the city centre, the width of both channels are notably narrowed and are possibly more favourable for movement over busy city centre streets, as traffic has a significant dampening on bird movement (Tremblay & St.Clair, 2009). By availing of the river network in the city centre, birds can fly between either side of the city and expend less energy while gaining access to further habitats and food sources.

The riparian corridors along the River Lee (Fig.28) from the city centre westwards also act as important connective networks, with either side of the Lee predominantly composed of non-woody and woody habitat as was demonstrated by the PLAND results for sites on the river, and was also indicated by the positive relationship found in the regression results between woodland and water. The interaction between the built class and CONNECT with richness at 200m also shows a strongly negative relationship, further emphasising that impervious surfaces are a hindrance to connectivity.

Fig.28: An example of the connective network of woody and non-woody habitat present along the River Lee on the west side of Cork City.

5.4 Limitations

As discussed previously, there were limitations encountered with the UGBS mapping of Cork City such as the poor classification of blue space caused by cross-pixel contamination. Some other limitations were encountered undertaking the field surveys in Cork City for this study. Spatial bias was one of these limitations, where there was a lack of access to many parts of the city due to private and restricted lands. One bias as stated by Bibby et al (2000) is the comparison of results between a 'noisy' environment (e.g. built) and a 'quiet' habitat (such as woodland). However, in this project, a comparison between 'noisy' and 'quiet' habitats was necessary to assess the impact of urban green space on bird diversity. The built or 'noisy' sites had low richness and abundance numbers compared to the green space sites, which was supported further by the negative relationships the built class had with both variables in the regression results. However, this bias was generally negated with the early survey times taking place between 5am to 8am.

The issue of private lands and restricted areas was prevalent in Cork City while conducting the field surveys. Naturally, gardens could not be entered so most of the 'non-woody' surveys took place on greens in or nearby housing estates, which still allowed for bird species in gardens to be identified through their songs and calls. Certain woodlands were also inaccessible which led to the surveys taking place as near to them as possible. A number of fields and disused lands, particularly in the north-side of the city, were inaccessible which proved frustrating as these lands could have had interesting survey results. For example, such lands often had scrub-like habitat present where particular bird species such as Meadow Pipit, Whitethroat and Linnet would potentially be present. The restrictiveness of some areas also caused issues in the lack of surveys with the mudflat class. A large strip of mudflat could not be accessed on the north side of Cork Harbour at the Tivoli docklands as security clearance and a proof of identification is required for such an industry-heavy area. A similar case occurred at Mahon Golf Course where access to the mudflats was not possible without passing through the golf club which was closed during the early hours of the morning. If it was possible to survey more of the mudflat class where a broader range of results were possible, the habitat could have been kept in the statistical analysis. The problem of opening hours was also an issue in many of the parks in the city where they would not open until half 8 or 9, which was after the designated time of the surveys being completed between the times of 5-8 am. However, certain parks were opened earlier and if a park was closed, the surveys were taken nearby or through open fences which negated any impact on results.

By surveying a site more than once, there is a chance that a species may be recorded the second or third attempt if it was not recorded the first time (Blair, 1999; Gu & Swihart 2004; McGrath et al 2015). This was unfortunately not possible for this study due to time constraints. For someone with no prior knowledge of the bird diversity in Cork City, the survey results from this study would suggest that a number of species are not found in Cork City, when in fact they are present and also breed in the city's boundaries. One example of this is with the amber listed Spotted Flycatcher. This species was not recorded during the survey period, but a pair were seen to successfully breed near site (S10) later in the summer (Fig.29). Other Amber listed species not recorded during the surveys such as the Common Sandpiper (Fig.30) can often be seen along the Lee in the summer (Cork City Council, 2019). The Dipper (Cinclus cinclus) is also found in the city, where an ongoing study has been carried out on the species by UCC on the River Bride. This shows that the three true river specialists in Ireland, the Kingfisher (Alcedo atthis), Dipper and Grey Wagtail (Wilson & Carmody, 2011), are all present in Cork City, strengthening the case that the river network of Cork City supports a healthy ecosystem and should be monitored and protected to conserve these species.

Fig.29: A Spotted Flycatcher in UCC. This was seen a few weeks after the surveys had been concluded where none were recorded across all sites. This species may also have been missed during the field surveys due to its quiet song which may have been drowned out by more vocal species in the vicinity.

Fig.30: The Common Sandpiper, an Amber listed species, can often be seen on the River Lee in the summer, but was not recorded during the surveys. This is another species that indicates the health of the river ecosystem in the city.

Another limitation found in the filed surveys was that some bird species are more vocal than others and this may have led to the under recording of quieter species. This was addressed by performing the surveys between 5 and 8 am when the majority of species are most actively singing during the breeding season. However, there are some bird species that may have been under recorded, such as the Bullfinch (*Pyrrhula Pyrrhula*) and the aforementioned Spotted Flycatcher, whose songs and calls are much quieter than most species and may have gone unnoticed.

Despite some of the limitations, the field surveys proved to be successful in demonstrating the wide variety of bird diversity present in the city and the point count method, as shown in the literature review, proved to offer a clean sampling structure with a robust and easy to use form of data collection.

5.5 Future Studies

There is future potential for a study like this to be expanded upon to further examine the impacts of UGBS on bird diversity in Cork City. With a longer study time frame, field surveys could be taken in winter as well as summer to investigate the change in bird diversity and how habitats can change in significance between seasons. For example, surveys taken in winter would swell the numbers for richness and abundance for the water and mudflat class dues to the large numbers of wildfowl and waders that winter in Ireland. This would also be of interest from a conservation standpoint if any recorded species are on the Amber and Red lists for wintering in Ireland. This also shows the dynamic nature of habitats, where it is important not to make policy decisions based on only a snapshot of time.

Sites such as the newly opened Tramore Valley has the potential to become a key site in Cork City for species of conservation concern and could become an integral feature of future studies on urban bird diversity in Cork City. The park has a mixture of habitats in woodland, reedbed, scrubland and meadows (Fig.31), as demonstrated in the FRAGSTATS results for this site (see Appendix), and has the potential to support many breeding pairs of species of conservation concern, such as the Amber listed Linnet (*Linaria cannabina*), Reed Bunting and Sedge Warbler which were recorded in this studies field surveys of this site and the Stonechat (Fig.32) and Red listed Meadow Pipit which were recorded there after the survey period ended. The groundwork has also been developed to create a lake in the park, which could further entice freshwater species to breed in the area and offers the potential for further reedbed habitat to grow, as well as increase edge habitat dynamics at the site. The park shows how Cork City Council has created a unique site in the suburbs of the city that caters for many human recreation activities while also creating a biodiversity refuge that can easily be managed for conservation. The park has the potential to be an integral part of the Cork City Natural Heritage Plan 2015-2020, offering a key opportunity to promote flagship species breeding within the city and raising awareness within the public domain in helping to conserve these fragile species and their habitats.

Fig.31: The many habitats of Tramore Valley Park such as the meadows (left) provide breeding habitat for Red listed Meadow Pipit and Amber listed Stonechats. The reedbeds (right) also provides habitat for breeding Sedge Warbler and Reed Bunting.

Fig.31: The Stonechat was another Amber listed species that was not recorded during the surveys but was later found breeding in Tramore Valley Park. This can be one of many species from this site that can become a flagship species for the Cork City Heritage Plan 2015-2020.

The new city boundary could also be incorporated into another study. The new boundary contains a sizeable amount of rural areas interspersed between Cork City's satellite towns and the city itself. A study could be conducted by comparing and contrasting the bird diversities of the rural and urban areas in the new city boundary with similar survey and statistical approaches to this study. An expansion of the study area in Cork would also accommodate a larger area of mudflats as another blue space type, which could have interesting results if surveys were to be taken in winter. The change in boundary also has the potential to enhance Cork City's bird diversity and biodiversity as a whole. It would also be recommended to conduct more than one survey at each site for a more accurate representation of each sites bird diversity.

One perspective that would have been interesting in this research would have been to classify different tree cover types such as coniferous and deciduous trees or classing the different green space types into parks, cemeteries, gardens etc. The coniferous and deciduous types of wooded areas would make a difference when it comes to bird diversity. This is because certain species or habitat specialists prefer coniferous woodland, such as Coal Tits (*Periparus ater*), Crossbills (*Loxia curvirosta*) and Goldcrests (*Regulus regulus*) compared to deciduous woodland which would have a larger assortment of species (Nairn & O'Halloran, 2012). A classification of the various green space types in Cork City coupled with survey results for each green space type would also provide key information on bird diversity that could help the necessary stakeholders develop and distribute information on heritage for the Cork City Heritage Plan. It was not possible to discriminate between coniferous and deciduous woodland however, as the spatial resolution was not adequate or fine enough to allow for such identifications. The lack of cloud free imagery for the winter months also played a part in this as it may have been possible to notice the lack of leaves on deciduous, compared to coniferous trees. Satellite imagery with finer resolution could possibly be more effective in classifying the vegetation types such as deciduous and coniferous vegetation and produce a more accurate result for water (Qian et al 2015; Giezen et al 2018; Wang et al 2018). Access to data from the finer resolution satellites would have been difficult for this study, due to these satellites being commercial products and expensive. However, the finer resolution satellites do not have such a high revisit frequency as Sentinel-2, so it might not be possible to get more than one cloud-free image of Cork City, where potentially the high accuracies of landcover gained for this study came from the use of a time series.

Different sensors could be experimented with depending on the study area. Finer resolutions would be required for a more in depth look at the green space types in Cork City, while a larger swath width may be required for a study concerned with the new Cork City boundary which encompasses a much larger area. Other methods such as LiDAR or UAVs (with permission) could also be incorporated into future studies, providing ultra-detailed maps of Cork City's landscape.

Future studies with a similar methodology could also be conducted in other cities in Ireland. A comparison on bird diversity between cities such as Belfast, Cork, Dublin, Galway and Limerick could provide a fascinating insight in each cities green and blue spaces and their respective impacts on bird diversity. These studies could also provide information and aid each city's respective plans and policies for green space management and biodiversity conservation. They could also enhance the data and information for some of the objectives in the National Biodiversity Action Plan 2017-21 such as increasing awareness and appreciation of biodiversity and ecosystems services in Irelands cities and strengthening the knowledge base for conservation, management and sustainable use of biodiversity in urban areas. This does not have to be necessarily restricted to Ireland, as there are green spaces in the majority of cities around the world, and similar studies investigating the impact of green and blue space on bird diversity could be conducted in any one of these cities in the future.

6.Conclusion

At the beginning of this study on urban green and blue space in Cork City and its importance to bird diversity, the aims were broken down into three research questions:

- Can areas of green and blue space be identified in Cork City from satellite imagery?
- Are there relationships between bird diversity (richness and abundance) and the landscape metrics of UGBS?
- How does spatial scale impact these species-landscape relationships?

This study has shown that it is possible to identify the green and blue space of Cork City through satellite imagery. A maximum likelihood classification using Sentinel-2 data has displayed a comprehensive landcover map of Cork City where two thirds of the city was found to compose of green and blue space. This study has also displayed the suitability of Sentinel-2 as a reliable product for mapping UGBS with an accuracy of 87.85% and a kappa coefficient of 0.8421, improving on other products such as the Urban Atlas project.

The statistical analysis gathered from FRAGSTATS v4.2.1 and regression analysis in R 3.6.1 displayed the relationships between the landscape metrics and the bird diversity of Cork City. Green space was found to be one of the main drivers in increasing species richness and abundance, particularly the woody class. A mixed relationship was encountered between blue space and bird diversity, with the edge effect phenomenon playing a key role in determining such relationships, where blue space had a significantly positive impact on bird diversity when woodland was an adjacent habitat and a significantly negative impact when the built class was the adjacent habitat. The built class in general was found to be detrimental to bird diversity.
In terms of the metric classes generated through FRAGSTATS, landscape composition was a key component in understanding the metric relationships with bird diversity. The levels of CONTAG and PLADJ varied in value depending on the landscape composition, where an interspersion of green spaces positively impacted richness and abundance while an interspersion of urban infrastructure fragments the landscape and negatively impacts bird diversity. COHESION also demonstrated a negative relationship with bird diversity as the high values showed that habitats that dominated a particular site decreased richness and abundance, particularly when the built class was the dominant habitat.

While the step AIC models showed little difference for species richness and abundance as the scale increased, the spatial scales implemented into this study produced interesting results regarding their impact on species-landscape relationships. The results revealed that a more diversified and varied landscape was preferable to bird diversity as the scale was increased, with significantly positive relationships found between bird diversity and CONTAG at 100 and 200m and significantly negative relationships with COHESION at the same scales. The diversity metrics of SHDI and SIDI were found to be insignificant in this study, with both metrics maintaining similar values with only a significant difference between the smallest and largest scale. Connectivity unsurprisingly decreased with the increase of the built class with scale. The positive interaction between water and the CONNECT metric indicates the potential of blue corridors as a connective function in the city. However, it was that this is dependent on the relative scales of the blue corridors themselves, as the wider a river is the less likely a bird will travel over it. The River Lee in Cork City splits either side of the city centre creating two smaller channels which act as connective corridors for bird diversity, particularly the north channel which is flanked by vegetative riparian corridors which positively influences bird diversity, as indicated by the positive interaction found between the water and woody class in the models.

This study has demonstrated that urban green and blue space is intrinsically linked to bird diversity in Cork City. The study also shows that urban areas can play an important role for bird conservation, particularly in Ireland. The field surveys from this study recorded 62 species in the city, 40% of which are species of conservation concern in Ireland. Five of these species on the Red list, showing that UGBS can provide suitable breeding and wintering habitats for threatened species in the country. The presence of all three of Ireland's freshwater passerines (Dipper, Grey Wagtail and Kingfisher) also signals a healthy ecosystem within Cork City's blue space network which can be a basis for future conservation as our freshwater ecosystems continue to be threatened by pollution and invasive species. This study has also laid the groundwork for future research on bird diversity in Cork City with the opportunity to incorporate the new city boundary. The methods used could also be adopted to study other Irish cities and beyond.

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