Spatial analysis of the Upper Mersey Estuary: land cover, land use and biodiversity monitoring

Dissertation for the speciality:
Management of Natural Environments

Claire Gely

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Abstract

The biodiversity of the Upper Mersey Estuary has been particularly highlighted since the planning of a new bridge to cross the estuary and the associated ecological studies. The lack of spatial analysis, and notably the absence of land cover mapping in the whole area, is however a gap in the knowledge and analysis of the area. The first aim of this study is to produce a land cover map for the Upper Mersey Estuary by interpreting aerial photographs, in order to identify areas which face strong environmental challenges. The second aim is to map land use and to set up a method for spatial analysis of ecosystem services. Finally, citizen science data (biodiversity recorded by professional or amateur naturalists) is studied to analyse species distribution related to land cover types.

The land cover map shows a significant presence of saltmarsh and a significant presence of reedbeds. The accuracy of the map was estimated by comparison with two reference maps, and found to be satisfactory. The land cover map enables the production of a land use map at first, then a method is proposed in order to map the ability of an area to provide ecosystem services. Citizen science data confirm the presence of species specific to saltmarsh and reedbeds, however there are limits to the species distribution analysis because of the mistakes related to the nature of the data (citizen science data) and under-sampling of areas that are hard to access.

Although a more even sampling would be profitable, data provided by this study tend to demonstrate the importance of some environments, particularly saltmarsh and reedbeds, and to give background information for conservation measures. The land cover map is a basic fundamental tool for the spatial analysis of the Upper Mersey Estuary.

Résumé

La biodiversité remarquable de l'Upper Mersey Estuary est particulièrement mise en lumière depuis le projet de construction d'un pont le traversant et les études écologiques qui ont accompagnées ce projet. Le manque d'analyse spatiale, et notamment l'absence de cartographie de la végétation sur l'ensemble de la zone, est cependant une lacune pour l'analyse du milieu. Le premier objectif de cette étude est de produire une carte de la couverture de végétation sur l'ensemble de l'Upper Mersey Estuary par photo-interprétation, afin de localiser les zones à forts enjeux environnementaux. Le second objectif est de cartographier l'utilisation des sols et de mettre en place une méthode pour l'analyse spatiale des services écosystémiques. Enfin, des données de “sciences participatives” (relevés effectués par des naturalistes professionnels ou amateurs) sont étudiées afin d'analyser la distribution des espèces en fonction des types de végétation.

La cartographie de la végétation montre une présence importante des prés salés et une présence non négligeable de roselières. La précision de la carte est estimée par comparaison avec deux cartes de référence, et montre des résultats satisfaisants. La carte de la végétation permet dans un premier temps d'obtenir une carte de l'utilisation des sols, puis une méthode est proposée pour cartographier la capacité d'une zone à apporter des services écosystémiques. Les données de sciences participatives confirment la présence d'espèces spécifiques aux prés salés et roselières, cependant l'analyse de la distribution des espèces comporte des limites du fait des erreurs que peuvent comporter des données issues de science participative et de la sous-prospection de zones difficiles d'accès.

Une prospection plus homogène serait profitable, néanmoins les études faites permettent déjà de montrer l'importance de certains milieux, en particulier les prés salés et roselières et d'orienter les politiques de conservation. La cartographie de la végétation constitue un outil de base pour l'analyse spatiale de l'Upper Mersey Estuary.

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Reader information

This dissertation is submitted for the completion of my studies at AgroParisTech with a specialization in Management of Natural Environments ('*Gestion des Milieux Naturels*') and exposes the work being produced during my end of study internship at the University of Salford, England.

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List of acronyms and abbreviations:

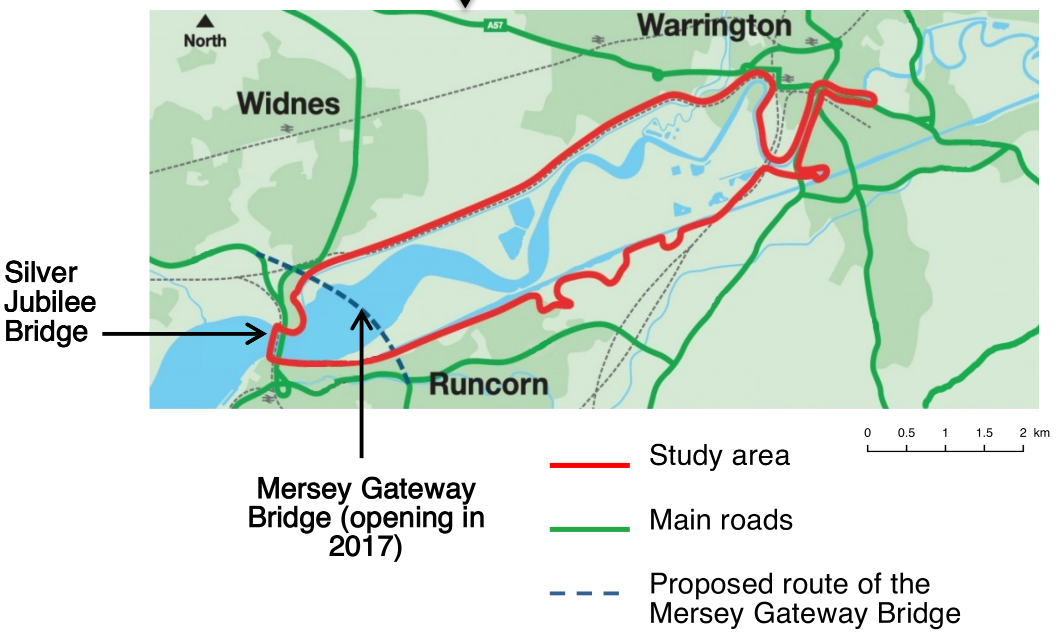
Defra: Department for environment, food and rural affairs
GIS: Geographic information system
JNCC: Joint nature conservation committee
MGET: Mersey gateway environmental trust
NERC: Natural environment research council
OS: Ordnance survey
RSPB: Royal society for protection of birds
SPA: Special protection area
UK BAP: UK Biodiversity Action Plan Broad Habitats
UME: Upper Mersey Estuary

Introduction

The 1,654 hectares study area is the Upper Mersey Estuary (UME), which is a part of the Mersey Estuary is located in the North West of England, in the boroughs of Halton and Warrington. The area of interest stretches along the estuary from the Silver Jubilee Bridge on the east side to the town of Warrington on the west side.

Figure 1: Geographical context

In addition to the Silver Jubilee Bridge, plans for a new bridge have been developed since 1994. Permission for the infrastructure was granted in 2014 after several surveys in the area, including ecology surveys.
The Upper Mersey Estuary is consequently facing major environmental and socio-economic changes. A long-term management strategy will be set up after the end of the construction in 2017.



Mersey Gateway Environmental Trust (MGET) has been created with the Mersey Gateway bridge project. The MGET aims to support the conservation, protection and improvement of the estuary environment. It has been agreed that the MGET will deal with the management of saltmarsh over a thirty years period after the completion of the bridge in 2017.
Despite the proximity with the Middle Mersey Estuary, an area that has the international designation of Special Protection Area (SPA) the Upper Mersey Estuary is one of the few estuarine habitats areas in Britain without a statutory protection. The Upper Mersey Estuary has however the designation of Local Wildlife Site. Local Wildlife Site is a designation used by local authorities in England for sites of nature conservation value. The MGET aims to improve the UME saltmarsh through the thirty years plan management and to get a similar quality to the Middle Estuary.

Reedbeds are among the most important habitats for birds in the UK because of their ability to support many breeding birds. They can be used as feeding and roosting site for many migratory species, and are also good for invertebrates. The small total area of reedbed in the UK (about 5,000 hectares according to UK Biodiversity Steering Group, 1998) makes reedbeds extremely sensitive. Sea-level rise as a result of climate change is predicted to lead to the loss of significant areas of habitat, including reedbeds (Harrison *et al.*, 2001). Besides, coastal saltmarsh is listed in the Countryside and Rights of Way Act (CROW act) in 2000 as a Habitat of Principal Importance. This listing is confirmed by the recent Joint Nature Conservation Committee (JNCC) revision of the CROW Act. Consequently, saltmarsh and reedbeds management is one of the key features of conservation measures for the UME.

MGET also has a willingness to establish an information baseline of habitat and species through monitoring. Citizen science has been highly promoted the last few years, as well as post-graduate and PhD research particularly with the University of Salford.

Despite the surveys and monitoring work that took place in the estuary, there is no complete, accurate and up to date land cover map for the UME. Most of the conservation work aim to improve or maintain saltmarsh and reedbeds, so it is essential to get a precise and recent map of their location and that is why it is the very first step of this study.
Another aspect of long-term management planning of the area is ecosystem services assessment. A PhD project, started in 2014, aims to assess ecosystem services and develop a tool for management measures based on an ecosystem services approach. This report will provide a land use map of the study area, and a starting point for setting up a method for spatial assessment of ecosystem services. Finally, the last part of this study will be focused on biodiversity monitoring and particularly citizen science contribution. Citizen science has been greatly supported the last few years, but the lack of methodology for this collection of data leads to the question of the relevance of citizen science data.

1. Aims and objectives

In the literature review the importance of a few sets of habitats for biodiversity in the UME. A lack of knowledge regarding the spatial distribution of land cover types, species, and ecosystem services would lead to inappropriate conservation measures. Considering the context of the UME, there is a crucial need of establishing an accurate land cover and land use map.

Hence, the first objective of this study is to produce a land cover map based on aerial photographs and to check the accuracy of this map. These data will enable to localise areas with strong environmental challenges such as saltmarsh and reed beds. The land cover map is the base of this study and all the following spatial analysis requires a land cover map.

Another objective is establishing a method for spatial assessment of ecosystem services. Producing a land use map is one step into this objective. Evaluation of the ability of various land cover to supply ecosystem services is the second step. The aim of this research is not so much analysing the spatial distribution of ecosystem services throughout the estuary, but rather setting up a method to map ecosystem services and discuss the advantages and limits of this method.

Finally, an important aim of this study is to evaluate how reliable and accurate are the species records from the RECORD centre, and determine what analysis we can do (or on the opposite what analysis is not possible to process) with this dataset.

2. Methods

2.1. Land cover mapping

The base of this study is the creation of a land cover map for the whole study area. Land cover map is important not only because of the analysis that will come directly from it (land cover structure, land cover categories proportions) but also because of the further work that allow a land cover map. Land use map is produced from land cover map, and ecosystem services spatial assessment relies on the ability of a land cover to provide the service.

2.1.1. Review of existing land map material

In 2007, a land cover map had been developed as an integral part of the UK Countryside Survey, funded and led by the Natural Environment Research Council (NERC), and the Department for Environment, Food and Rural Affairs (Defra). This land cover was established for all the UK. It was created by classifying satellite imagery into land cover classes based on similar spectral signatures. The land cover classes used were taken from the UK Biodiversity Action Plan (UK BAP) Broad Habitats.
This land cover method (Appendix 1) is an effective way to get large area of land cover map in small amount of time, as the process is based on digital information only (the spectral signature).
It is stated in the Countryside Survey (2007) that this method showed an overall accuracy of 83%, but that this accuracy may be different between land classes and areas mapped.
In the case of the Upper Mersey Estuary area, it is obvious that some confusions between land cover classes occurred during the mapping process. The majority of the area is mapped as 'Arable and horticulture', whereas in reality only a small portion of the UME is constituted of arable and farmlands. Most of the saltmarsh, reedbeds and grasslands were mapped as 'Arable and horticulture'. For this 2007 land cover map a simple qualitative checking is enough to state that the map cannot be considered as accurate for the study area.

There is a range of GIS data supplied by the Ordnance survey, including some land cover or land use features (open water area, woodlands, urban area, roads and paths…). The Ordnance survey is the national mapping agency for Great Britain. This GIS information is useful for further checking of land cover and land use map, as the reliability of this data is very high, the Ordnance survey being renowned for remarkable quality of data. However, the ordnance survey maps are not detailed enough as they only provide spatial information on a very limited number of land cover and land use category.

Finally, the assessment of terrestrial and avian ecology in 2011 for the Mersey Gateway Project (prior the beginning of construction) required Phase 1 habitat survey. Two areas have been surveyed and mapped, Astmoor Swamp and Widnes Warth (Appendix 2). The results are two detailed vegetation maps (Appendix 3, Appendix 4) for a small portion of the estuary. These maps can be considered as fairly accurate, as land cover maps produced based on field data are usually more accurate than land cover based on satellite imagery (Foody, 2002). The level of accuracy of these two maps makes them good candidates for being used as reference maps during land cover checking process.

2.1.2. Choice of land cover mapping method

The second step of the process of land cover mapping, after the review of existing material, is to choose which method is the most sensible for mapping land cover in the area.

Field assessment is a reliable way to generate a land cover map, but it is very time consuming and can be costly. Another issue raised by this method is that a significant portion of the UME is not accessible, such as brownfield sites.
Because of the limited access to the estuary, the most appropriate method for land cover mapping is the interpretation of aerial photographs. There is a range of good quality aerial photographs provided by Google Earth, the most recent ones being taken in early 2015.

2.1.3. Method for interpretation of aerial photographs

The material used for land cover mapping was Google Earth aerial photographs taken in 2015.

The land cover classification used for the land cover map is sensibly the same as the one used in the 2007 land cover map of the Countryside Survey. However, two categories have been added to the UK BAP classification: brownfield and reedbeds. Brownfield and reedbeds were indeed hard to fit in any category in the UK BAP classification. Reedbeds are an important land cover of the estuary that support many birds species so it was crucial that they appear clearly in the land cover categories.

*Table 3: Land cover categories used for the UME land cover map. Categories are based on the UK Biodiversity Action Plan Broad Habitats (UK BAP). * indicates categories added to the UK BAP classification.*

Land cover categories	Definition
Arable and horticulture	Annual crops, perennial crops
Broadleaved woodland	Broadleaved trees making up 90% or greater of the woodland. Area is considered forested if trees cover 70% or greater area
Brownfield*	Land previously used for industrial or commercial purpose
Improved grassland	Grassland with higher productivity, improved by management practices for agricultural purposes
Neutral grassland	Grassland characterised by vegetation dominated by grasses and herbs on a range of neutral soils
Reedbeds *	Reed *Phragmites communis* dominated wetland vegetation communities
Rough grassland	Unimproved, semi-natural grassland
Saltmarsh	Coastal intertidal zone between land and open water, dominated by dense stands of salt-tolerant plants such as herbs, grasses, and low shrubs
Urban, buildings	Built-up areas
Waterbody	All areas of open water

Most of the categories were relatively straightforward to map as they can be clearly identified on aerial photographs. All the woodlands in the UME have dense population with clearly defined limits so they were no problem of classification of semi-open forest. As exposed in the example Figure 2, aerial pictures show a clear difference between arable land and grassland, saltmarsh and reedbeds. On the other hand, distinction between rough, neutral, and improved grasslands is not something that can be easily interpreted on aerial photographs. In some photographs it may also be tricky to make the difference between saltmarsh and grassland. In those cases, a review from experts of the area is asked.

Figure 2: Aerial photograph of a part of the UME, Moss Side Farm, showing the difficulties of interpretation of photographs

2.1.4. Possibilities for land cover map accuracy assessment

2.1.4.1. Possible methods for accuracy assessment

Assessment of land cover classification accuracy is a complex issue. Foody (2002) pointed out three methods for checking the accuracy of land cover maps.
The first way is the easier but also the less rigorous. Accuracy assessment can be based on a basic visual appraisal of the map by experts with local knowledge of the area. This method is qualitative only and not very precise nor rigorous.
Another way of assessing accuracy is to collect on-site data for verification. This is probably the most precise and appropriate method for checking accuracy (Foody, 2002), but it is a process that is limited by accessibility to the site, and that is also time-consuming. A significant portion of the UME is not accessible, in particular brownfields, so that way of assessing accuracy was hard to consider and to apply to the study area.
Finally, comparing the map with existing land cover information and maps allows accuracy checking. Although there is no other comprehensive, up to date and detailed land cover map of the UME, some habitat surveys took place in the study area in 2011, prior the beginning of the new bridge's construction. Two vegetation maps were produced for two small portions of the UME, Widnes Warth (Appendix 3) and Astmoor (Appendix 4). The categories used for

the land cover map and these two vegetation maps differ slightly, but they all show open water, reedbeds and saltmarshes. The area of these three categories can therefore be compared.

2.1.4.2. Method used in this study

The two vegetation maps and the land cover map have been converted into raster on QGIS. The 25m pixels of the Widnes Warth and Astmoor area of the land cover map have been compared with the 25m pixels of the vegetation maps. The only pixels being compared were the saltmarsh, reedbeds, and broadleaved woodland pixels of the land cover map, because these categories were similar in the land cover map and the vegetation maps. The result of this comparison is an agreement rate for saltmarsh, reedbeds and broadleaved woodland mapping for Widnes Warth and Astmoor area.

The habitat and vegetation surveys also provided an estimation of the total area covered by saltmarsh and reedbeds (185 hectares), open water and mudflats (413 hectares) in the UME. This is a simple area estimation, with no map being give, so no comparison pixel by pixel is possible for the whole UME, however a simple comparison of the number of hectares may help to confirm the accuracy of the land cover map.

A comparison between the land cover area obtained in this study and the land cover area of existing material gives an overview of the accuracy of the land cover mapping work.

2.2. Land use spatial assessment

Although land cover and land use are distinctive features, and one land cover will not systematically have the same land use, a correlation between land cover and land use can often be seen. In this study a land use map is being produced based on a land cover map and additional informations.

2.2.1. Land cover to land use method

The classification adopted for land use corresponds to the National Land Use Database (NLUD) system.

Land use relates to the activity for which land is used, whereas land cover relates to the physical nature of the land surface. Relationships between land cover and land use can be used to infer land use from land cover. For example an arable land will be associated with agriculture. Most of the time some field information is required in this process. A woodland, for example, can be classified as managed or unmanaged forest.
The rules that were first applied to the UME are set out in Table 2. These rules identify trends in the relation between land cover and land use.

Most of the semi-natural areas of the UME or the area not covered by agricultural crops or forests will be considered as ‘unused land’ in this classification. The NLUD classification is very detailed for anthropized areas so these areas need to be studied case by case to see in which category of the NLUD classification they would fit. There is no unmanaged woodland in the UME so they will be all classified as managed forest.

Table 4: Land use from land cover categories

Land cover category	Land use category
Arable and horticulture	Agriculture
Broadleaved woodland	Managed forest
Brownfield	(1)
Improved grassland	Unused land
Neutral grassland	Unused land
Reedbeds	Unused land
Rough grassland	Unused land
Saltmarsh	Unused land
Urban, buildings	(2)
Waterbody	Waterways

(1) Land use category will often be ‘refuse disposal’, but needs further analysis case by case
(2) Need further analysis case by case

This method was then completed with local information, particularly on woodlands and urban areas, to get an accurate idea of land use spatial distribution along the estuary. Local information is essential to identify land use types that are hard to assess base on land cover categories (for example industry and business, or dwellings, which will be all under the urban and buildings land cover category).
Some other basic information was also added to the land use map, such as roads and paths or presence of car parks. Land access is an important feature of land use.

The land cover map and additional local information have enabled the production of a detailed land use map for the study area, which is a step further into ecosystem services spatial assessment.

2.2.2. Methodological approach for spatial assessment and mapping ecosystem services

Ecosystem services are the benefits people obtain from ecosystems. There are ecological or physical processes which society need, want, and use (Lawton *et al.*, 2010). Flood protection, carbon sequestration and biodiversity are examples of ecosystem services. Ecosystem services can be divided into four categories (Millennium Ecosystem Assessment, 2005):

- provisioning services (food, freshwater, fibre, fuel wood, biochemical, genetic resources)
- regulating services (climate regulation, disease regulation, water regulation, water purification, pollination)
- supporting services (primary production, soil formation, nutrient, cycling)
- cultural services (spiritual and religious, aesthetic, recreation and ecotourism, inspirational, educational, sense of place, cultural heritage)

Methodologies used for identifying, assessing and mapping ecosystem services are diverse and often inconsistent. Similarly, the spatial representation, objective of mapping, and number of ecosystem services assessed and mapped vary widely. Assessing and mapping the distribution of multiple ecosystem services is a complex task due to lack of data (Naidoo *et al.* 2008, Seppelt *et al* 2011). Two methods identified from a range of recent studies are to either use expert opinion to rank the relative capacity of ecosystem services (Burkhard *et al* 2009 & 2012, Nedkov & Burkhard 2012, Vihervaara *et al*. 2010, Yapp *et al.* 2010) or estimate values using proxies (Luck *et al*. 2009, Turner *et al.* 2007).

A number of studies estimated the capacity of a land cover category to provide ecosystem services (Appendix 5 and 6). The method for ecosystem services mapping consist of inferring a capacity of ecosystem services to a land cover type. This process is then completed by some land use information that helps to refine the assessment of ecosystem services. For example, knowing if a saltmarsh (land cover type) is being grazed or not (land use information) will help to estimate more precisely the level of a range of ecosystem services.
The material used as a base of this work is therefore: the UME land cover map, land use map, and literature review evaluating levels of ecosystem services provided by land cover and land use types. In this study, we assess and map four ecosystem services with the methodological approach explained in Figure 3.

The ability of the UME land cover types to provide an ecosystem services were estimated based on the evaluations found in the literature review (Burkhard *et al* 2009 & 2012, Nedkov & Burkhard 2012, Vihervaara *et al*. 2010, Yapp *et al.* 2010) and are exposed in Table 5.

Figure 3: Methodological approach for spatial assessment and mapping of ecosystem services

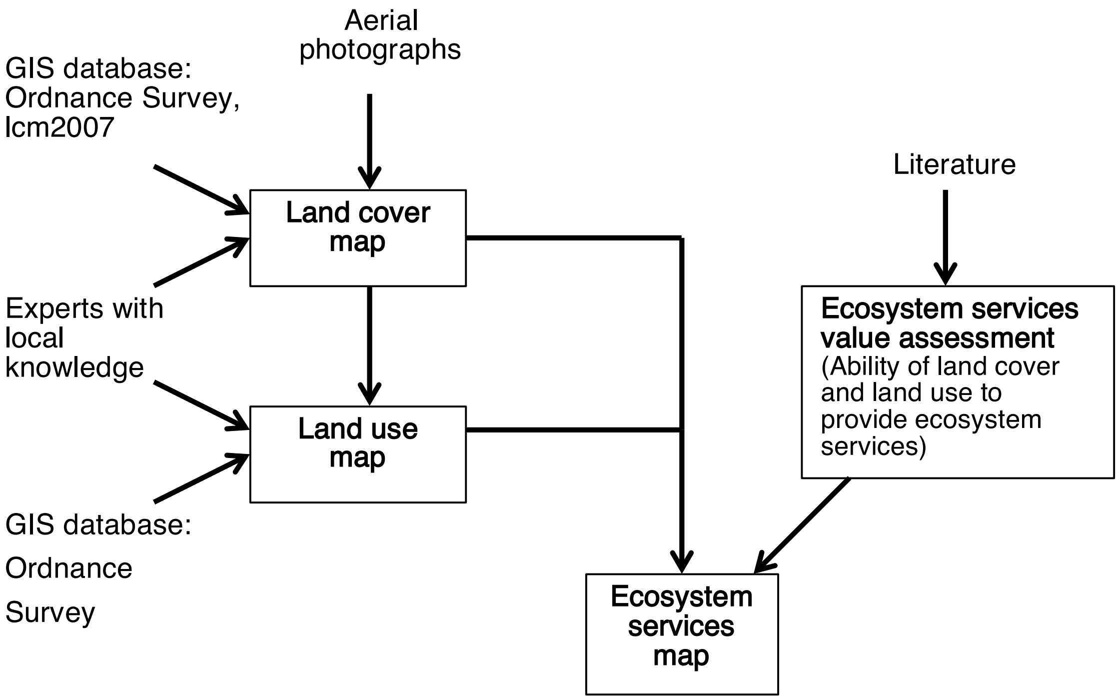


Table 4: Relative ecosystem services capacity depending on the land cover. L=Low, M=Medium, H=High.

Land cover \ Ecosystem services	Biodiversity	Carbon sequestration	Provision of water	Aesthetic value
Waterbody	M	L	H	H
Grassland (rough or neutral)	H	M	M	H
Improved grassland	M	M	M	H
Arable and horticulture	L	M	L	M
Broadleaved woodland	H	H	M	H
Non grazed saltmarsh	M	H	H	H
Grazed saltmarsh	M	H	M	H
Reedbeds	H	H	H	H
Brownfield	L	L	L	L
Urban, buildings	L	L	L	L

This method can be used as a base of work for ecosystem services mapping. This base work needs to be completed with local information on ecosystem services in order to get a greater precision of ecosystem services assessment. This information may be added when further information will be available through the PhD research project currently working on the UME ecosystem services.

In this report, ecosystem services spatial assessment is based mostly on the land cover type and therefore will have some imprecision in the assessment. It is important to remind here that the aim of this study is to determine the bases of a method for ecosystem services spatial assessment, rather than analysing the results of this spatial assessment.

Land cover map is a sensible tool for spatial assessment of land use and ecosystem services. In this study the land cover map is also used for spatial analysis of biological records from citizen science.

2.3. Data treatment of species records provided by citizen science

Citizen science is a designation for contributory projects with a wide range of volunteers from the community collecting data for a scientific study. Citizen science is commonly used for ecology projects, as it is enables research to be performed on a larger spatial and temporal scale.
Professional and amateur naturalists in Cheshire are regularly invited to enter the species they have recorded on the field into RECORD database. RECORD is a charity that aims to supply useful data for on biological records within the Cheshire region. One of the objectives of this study is to evaluate how reliable these records are.

2.3.1. Data treatment procedure for RECORD database

2.3.1.1. Data entry

When they add an entry to RECORD database, users are required to fill a web-based data form with the following information:

- Species recorded (vernacular name, scientific name, order, family)
- Number of individuals recorded
- Location of the record (grid reference number, name of locality)
- Name of recorder
- Date of record
- Date of data entry

Recorders are asked to locate on the Ordnance survey national grid map the place of their record, which will give a grid reference number. They can choose the size of the grid depending on their level of confidence regarding the location of the record:

- 4 numbers in the grid reference: precision 1 km^2
- 6 numbers in the grid reference: precision 100 m^2
- 8 numbers in the grid reference: precision 10 m^2
- 10 numbers in the grid reference: precision 1 m^2

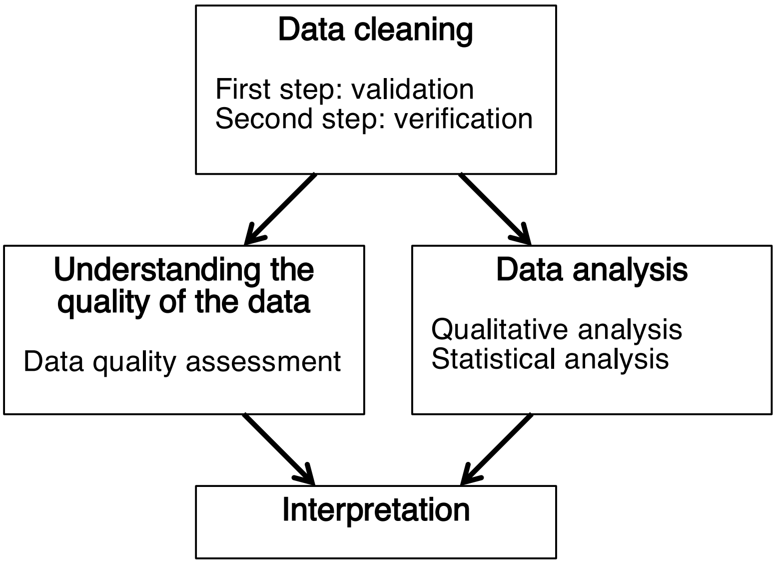
2.3.1.2. Validation and verification process

Every data entry is going through a validation-verification process before being incorporating in the database.

Validation:
It is an automated process that enables to filter the obvious errors and the data that is not in the adequate format. The criterions being checked are:
- species names must be within a list of national names
- date of the record must be in the correct format
- grid reference accuracy: must have between 4 and 10 figures and refer to an area in the UK

Verification:
Verification is an additional, non-automated process. Some county recorders and specific taxon experts check records for the taxon and locality where they have a level of expertise. This is not a systematic process, and it will be more likely to be done for rare species rather than common species.

Figure 4: Usual process for citizen science data treatment



Some data cleaning is provided by RECORD centre. Further data cleaning is done in this study as well as an assessment of the quality of the data.
Land cover types are attributed to species records, using the 'Joint attributes' function of QGIS. The result of this work is a database with all the species records and the land cover where they have been recorded and there will be further analysis on this data.

2.3.2. Data quality assessment and data cleaning

One of the aims of this study is to evaluate what kind of analysis is possible with this citizen science dataset and identify if it could be one of many tools for conservation policies, or if management measures should rely on scientific systematic monitoring only.
First, it is important to highlight the fact that there are various levels of quality amongst citizen science projects, as some of them involved a detailed monitoring plan, training of the participants, or feedback of the participants via a questionnaire. The dataset studied here does not involve any of this process, the advantage being an important amount of records can be incorporated into the dataset, but it raises the question of the quality of the data.

2.3.2.1. Random error and bias of citizen science data

Fitzpatrick et al. (2009) found difference between observations made by volunteers and by experienced scientists led to biases in their results.
First, citizen science data is prone to greater error, due to differences in the skills of volunteer participants. Sampling error may happen in identification of species and quantification of individuals.
Second, without a monitoring plan, sampling bias is likely to occur in the collection of data. For example, surveys are often located in areas that are more accessible, such as sites near roads (Tulloch and Szabo, 2012). Over and under-sampling of areas of the UME may lead to incorrect estimates of species abundance and occurrence.

Mapping the species records will help to assess over and under-sampling in the UME. It is however a complex task to estimate the rate of error and the skills of volunteer participants. In this study attention will be brought to the error in the location of the records

2.3.2.2. Accuracy of location

Records have been located into a grid reference with a precision that can vary between one square kilometre up to one square metre.
One of the questions rising from this disparity is the relevance of the data with very poor precision. In this study, land cover types are attributed to species records, but a one square kilometre precision does not allow any conclusion on the habitat where the species have

been recorded. It seems appropriate to discard the records with only four figures in the grid reference number for spatial analysis, but there need to be a further analysis to determine if records with six and eight figures in the grid reference can be used for spatial analysis.

The superposition of the land cover map and the species records map show some obvious mistakes in grid referencing. For example, a fox record indicates a location in the middle of the estuary. Other terrestrial animals have been found being recorded in open water.
These errors on the can be either due to

- a mistake whilst the record has been identified
- a mistake whilst the record has been reported
- an approximation of the place of the record because of the constraint of a grid reference. Records are placed in the centroid of the grid, which can lead to an approximation of the record location if the species has been seen at the edge of the grid. Consequently, records may not be attributed the correct land cover during the superposition of the land cover map and species map

An other explanation for incoherence between species records and their land cover attributes could be an approximation in the land cover map. For example, some small ponds may not appear on the map (if there are too small to be mapped, or if there are hidden by tree cover) and can lead in an aquatic species having a land cover attribute that is not water.

Data cleaning process first involved spotting the obvious incoherence between species records and their land cover attribute, such as terrestrial species being recorded in open water. Land cover map was then checked in order to see if the mistake was coming from the land cover map precision or, as it was in most of the case, from the record spatial referencing. This first approach gives a fairly similar error rate for the records with a six figures grid reference and with eight figures or more (respectively 1.28% and 1.13 %). This tends to show that the records with a six figures grid reference are accurate enough to be considered for spatial analysis.
This error rate only takes into consideration the most evident mistakes and it is very likely that other location mistakes are present in the dataset.

A further step into data cleaning was to correct these location mistakes. In most of the case these errors could easily be corrected. For example, if a fish was located in a grassland but only a few meters away from the estuary, the record was re-located into the estuary.

Following data cleaning, the numbers of records that can go through analysis has considerably decreased. The simple fact of selecting only recent records with four figures or more in the grid reference induces a substantial loss of data.
In this study, the records distribution analysis will be mostly focused on birds, as other taxa do not have a sufficient number of records for robust analysis after data cleaning.

In conclusion, the land cover map, based on interpretation of aerial photographs, enables the production of a land use map. A further step is the analysis of the ability of the UME to provide ecosystem services based on the land cover types.

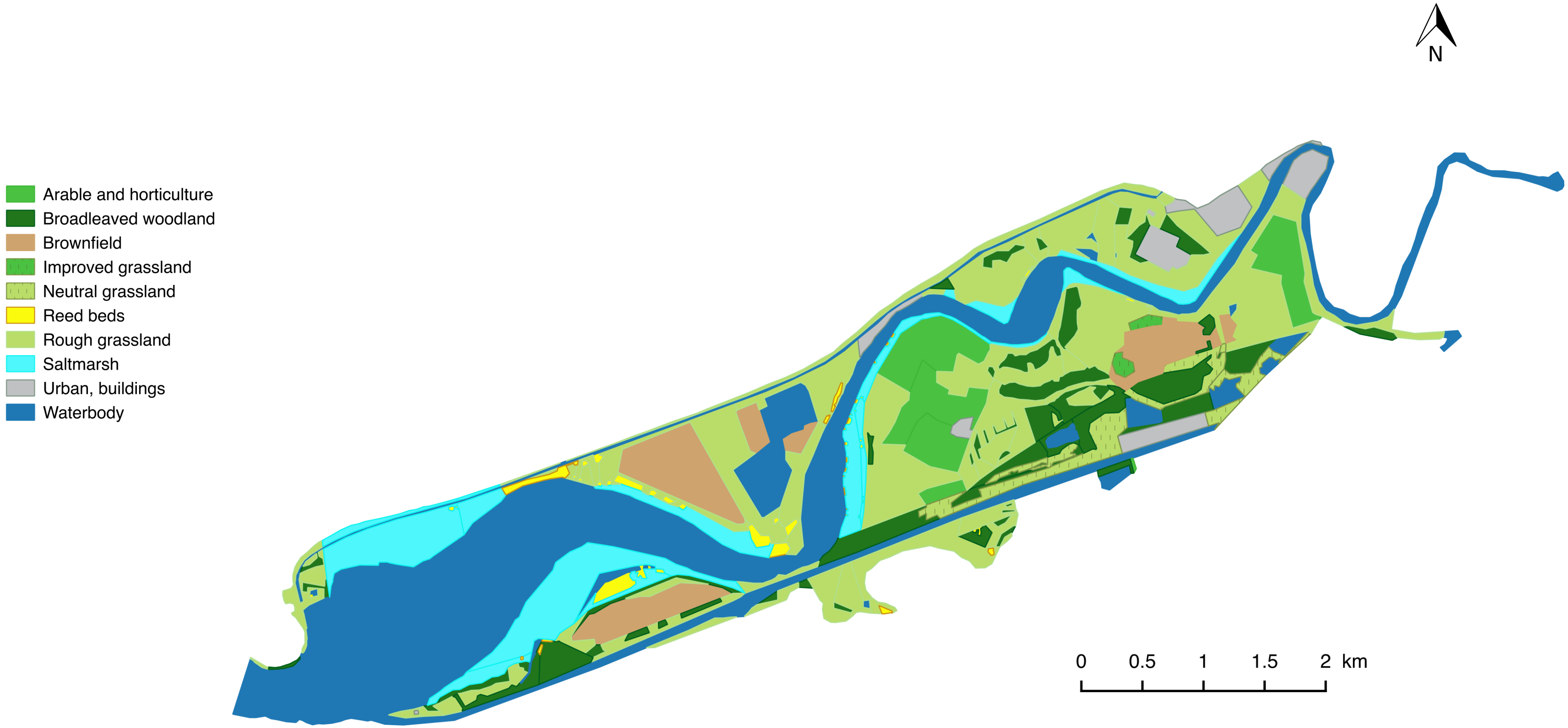
3. Results

3.1. Land cover

3.1.1. Land area distribution and proportion

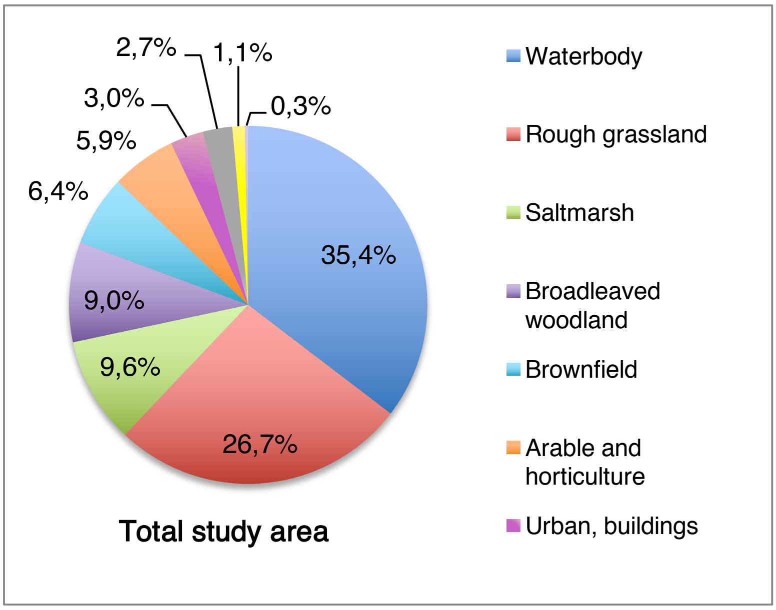
The map presented in *Figure* ***5*** provides comprehensive 2015 land cover information for the UME. Land cover categories are based on UK Biodiversity Action Plan Broad Habitats classification, with an addition of two classes, reedbeds and brownfields.

Figure 5: Land cover map of the Upper Mersey Estuary obtained via aerial photographs interpretation.



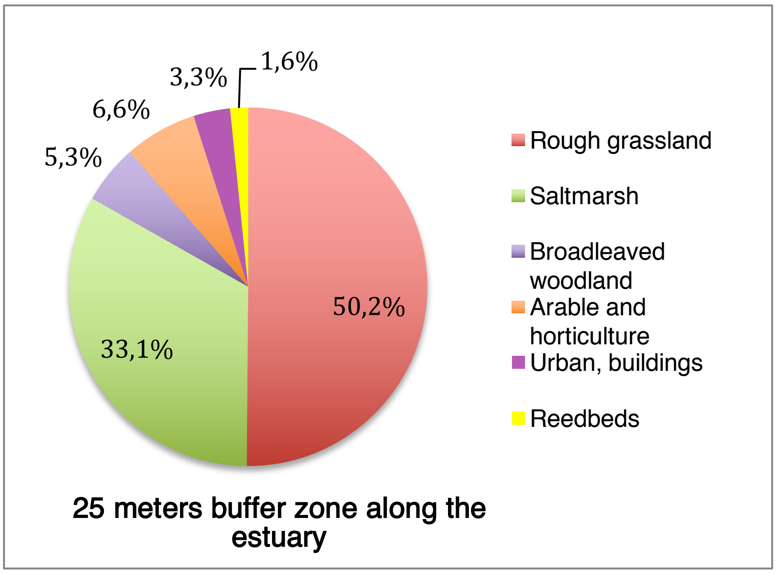
The following charts show that some land cover features are predominant in the UME.

Figure 6: Land cover area proportion in the UME



Rough grassland and the estuary dominate the landscape in the study area.

Saltmarshes also have a substantial share of the UME (9.6% of the study area, relatively 14.9% if we consider only the land area and not the area covered by the estuary.)



Saltmarshes are predominant along the estuary, as 33.1% of the land within a 25 metres buffer zone around the estuary is saltmarsh.

Reedbeds count as a small portion of the UME (1.1% of the UME, with a total area of 19 ha). Nevertheless, this area is not negligible, as there are only about 9,000 ha of reebdeds in the UK (Hardman, 2012).
The UME provides mainly some small patches of reedbeds (90% of reedbeds patches cover less than 1 ha), but also some bigger blocks of 3 and 4 ha.
This variety of reedbeds sizes is an interesting feature for specialist bird species associated to reedbeds. These species have different requirements regarding vegetation structure. Bittern (*Botaurus stellaris*), for example, appreciate large continuous block of wet reedbeds. Water rail (*Rallus aquaticus*) prefers a mosaic of habitat with dense clumps of reed (RSPB, 2014) The detail of birds species requirement regarding reedbeds and particularly reedbeds structure is exposed in the following table.

Table 5: Breeding and feeding requirement for a range of bird species recorded on reed beds in the UME. Adapted from RSPB, 2014

Species	General requirement	Breeding requirement
Bittern *Botaurus stellaris*	Generally large wet reedbeds, with wet areas, particularly flooded reed edges adjacent to open water, accessible and available throughout the season	A continuous reed block, wet through the season, for females to nest. Females will fly >1km to find food but prefer if good feeding is nearby
Marsh Harrier *Acrocephalus palustris*	Tall vegetation, traditionally reedbeds where they will choose wetter areas, but recently also in arable fields	Freshwater or brackish reed swamps with large areas of dense emergent aquatic growth
Water Rail *Rallus aquaticus*	Mosaic of habitat with tall dense clumps of reed or marsh vegetation in shallow standing water or slow moving water, close to fringing scrub and exposed mud or drier patches	Territories are particularly associated with a mosaic of scrub, vegetation, exposed soil and water. Nests are found in sedges, reeds, grasses, bracken or a mixture of these with standing water
Grasshopper Warbler *Locustella certhiola*	Dense ground cover, including tall marshy vegetation, ideally with some small shrubs	Breeding birds will nest and feed within the same area, so dense ground cover should extend across as large an area as possible (about an hectare is optimum). A wet or dry tussock structure is ideal with birds being able to move unseen between tussocks.
Bearded Tit *Panurus biarmicus*	Mixed reedbed, with areas of reed litter, with a high reed/water interface. They prefer the reedbed edge near water for foraging, and, in spring and summer, fly to wetter areas.	Drier, older area of reedbeds is needed for nesting and a dense cover of dry, thin reed stems is important for concealing nests. Nesting areas may be well separated from feeding areas.
Reed warbler *Acrocephalus scirpaceus*	Summer visitor able to adapt to a range of reedbeds	Nesting structure provided by stronger plant species like meadowsweet, nettles or Japanese knotweed

Consequently, the variety of reedbeds size within the Upper Mersey Estuary is profitable for bird species.

3.1.2. Results of map accuracy assessment

Experts with local knowledge of the area have reviewed the land cover map to correct minor mistakes that occur because of the difficulty to discriminate land categories based on aerial photographs. That first approach showed that the main confusion possible were between the grassland categories (rough grassland, improved grassland, neutral grassland). Others categories tend to be much more blocky and homogeneous, and interpretation of aerial photographs is not likely to induce confusion.

The results of the habitat and vegetation survey that took place in 2011 were used as reference information for accuracy assessment.
Areas of land cover classes have been compared:

- on a small scale (nearly 200 hectares), in Widnes Warth and Astmoor (Table 5) with a pixel by pixel comparison
- on a large scale for the whole UME (Table 6) with a simple number of hectares comparison.

Table 6: Similarity between the land cover map pixels and the habitat and vegetation map pixels for two areas of the estuary

Area surveyed	Widnes Warth			Astmoor		
Land cover class	Saltmarsh	Reedbeds	Open water	Saltmarsh	Reedbeds	Open water
% agreement between land cover and vegetation map	96.8	90.3	98.5	88.3	83.5	85.0

Table 7: Area difference between the land cover map and the habitat and vegetation survey for saltmarsh and reedbeds, open water and mudflats

Area (hectares)	Land cover map	Habitat and vegetation surveys	% difference
Total saltmarsh and reedbeds	181	185	2
Total open water and mudflats	428	413	3.5

Overall the land cover map produced in this study with interpretation of aerial photographs seems to have a relatively good accuracy. Comparison with habitat and vegetation surveys information shows a high level of concordance. This land cover map may therefore help for elaboration of conservation measures.

3.2. Land use

The land use map has been established based on the land cover map, a range of GIS information and local knowledge of the area.
Land use data are needed for the analysis of environmental processes and understanding if conditions are to be improved or maintained.
The land use map (*Figure 7*) is one step further to the ecosystem services spatial assessment, as both a land cover and land use knowledge are needed for a spatial analysis of ecosystem services.
A spatial assessment of ecosystem services has also been possible based on literature review. The level of ability of land covers to provide an ecosystem service has been mapped in Figure 8 for the Upper Mersey Estuary area.

3.2.1. Ecosystem services spatial assessment

Ecosystem services change over space and time as a result of changing patterns of land use or changes in the composition and structure of different vegetation types.
The potentiality of a land cover category to provide ecosystem services has been assessed by several studies. Based on a literature review, four ecosystem services maps are produced:

- a supporting ecosystem service (biodiversity)
- a regulating ecosystem service (carbon sequestration)
- a provisioning ecosystem service (provision of water)
- a cultural ecosystem service (aesthetic value)

It would be interesting to map a wide range of ecosystem services in order to identify ecosystem services hotspot. Only a few ecosystem services are mapped in this study, and some land categories already seem to stand out. Woodlands, reedbeds and saltmarshes all have the ability to provide a high level of ecosystem services. Areas of the UME that gather these three land cover would have a great importance regarding ecosystem services.
However it should be stressed that this spatial assessment deals only with the capacity of a land to provide an ecosystem service, and not the actual level of ecosystem service. To provide a map of ecosystem services being actually provided, more local information on ecosystem services would be needed.

Figure 7: Land use map of the UME, using the national land use database (NLUD) categories. Background: Ordnance survey map 2015

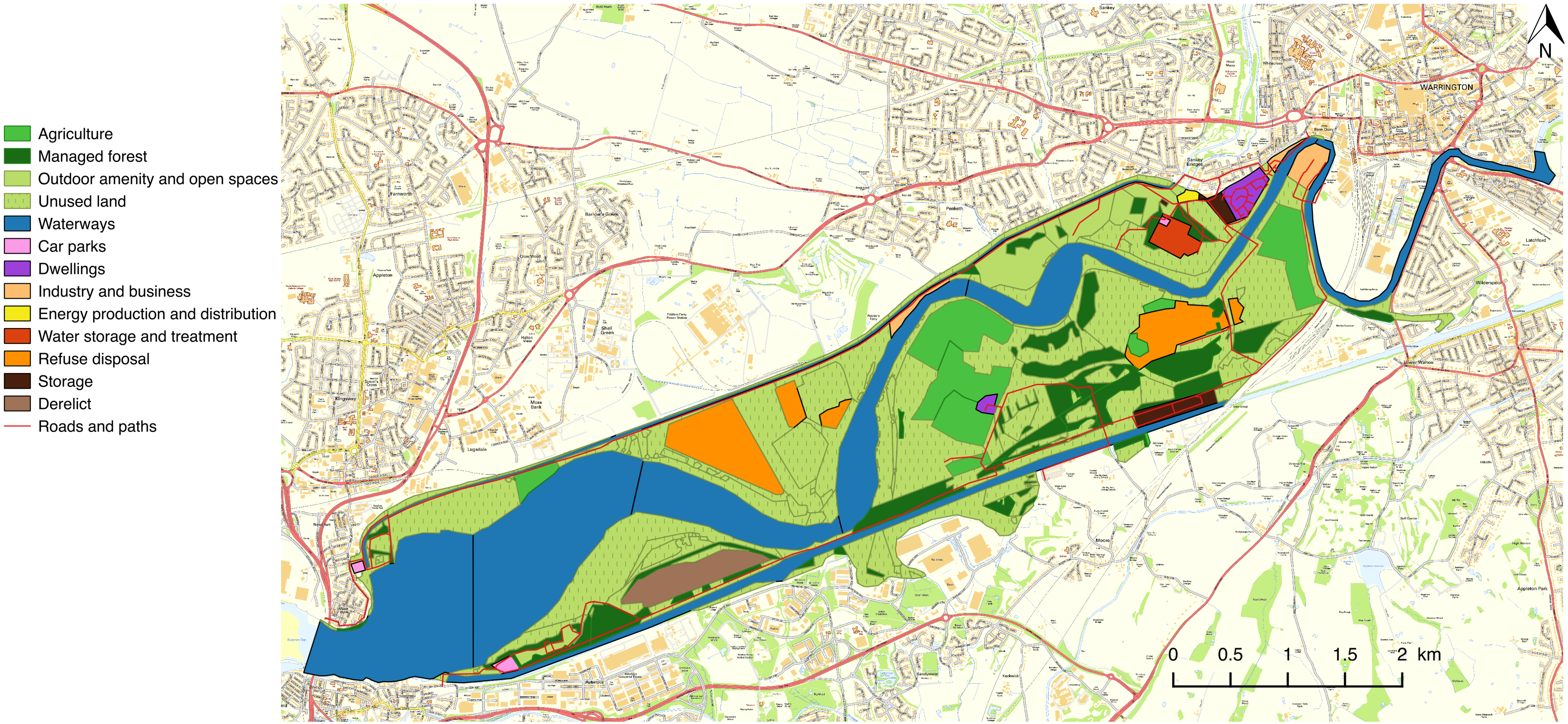
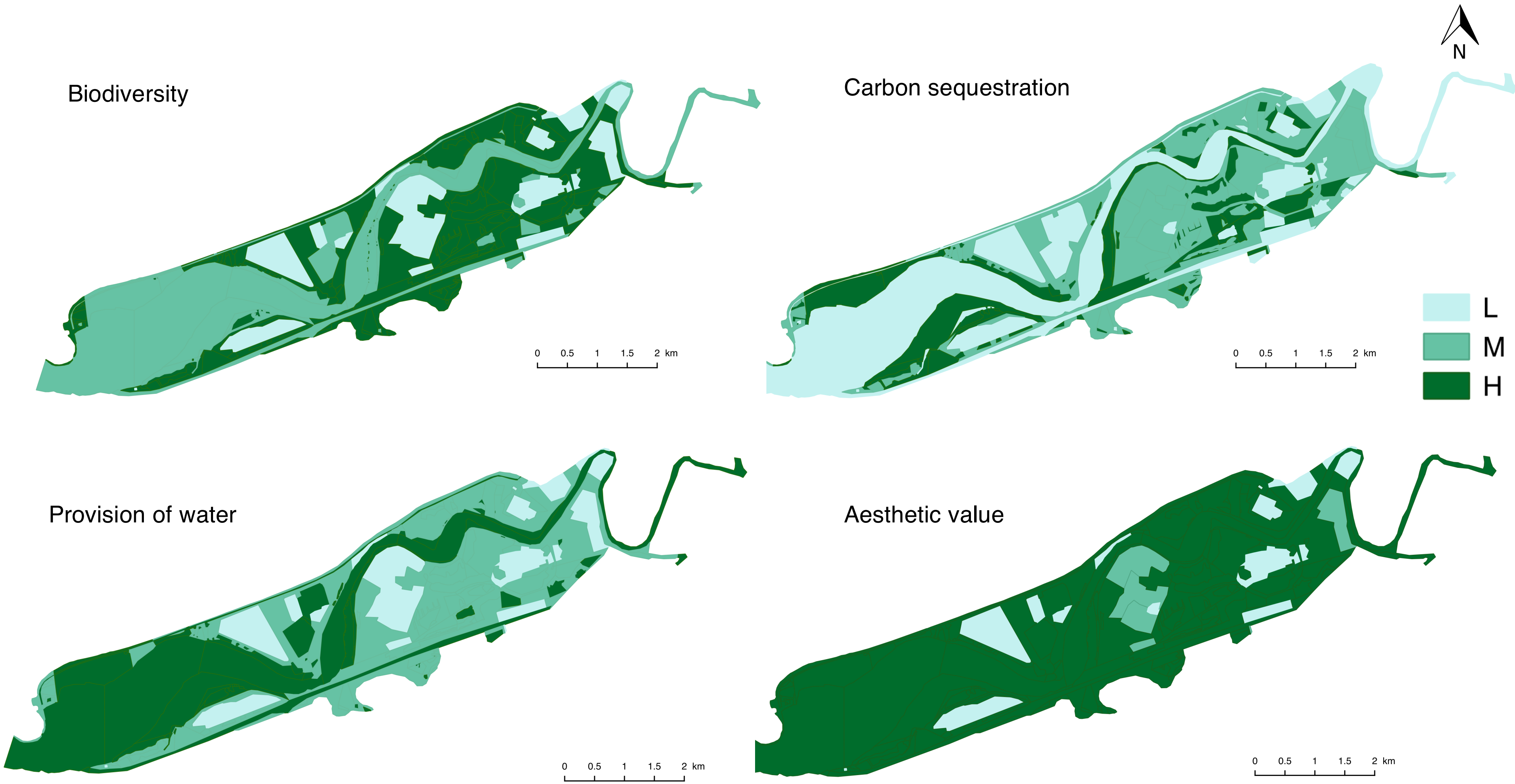


Figure 8: Spatial distribution of the providing probability of 4 ecosystem services: biodiversity (supporting ecosystem service), carbon sequestration, (regulating ecosystem service), provision of water (provisioning ecosystem service), aesthetic value (cultural ecosystem service). L: Low capacity to provide the ecosystem service, M: Moderate capacity, H: High capacity



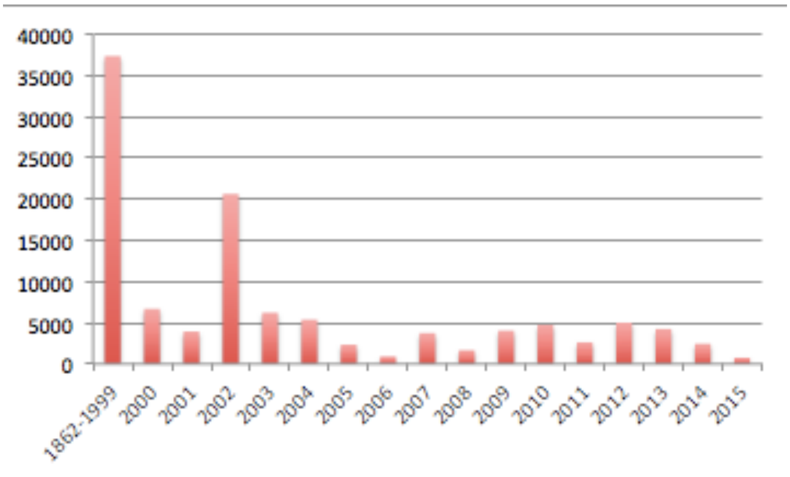
3.3. Citizen science data spatial analysis

The UME counts a broad range of species since the area offer a diversity of land cover and vegetation. Species records from RECORD centre give an opportunity for a better understanding of the estuary diversity and species assemblage.

3.3.1. Data overview and relevance of old data

RECORD centre has the advantage of providing data on a range of species (Appendix 7) and a large temporal scale. This data would therefore be very useful for research projects looking at the evolution of species diversity, abundance, or spatial repartition.
However, if a research project is focused on the current state of the estuary, the number of records that can be studied decrease dramatically. Figure 9 shows that only a few thousands of records (for all the taxa) have been recorded the last few years. The global dataset counts 112,715 records (mostly birds records), but that number decrease to 25,500 if we consider only the 'recent' records (what is designated as recent here is a record that has less than ten years), and 21,161 if we also take out the records with only four figures in the grid reference as they are not spatially accurate enough.

Figure 9: Number of records every year within the Upper Mersey Estuary



Overall, this database seems to be more relevant for temporal analysis than for assessing current state of the UME.
For the rest of the study, only the records sine year 2005 and with a grid precision of six figures or more will be considered.

3.3.2. Species specific to a land cover or vegetation type

The combination of the land cover map and the species record map enables the production of a list of species found in each land cover and the number of records of these species in those habitats. In Appendix 8 a sample of the table is given in order to show the format of the list obtained.

This process pointed out some species assemblage.

3.3.2.1. Species specificity to reedbeds

Analysis of the list of species recorded on reedbeds show that the UME supports a distinctive breeding bird assemblage including Bittern (*Botaurus stellaris)*, Marsh Harrier (*Acrocephalus palustris)*, Grasshopper Warbler (*Locustella certhiola)*, Reed Warbler (*Acrocephalus scirpaceus*), Water Rail (*Rallus aquaticus*), and Bearded Tit (*Panurus biarmicus*). In addition, reedbeds occasionally provide roosting and feeding sites for several birds including Starling, Swallow and Sand Martin. There are significant populations of priority species, notably Skylark *Alauda arvensis* and Reed Bunting *Emberiza schoeniclus*, which use the saltmarsh habitats.

Figure 10 shows the spatial distribution of Reed Rarblers and the clear clustering of this species around reedbeds habitats. For some species, like the Reed Bunting, the results are more mixed: there is an important number of records in the reedbeds located in Astmoor area, but few records in other reedbeds. This can be interpreted either as:

- the Reed Bunting population living only in Astmoor saltmarsh reedbeds
- an undersampling bias in the other reedbeds areas

Reedbeds are not only a rich environment for birds, but also for invertebrates. In the UK, at least 700 species of invertebrates have been found to be associated with reedbeds. Some 64 insect species are known to be dependent on reed to some extent and some 40 species of insect feed solely on reed. (Fojt and Foster, 1992). The number of inverterbrate records in the UME is too low to assess their diversity, but the presence of reedbeds-associated bird species could be an indicator of a high invertebrate abundance and diversity.

3.3.2.1. Birds specificity to various land cover

Bird species recorded in the Upper Mersey Estuary were assigned to different guilds according to their general common characteristics of habitat use, feeding and breeding behaviour. The following table is based mostly on the analysis of land cover where species can be found, and general background knowledge on Cheshire's birds feeding and breeding behaviour was given in James *et al.*, 2010.

Table 8: Guild of breeding birds recorded more than ten times during the last ten years in the Upper Mersey Estuary.

Guild	List of species (vernacular name)	Number of species recorded
Waterbirds	Shoveler, Kingfisher, Gadwall, Great Crested Grebe, Black-necked Grebe, Tufted Duck, Teal, Shelduck, Mute Swan, Black Swan, Canada Goose, Greylag Goose, Reed Bunting, Mallard, Wigeon, Water Rail, Coot, Moorhen, Pochard, Smew, Goldeneye, Cormorant, Great Black-backed Gull, Lesser Black-backed Gull, Common Gull, Herring Gull, Black-headed Gull, Caspian Gull, Iceland Gull, Mediterranean Gull, Little Egret	31
Waders	Curlew, Lapwing, Oystercatcher, Snipe, Common Sandpiper, Dunlin, Grey Heron, Little Egret	9
Woodland specialists	Sparrowhawk, Jay, Nuthatch, Great Spotted Woodpecker, Lesser Spotted Woodpecker, Green Woodpecker, Short-eared Owl, Tawny Owl, Lesser Redpoll, Common Redpoll, Goldcrest, Treecreeper, Brambling, Blackcap, Song Thrush, Eurasian Siskin, Cuckoo, Waxwing, Willow Tit, Coal Tit, Chiffchaff	21
Reedbeds associated	Bittern, Marsh Harrier, Bearded Tit, Grasshopper Warbler, Water Rail, Reed Warbler	6
Farmland seedeaters	Skylark, Grey Partridge, Yellowhammer, Stock Dove, Collared Dove, Pheasant, Linnet, Woodpigeon	8
Associated with open woodland, open grassland, scrub, hedges or shrubs	Blue Tit, Lesser Whitethroat, Grasshopper Warbler, Garden Warbler, Sedge Warbler, Willow Warbler, Meadow Pipit, Pied Wagtail, Stonechat	9
Raptors	Buzzard, Kestrel, Peregrine	3
Aerial insectivores	Sand Martin, House Martin, Swift, Swallow	4
Generalist species living in a wide range of habitats	Blackbird, Wren, Robin, Carrion Crow, Jackdaw, Magpie, House Sparrow, Great Tit, Mistle Thrush, Greenfinch, Bullfinch, Chaffinch, Goldfinch, Dunnock, Starling	15

Figure 10: Spatial distribution of Reed Warblers records in the Upper Mersey Estuary

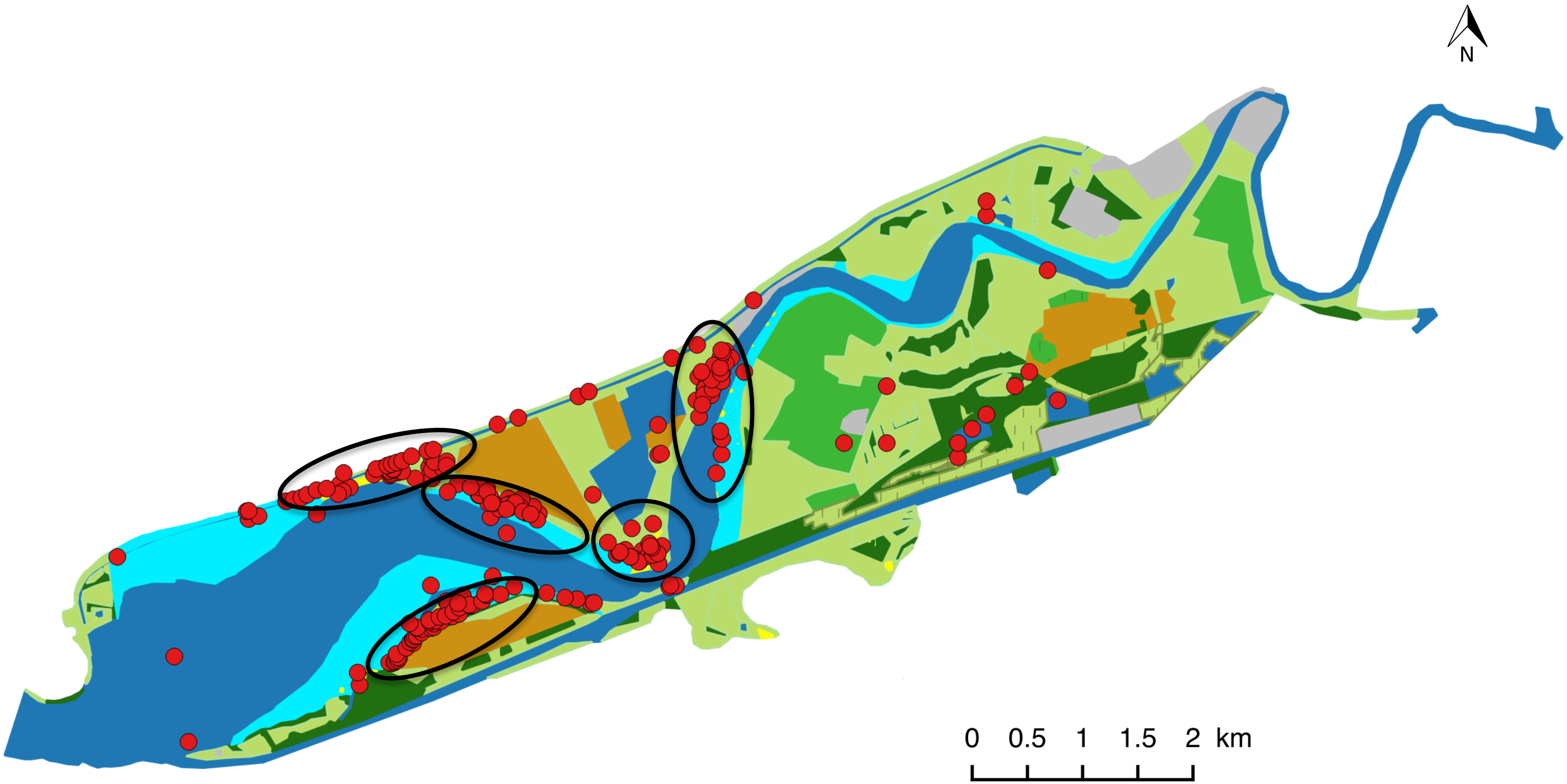
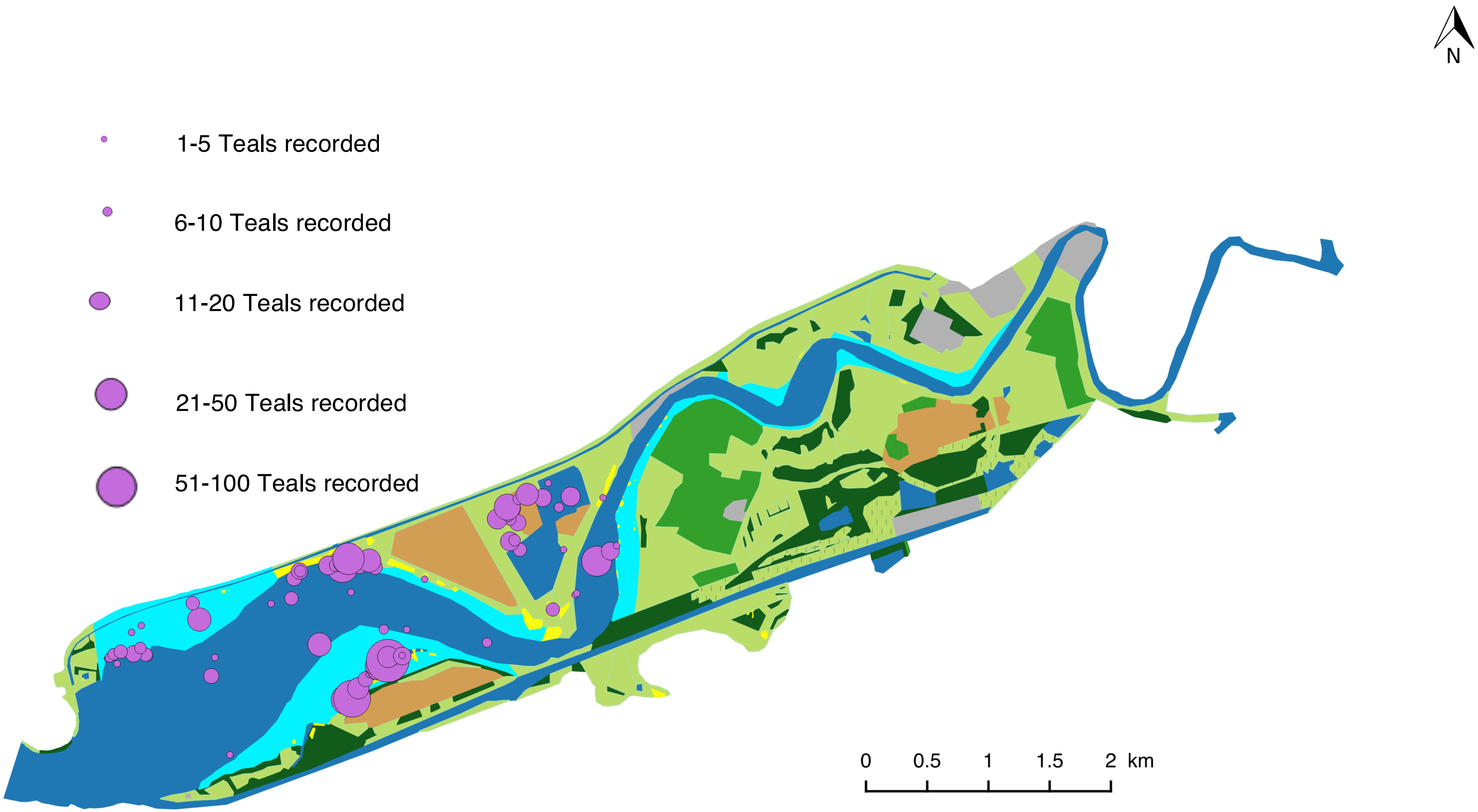


Figure 11: Spatial distribution of Reed Buntings in the Upper Mersey Estuary

Figure 12: Spatial distribution of Teals and number of individuals recorded in the Upper Mersey Estuary



The analysis on specifity of species to land cover types is limited because of the uncertainty of accuracy of citizen science records. However it stresses some trends in the spatial distribution of species. Attention is brought particularly to saltmarsh and reedbeds habitats.

3.3.3. Focus on one species spatial distribution: case of the Teal

A focus on one species may help to give a better image of the importance of habitats, in this case the importance of saltmarsh for the Teal (*Anas crecca*). The distribution of the Teal is shown on figure 13.
Records show that the UME is a major site for wintering Teal. A high density of Teal is present along the UME although a recent decrease of Teal records seems to point out a decline of the population the last few years.
The Teals are largely concentrated on saltmarshes and freshwater. This can be explained by the fact that Teals feed on the seeds of saltmarsh and freshwater plant species. They can be found in large numbers in the Astmoor swamp area, near Fiddler's Ferry Power Station lagoons and on Spike Island saltmarsh.

RECORD database, combined with the land cover map, is a good tool for better understanding species spatial distribution and species specificity to a land cover type. Nevertheless, many records from RECORD database have to be discarded through the validation and verification process, so the number of records that can be used is diminished. The database presents also some bias in the sampling, so analysis of the biological records should be seen as pointing out some trends rather than exposing an exhaustive list of species and their spatial distribution.

4. Discussion

Accuracy of the land cover map, land use map, ecosystem services analysis is subject to discussion. Mapping ecosystem services is not a new process, as several studies have assessed and map the global value of ecosystem services, however these studies are often limited in scale and concentrated on a specific ecosystem or habitat type (Baral *et al.* 2014). Consequently it is crucial to determine the degree of vigour of the methods used in this study.
Assessing the quality of citizen science data is also necessary as this data could be used for brainstorming for management of the Upper Mersey Estuary if it was accurate enough.

4.1. Land cover map

There were some existing materials on land cover but there were either lacking details, not recent, or not covering the whole UME area. This study has produced the most comprehensive, detailed and up to date land cover map of the Upper Mersey Estuary. Good knowledge of land cover may help for habitats management, provided the land cover map is accurate.

The most rigorous method for land cover accuracy assessment would have been to check on site, but practical conditions regarding access constrain the desirable.

The following process contributed to assess accuracy:

1) Verification by experts with local knowledge of the area
2) Comparison pixel by pixel of the land cover map with two existing vegetation maps of two UME areas (assessment of three land categories)
3) Comparison of the number of hectares for some land categories

Several aspects of this method have to be considered cautiously.
First, the existing vegetation maps were produced in 2011, so a change in the land cover is a possibility. Nevertheless, a comparison of the aerial photographs from 2011 and 2015 show that the land cover spatial distribution in Widnes Warth and Astmoor has not undergone any major change since 2011.

The last approach, comparing only the number of hectares between the land cover map and the results of the habitat and vegetation survey, has a major limitation. A map could easily display the classes in the correct proportions but in the incorrect locations. This approach has to be taken cautiously.

Overall the land cover map based on interpretation of aerial photographs seems accurate on a fine scale. Verification by experts highlighted the difficulty of making the difference and setting the boundaries between some land categories, especially grasslands.

4.2. Land use and ecosystem services spatial assessment

4.2.1. Land use categories

One of the key points for mapping land features is the choice of the land categories.

The national land use database classification (NLUD), used in this study for land use mapping, outline mostly anthropized environments. Land use categories are very detailed for urban and semi-urban areas, with a wide range of land use categories proposed, whereas natural areas (such as non-agricultural grasslands, wetlands, scrublands fit in very few categories. Natural areas that are not used for agriculture or as an outdoor amenity and that are not forested will be qualified as an 'unused land' in this classification. This denomination fail to reflect that natural areas can provide a broad range of ecosystem services, even if there are not used for agriculture or forestry.
This classification has been used as it is a reference in the UK for land use mapping, but it may be advantageous for the Upper Mersey Estuary to adapt the NLUD categories for a greater precision of natural areas description.

4.2.2. Relevance and rigour of ecosystem services spatial assessment

Spatial assessment of ecosystem services based on land cover and land use information has varying degrees of rigour (Reyers *et al.*, 2009). Reyers stated that confidence level for mapping ecosystem services is

- low for biodiversity and aesthetic value
- moderate for provision of water
- high for carbon sequestration.

Some ecosystem services are indeed easier to assess quantitatively. Several studies have estimated the average quantity of carbon stocked based on the land cover (Battaglia *et al.,* 2004; DCCEE, 2011) and the amount of potential ground water recharge for various land cover (Benyon *et al.*, 2007,2009). Aesthetic value is something more difficult to assess, as it may differ widely amongst different viewers.
In this study, a method has been applied to get a probability of ecosystem service map. This method requires an evaluation of the capacity of land cover and land use categories to provide an ecosystem service. It is however considerably difficult to estimate biodiversity based on the land cover and land use categories only. Biodiversity does not only depend on land cover and land use, but also on local context and the particular taxonomic unit under consideration. Besides, biodiversity value includes many aspects (number of species of flora and fauna, presence of rare, threatened, and endangered species, area supporting vulnerable habitat type), which importance may vary depending on the area studied, and not just because of the land cover characterization.

That is why it is crucial to highlight the fact that with this standardized method, the maps produced show the *ability* of a land to provide an ecosystem service and that the *actual* ecosystem service provided may differ.

4.3. Perspectives of contribution of citizen science data

The contribution of citizen science data to conservation measures seems limited because of the propensity of data generated to contain great levels of variability (measurement error, identification mistake) or bias (spatio-temporal clustering) in comparison to data collected by scientists following a monitoring plan (Bonter and Cooper, 2012, Wiggins *et al.*, 2011).

The data cleaning process pointed out a fairly similar location error rate for the records with six or eight figures in the grid reference. Records with six figures or more can be considered for spatial analysis but one must remain cautious because of the number of variability and bias of the data.
Spatial distribution of records demonstrates that some areas, for example the northwest of the UME, near the town of Widnes are over-sampled compared to others. The data in Figure 13 and 14 shows the unequal repartition of species records. The areas with a high density of records correspond to the area with easy road access.

Because of the number of mistakes and bias, dataset is moderately reliable. The analysis of the data tends to show a specificity of some birds species related to habitats. A clustering of the reed warblers around phragmites reedbeds for example has been highlighted. Species clustering is apparent but it is important to keep in mind that the dataset involves some major over and under-sampling bias and therefore it is hard to conclude on clustering and high density of species. Similarly, bird guilds that appear in the analysis of the data should be considered as a indication of possible bird guilds rather than an established fact.

Overall, further field surveys have to be undertaken before concluding on the species records dataset. This dataset is a good opportunity for investigating species spatial distribution and abundance, and can be considered as a base of work prior to verification with field surveys, rather than as an accurate representation of species spatial distribution.

Figure 13: Species records repartition in the Upper Mersey Estuary. Background Ordnance survey map 2015

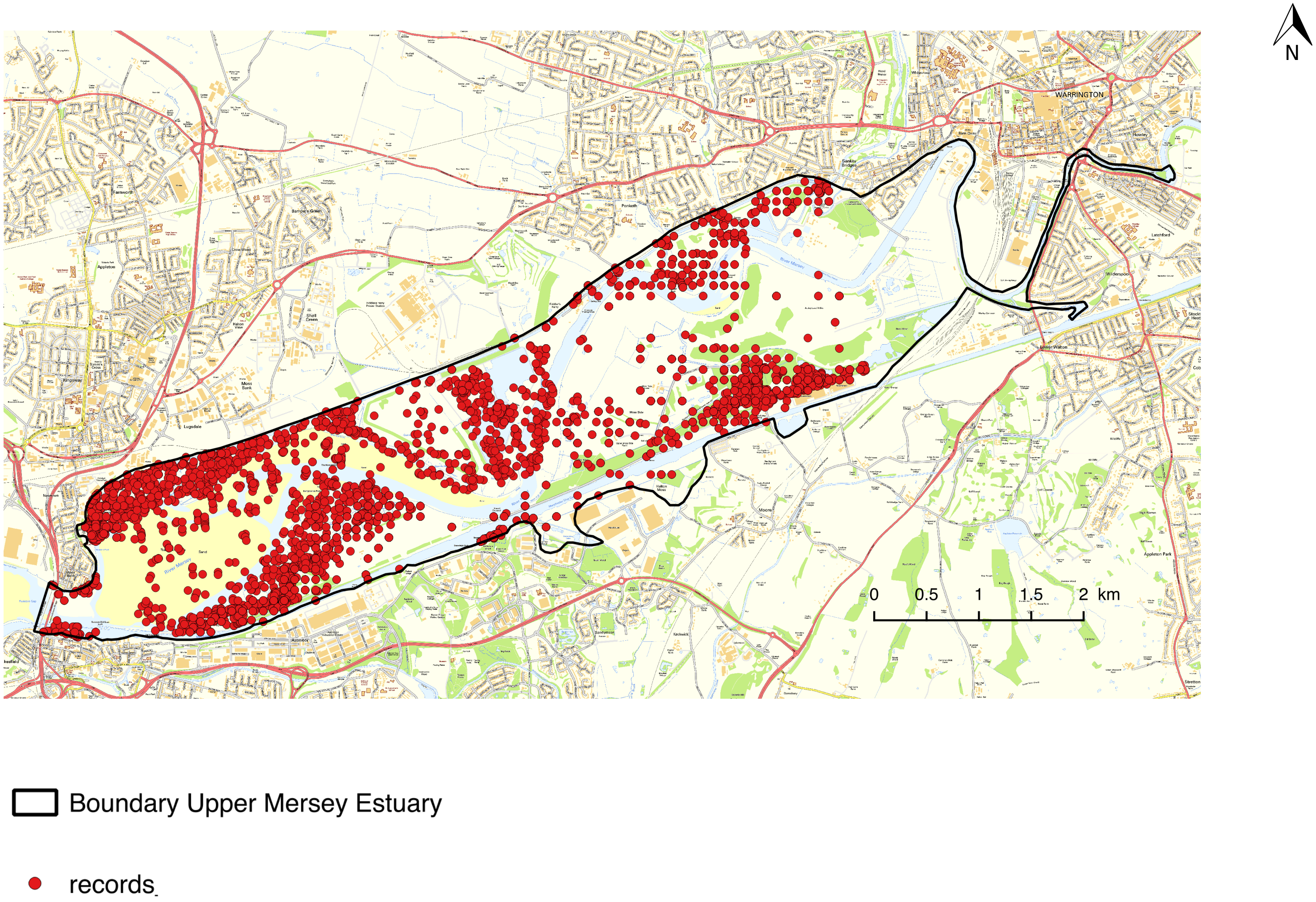
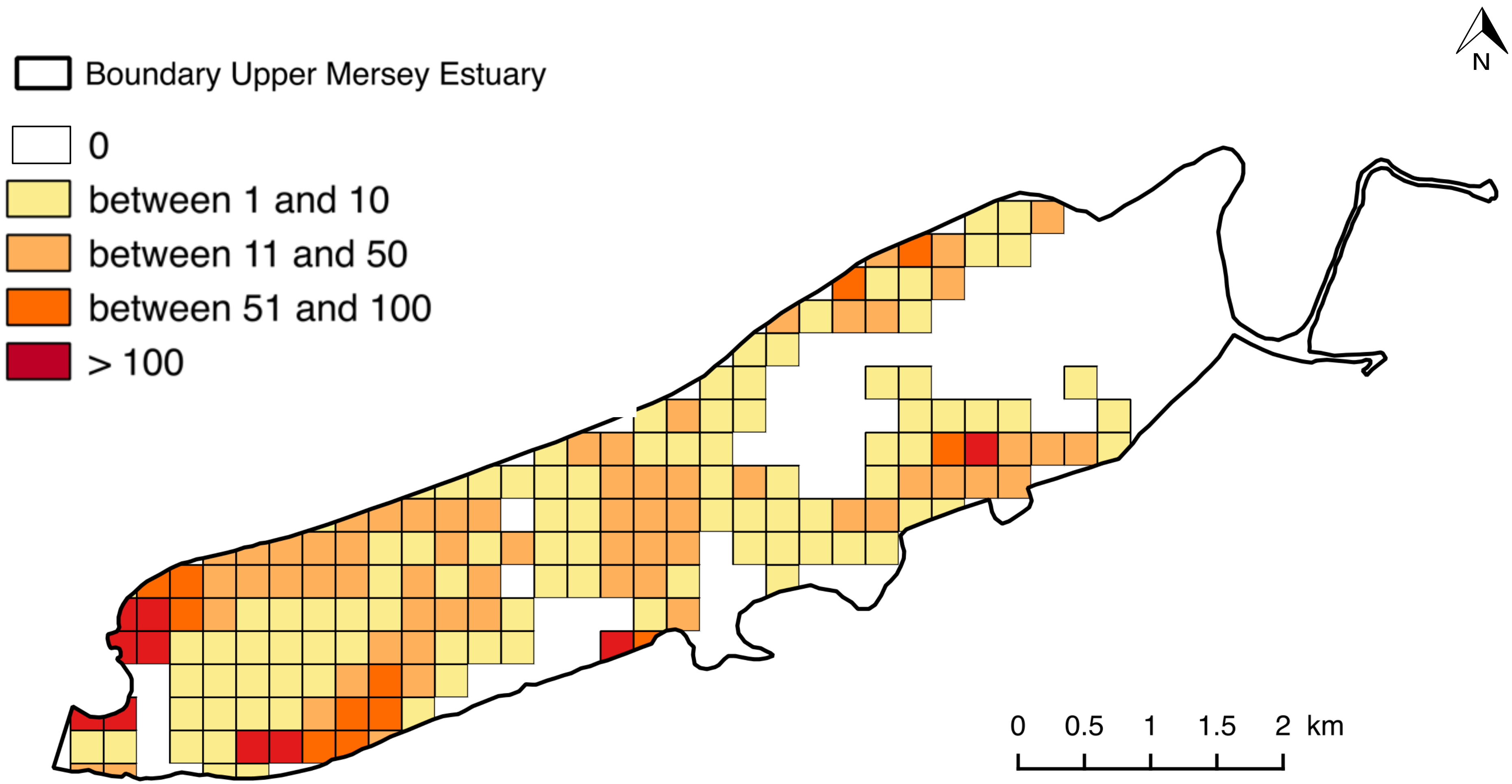


Figure 14: Density of records in the Upper Mersey Estuary



Conclusion

This project produced the most complete, detailed and up to date Upper Mersey Estuary land cover map to this day, as well as a land use map. This study also proposes a method to map ecosystem services probability, based on land cover and land use map. This method is easy to apply on a large scale, providing the land cover and land use data is known.

Generating a land cover map is an essential base for management measures, analysing species records in relation to their habitats and getting an ecosystem services spatial assessment. The land cover map generated via interpretation of aerial photographs is accurate and therefore may help for elaboration of conservation measures.
Mapping the evolution of land cover within the UME would contribute to further analysis of how the ecosystems have changed and will change with the Mersey Gateway Project being implemented in the UME.
A quality assessment of RECORD database has also been produced. Citizen science is an opportunity to bring constantly a significant amount of data. Nevertheless, a large proportion of records have to be discarded following data cleaning, and records spatial distribution analysis is to been taken cautiously because of bias in sampling method. Therefore citizen science can be useful to demonstrate some presence features (high density of species, presence of species specific to a habitat or vegetation structure, but studying absence features should be taken cautiously (a species absence in an area may be simply an under sampling bias)
Some procedures such as volunteer training, data standardization, validation and filtering procedures reduce potential sources of error and bias before, during and after collection of data (Bonter and Cooper, 2012, Wiggins *et al.*, 2011).

Perspectives for conservation measures in the Upper Mersey Estuary:

This study confirms the importance of reedbeds and saltmarsh management for the UME.
A range of saltmarsh plant communities would benefits animals and particularly birds species in the UME. The spread of plant species of importance to grazing herbivorous wildfowl should be encouraged. These species include Common Saltmarsh Grass (*Puccinellia maritima*), Sea Aster (*Aster tripolium*), Sea Purslane (*Atriplex portulacoides*), Herbaceous Seablite (*Suaeda maritima*) and Glasswort (*Salicornia europae*).
Large wintering flocks of herbivrous wildfowl, particularly Wigeon, and roosting waders such as the Dunlin seems to be attracted to the cattle-grazed *Puccinellia* dominated areas in the north of the study area.
Reedbeds play an important role in the estuary. Poor management of those areas could lead to scrub encroachment. A restoration plan can be imagined involving cutting back scrub and encroaching woodland.

The long-term management contract obtained by the Mersey Gateway Environmental Trust offer encouraging perspectives regarding the future ecological state of the Upper Mersey Estuary. They dispose of a number of tools to set up appropriate management plans for the Upper Mersey Estuary.

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Lexicon

Brownfield: term used in urban planning to describe land previously used for industrial purposes or some commercial uses. Such land may have been contaminated with hazardous waste or pollution

Ecosystem services: benefits provided to the population by ecosystems and their components: water, soil, nutrients and organisms

Local Widlife Site: Non statutory designation used by local authorities for sits with local nature conservation value. They are a contributing to local biodiversity actions plan, as well as maintaining local nature character and distinctiveness

Ordnance survey : National mapping agency for Great Britain, one of the world's largest producers of map. Since April 2015 it operates as a government-owned company, 100% in public ownership

Reedbeds : Common reed *Phragmites communis* dominated wetland vegetation communities where the water table is at or above ground level for most of the year. Reedbeds are therefore swamp communities, which may be defined as species-poor vegetation types, generally dominated by bulky emergent monocotyledons, with permanently or seasonally submerged substrates. Reedbeds provide a habitat for a range of specialist species most notably breeding birds

Saltmarsh: coastal ecosystem in the upper coastal intertidal zone between land and open salt water or brackish water that is regularly flooded by the tides. It is dominated by dense stands of salt-tolerant plants such as herbs, grasses, and low shrubds

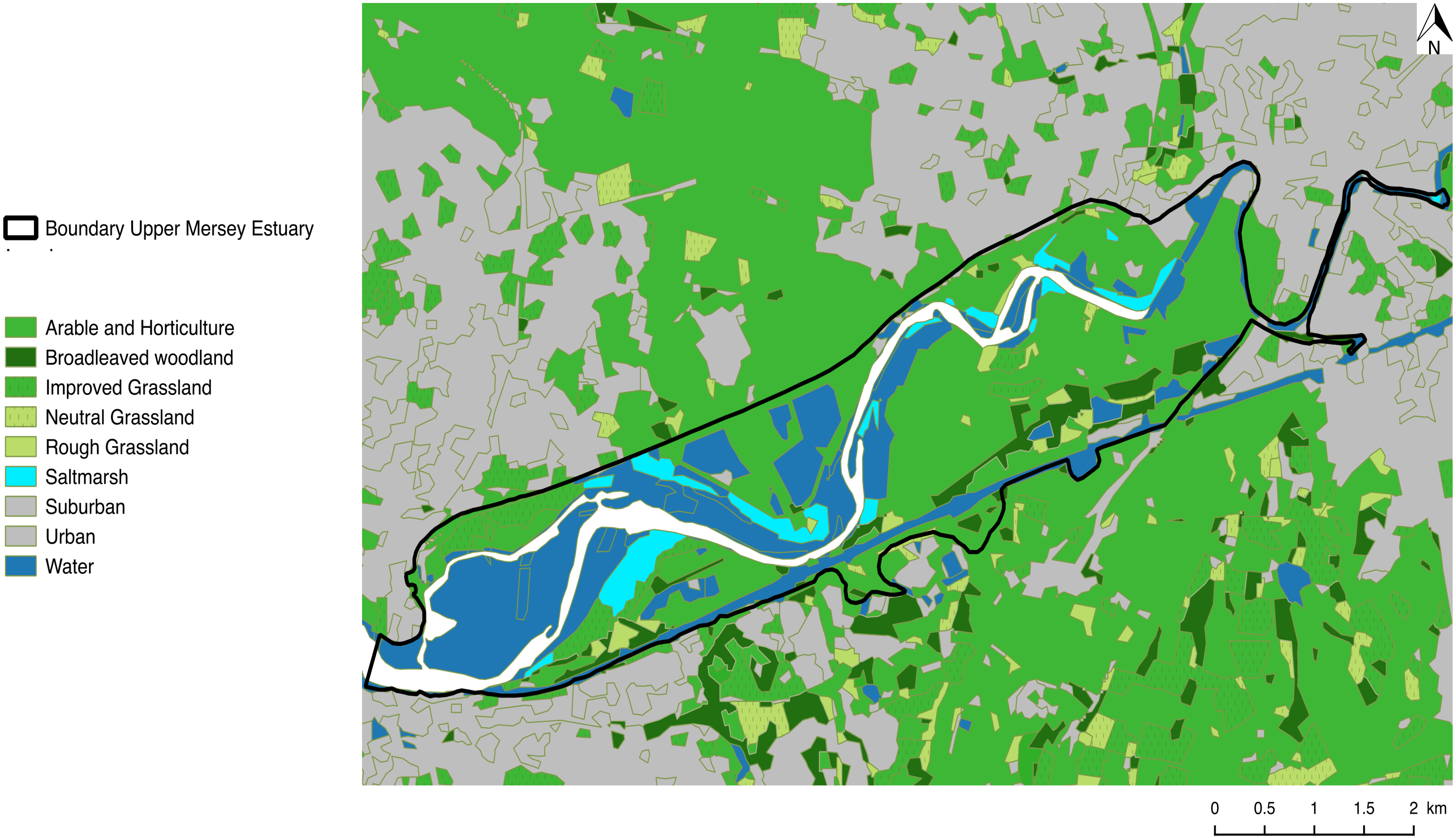
SPA: designation under the European Union Directive on the Conservation of Wild Birds

Phase 1 habitat survey: precise field survey technique that provide a relatively rapid system to record semi-natural vegetation and other wildlife habitats. Each habitat type/feature is defined by way of a brief description and is allocated a specific name, an alpha-numeric code, and unique mapping colour

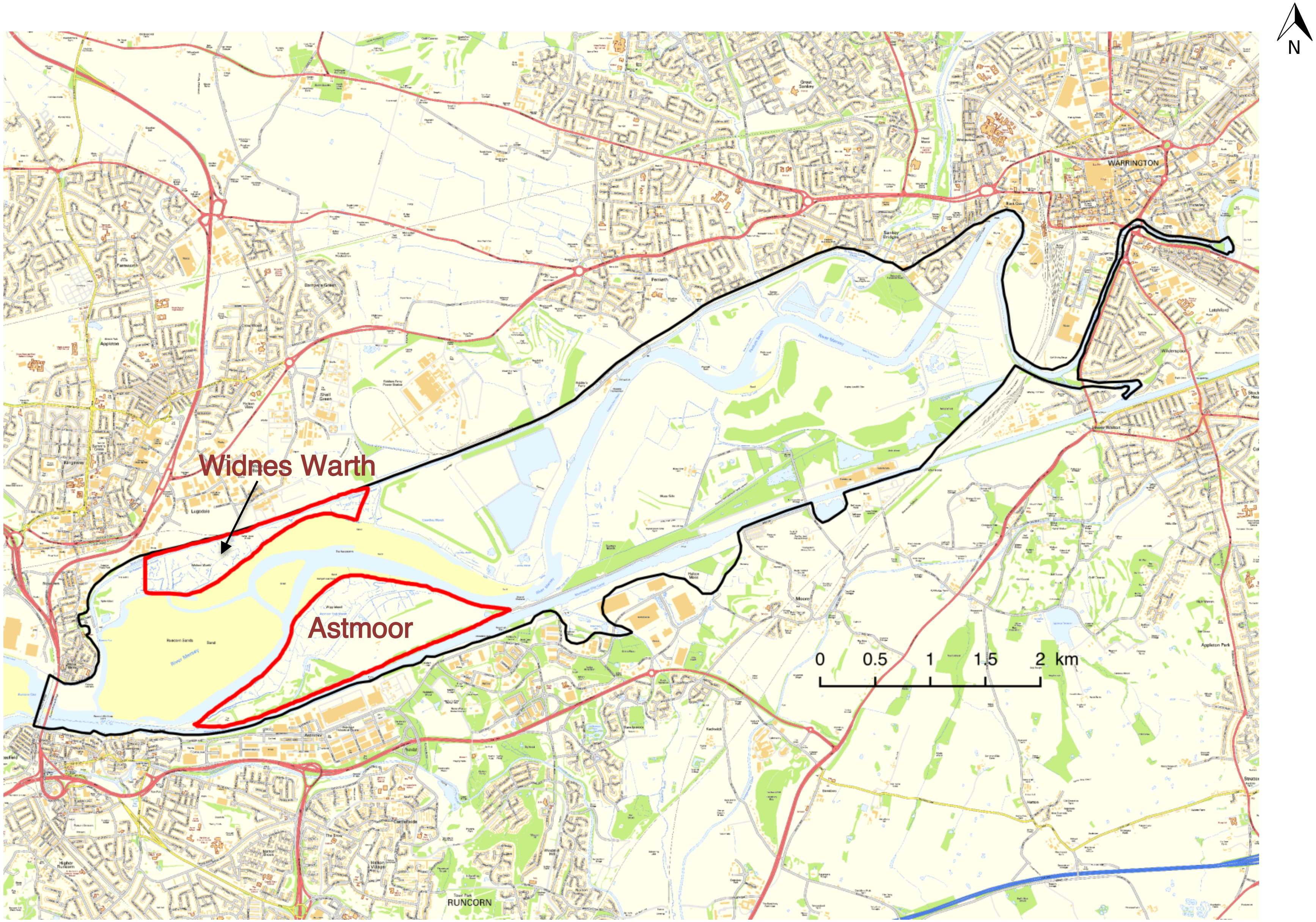
Waders: also called shorebirds, members of the order Charadriiformes, excluding the more marine web-footed seabird groups

Table of appendices

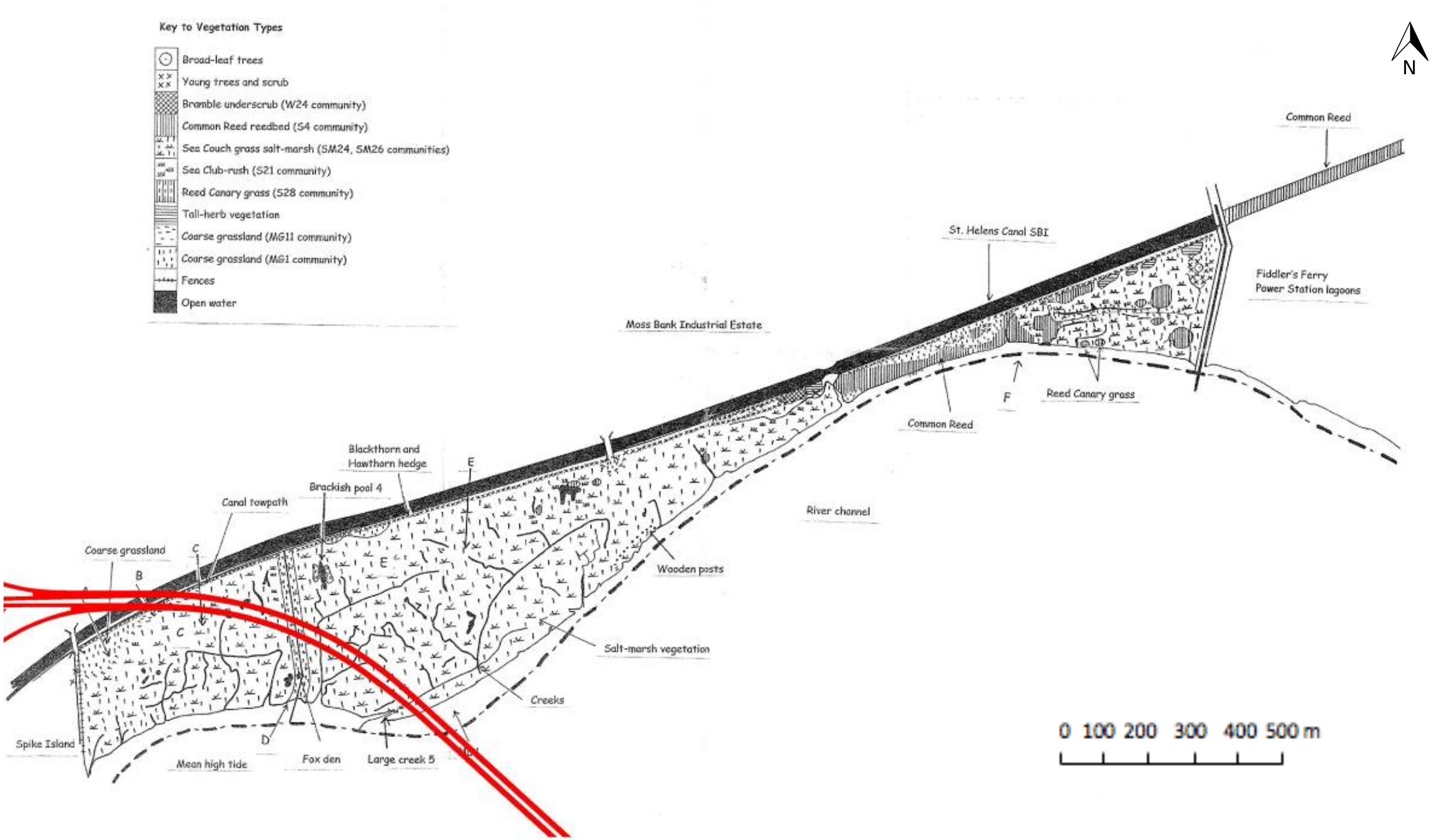
Appendix 1: 2007 land cover map produced by the Countryside Survey via a digitalised method



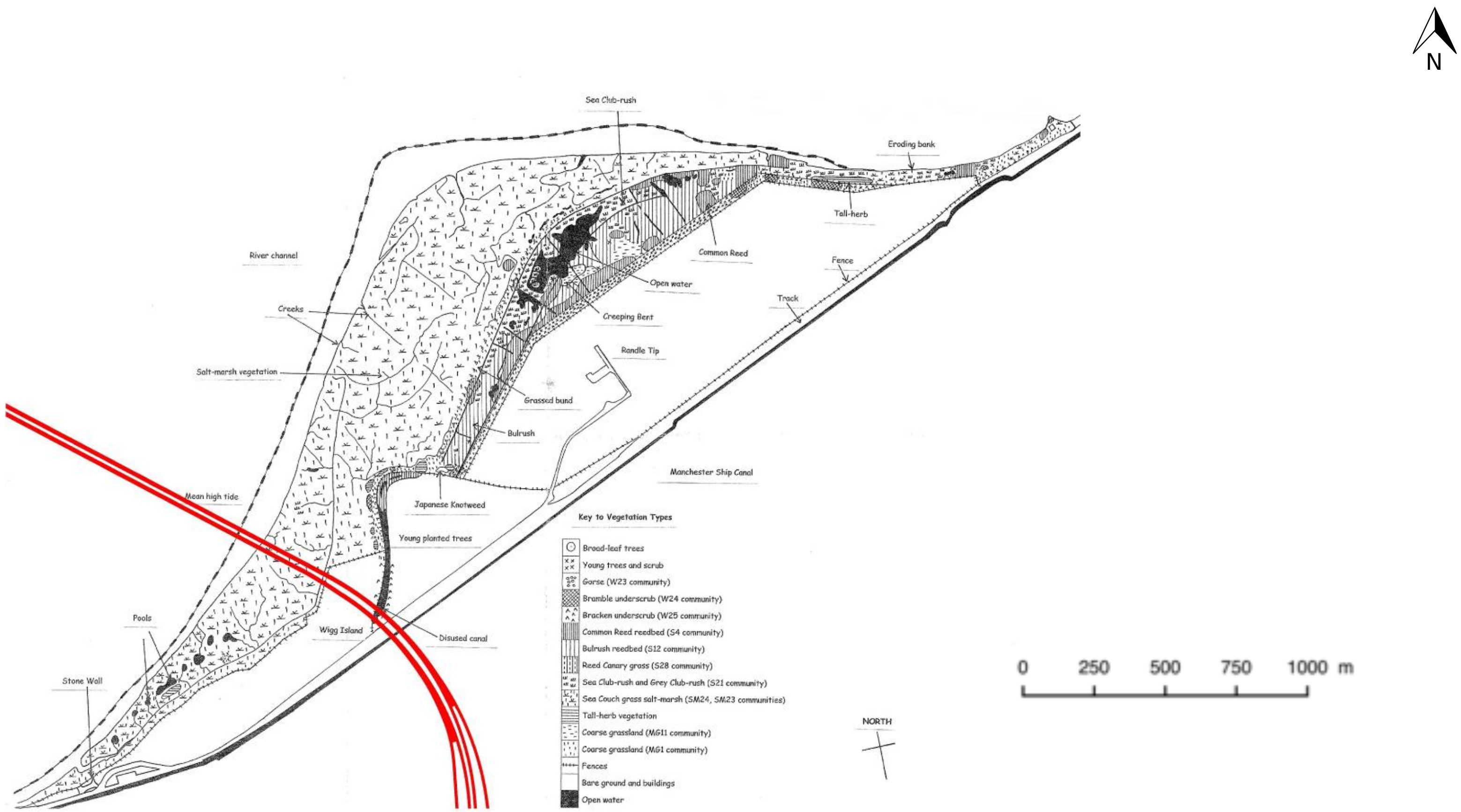
Appendix 2: Location of Widnes Warth saltmarsh and Astmoor saltmarsh



Appendix 3: Habitat and vegetation map of Widnes Warth saltmarsh (source: Mersey Gateway Project), used for comparison with land cover map



Appendix 4: Habitat and vegetation map of Astmoor saltmarsh (source: Mersey Gateway Project), used for comparison with land cover map



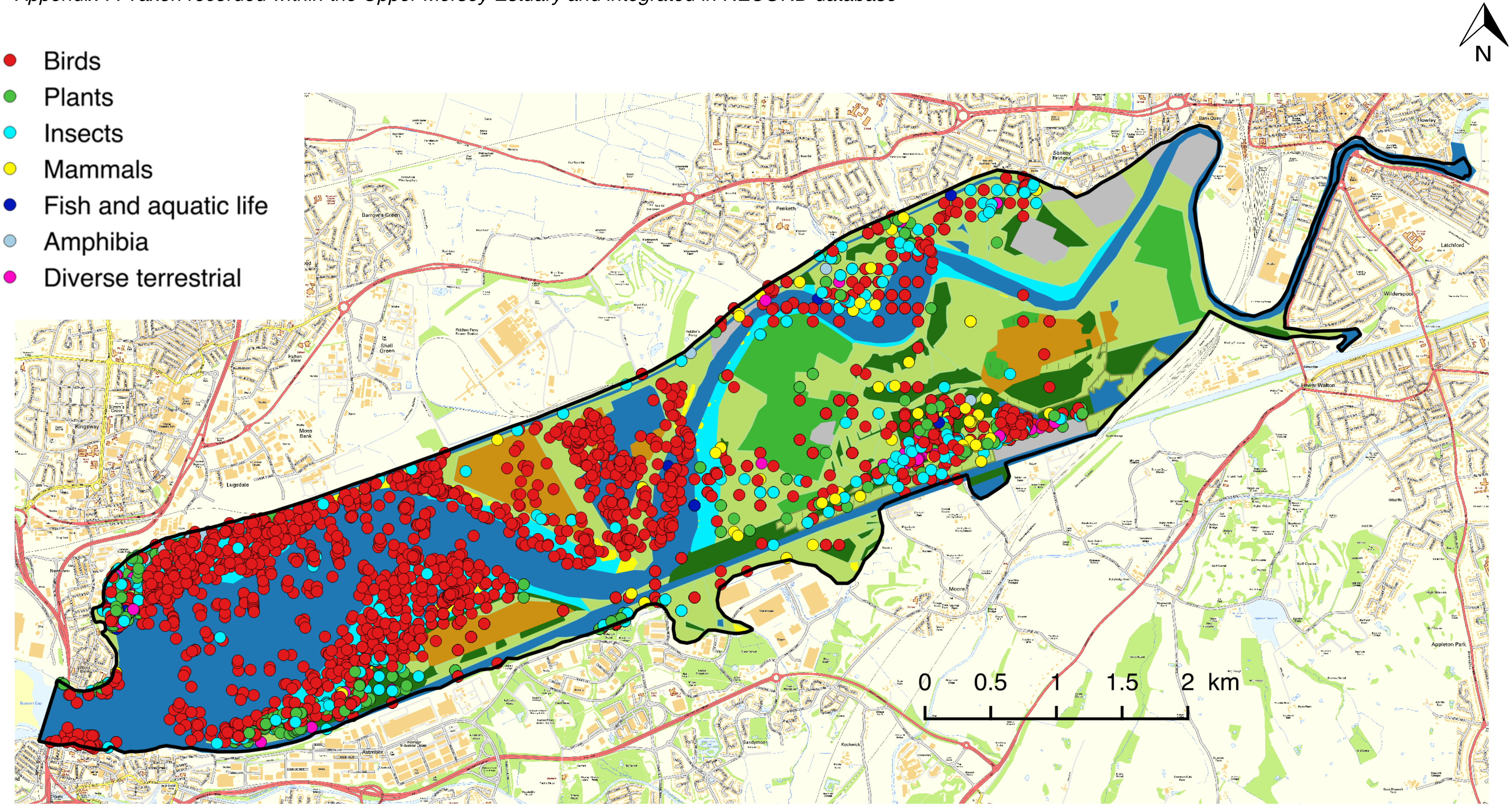
Appendix 5: Summary of recent studies on assessment and mapping of ecosystem services. Adapted from Baral et al. 2013

Location	Method and objectives	Ecosystem services assessed and mapped	Reference
Leipzig-Halle, Germany	easy-to-apply concept based on a matrix linking spatially explicit biophysical landscape to ecosystem services for appropriate quantification and spatial visualisation of ecosystem services	22 ecosystem services based on Millennium Ecosystem Assessment categories	Burkhard et al. (2012)
California, USA	use of spatially explicit conservation planning framework to explore the trade-offs and opportunities for aligning conservation goal for biodiversity and ecosystem services	carbon stock, flood control, forage production, outdoor recreation, crop pollination, water provision	Chan et al. (2006)
South Africa	use of statistical distribution of proxy indicators to quantify the amount an distribution of ecosystem services across the landscape and spatial congruence	water supply, water flow regulation, soil accumulation, soil retention, carbon stock	Egoh et al. (2008)
Ewaso Ngiro, Kenya	mapping bundles of ecosystem services at the land use scale for land use planning and management in data-poor regions	carbon, wildlife species, timber, livestock, crops, freshwater, flood regulation, cultural value	Ericksen et al. (2012)
Global wathersheds	spatial distribution of multiple ecosystem services for reconciling conservation and human development goals	water provision, flood mitigation, carbon storage, biodiversity priorities	Luck et al. (2009)
Willamette Basin, USA	combination of land use and land cover classification with a suite of models to map ecosystem services	water quality, soil conservation, storm peak management, carbon sequestration, biodiversity conservation, commodity production	Nelson et al. (2009)
Quebec, Canada	mapped spatial distribution of proxy indicators for selected ecosystem services and identified bundles using spatial location	crops, pork, drinking water, maple syrup, deer hunting, nature appreciation, carbon sequestration, soil retention, soil organic matter	Raudsepp-Hearne et al. (2010)
Little Karoo Region, South Africa	use of land cover data as the basis for identifying ecosystem services and mapped the overlap in provision of ecosystem services	forage production, carbon stock, erosion control, tourism, water regulation	Reyers et al. (2009)
Lapland, Finland	effect of various land uses on provision of ecosystem services using GIS techniques	27 ecosystem services based on Millennium Ecosystem Assessment categories	Vihervaara et al. (2010)
Glenelb Basin, Australia	use of land cover data and literature review	Timber production, carbon stock, provision of water, water regulation, biodiversity, forage production	Baral et al.

Appendix 6: Description of ecosystem services and their assessment criteria. H=high capacity, M=medium capacity, L= low capacity. Adapted from Baral et al. 2013.

Ecosystem services	Category	Description	Assessment classes	Data source/ Literature
Biodiversity	Supporting	Landscapes and ecosystems ability to support a diversity of plant and animal life	H =Relatively intact areas of native vegetation, with an ability to support protected or rare species M = Native vegetation with relatively smaller patch sizes, moderate number of species. L = Areas with planted forest, pastures, anthropized environment	Baral *et al.*, 2013
Carbon sequestration	Regulating	Capacity to capture atmospheric carbon dioxide in trees, shrubs and other vegetation	H = High carbon stock potential, >250 mg/ha M = Moderate carbon stock potential, 50-250 mg/ha L = High carbon stock potential, 50 mg/ha	IPCC, 2006 DCC, 2008 URS Forestry, 2009 CFI reforestation tool (DCCEE, 2011) Grierson *et al.,* 1992
Provision of water	Provisioning	Capacity of filtering, retention and storage of freshwater available for human consumption or industrial use	H = Low level of water use and high recharge potential, 10-30% of annual precipitation M = Moderate level of water use and moderate recharge potential, 10-30% of annual precipitation L = High level of water use and high recharge potential, <10% of annual precipitation	Benyon *et al.*, 2007 Zhang, 2001
Aesthetic value	Cultural	Attractive landscape features help enjoyments of scenery	H = High level of aesthetic value M = Moderate level of aesthetic value L = Low level of aesthetic value	Baral *et al.,* 2013

Appendix 7: Taxon recorded within the Upper Mersey Estuary and integrated in RECORD database



Appendix 8: Sample of the species/land cover list obtained after superposition of the land cover map and the species distribution map

Taxon order	Species	Rough grassland	Broadleaved woodland	Saltmarsh	Water	Urban, buildings	Reedbeds	Neutral grassland	Brownfield	Arable and horticulture	Total
Total (all records with 8 figures in the grid reference = precision 10 m^2)		1498	1228	659	744	151	90	76	69	3	4518
Passeriformes	Meadow Pipit	17		142	3		2		8		172
Asparagales	Bluebell	12	58	60							130
Charadriiformes	Black-headed Gull	8	2	6	91	4			2		113
Anseriformes	Mallard	30	7	12	51	7	2	1	1		111