An ecosystem services mapping method for use in green infrastructure planning

Tom Butlin [a,], Dr Susannah Gill [a,b] and Paul Nolan [a]*

[a] The Mersey Forest, Risley Moss, Ordnance Avenue, Birchwood, Warrington WA3 6QX, UK

[b] Honorary Research Fellow, The University of Manchester, Oxford Rd, Manchester M13 9PL, UK

[*] Corresponding author: tom.butlin@merseyforest.org.uk, +44 1925 816 217

Keywords

Ecosystem services; green infrastructure; mapping; spatial

Development of the mapping method was funded by:

- *The EU INTERREG IVB programme North West Europe (as part of the GIFT-T! project)*
- *Natural England*
- *Environment Agency (England)*
- *North West Development Agency (England)*
- *Liverpool City Council*
- *Liverpool Primary Care Trust*
- *Ayrshire Joint Planning Unit*
- *Carlisle City Council*
- *Liverpool Vision*

Published June 2015 by The Mersey Forest and the Green Infrastructure Think Tank

ISBN 978-0-9934267-0-4

1. Introduction

An ecosystem services approach to the planning and management of the natural environment can aid effective decision making for human wellbeing (Millennium Ecosystem Assessment, 2005). This has been recognised, to a degree, by the British Government, whose National Planning Policy Framework (Department for Communities and Local Government, 2012) requires that ecosystem services should be taken into account by the planning system. A green infrastructure approach to planning is also advocated by the framework.

It has been pointed out that both green infrastructure and ecosystem services have many definitions (e.g. Gill, forthcoming; Lamarque et al, 2010). One definition of green infrastructure is that it is "an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (Benedict and McMahon, 2002, p12), whilst ecosystem services have been defined as "the benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2003, p3). These definitions would suggest that it can be understood that green infrastructure provides ecosystem services (Gill, forthcoming). Indeed, a review of both academic (e.g. Cilliers et al, 2013; Farrugia et al, 2013; Lovell and Taylor, 2013; Gill et al, 2007) and more policy- or practitioner-oriented (e.g. European Commission, 2013; Natural Economy Northwest, 2010; Natural England, undated) literature suggests that it is often in this way that the two terms are linked (Gill, forthcoming). If this understanding is accepted, it would appear that the two approaches are very similar – if not identical, at least in a practical planning context.

For the purposes of the development of the mapping method described in this paper, it was deemed useful to distinguish between definition of green infrastructure itself and description of the green infrastructure approach to planning; and to define green infrastructure itself as plants, soil and surface water. This sets clear limits on what is included: for example, most cycle paths are paved, and therefore do not constitute green infrastructure under this definition, despite the fact that they facilitate the delivery of green infrastructure benefits (such as recreation) and are often considered within green infrastructure plans.

Ecosystem services approaches to the planning and management of the natural environment require spatially explicit information on both the supply of and the demand for ecosystem services (Cowling et al, 2008; Carpenter et al, 2009). Many mapping methods and frameworks have therefore been developed to attempt to meet this requirement (e.g. Maynard et al, 2010; Egoh et al, 2008; Naidoo et al, 2008; Chan et al, 2006; Maes et al, 2012; Durham Wildlife Trust, 2014). Reviews have found up to 122 papers that map ecosystem services (Martínez-Harms and Balvanera, 2012; Egoh et al, 2012; Crossman et al, 2013; Seppelt et al, 2011a; Nelson and Daily, 2010). These reviews classify mapping methods along a number of dimensions, including geographic coverage, services mapped, data sources and modelling methods.

Most of the studies reviewed map relatively few services: an average of 5.6 in the studies reviewed by Crossman et al (2013), compared with 48 listed in the Common International Classification of Ecosystem Services (European Environment Agency, 2013). Maes et al (2012) point out that this could lead to policy bias, whereby mapped services are given more weight in planning and management decisions than those that have been neglected.

The review by Martínez-Harms and Balvanera (2012) found that relatively few studies applied mapping methods to areas smaller than 1 000km^2. They also observe that demand for ecosystem services is mapped "much less often" than supply. This is at odds with Cowling et al (2008), who assert that a spatially explicit demand assessment (which they refer to as a 'social assessment') is a necessary part of an effective ecosystem services project; and with the common understanding in the literature (e.g. de Groot et al, 2002; Costanza et al, 1997; Daily, 1997) that ecosystem services provision is determined by human demand (or consumption) as well as biophysical supply potential.

Much of the emphasis in the literature is on the quantification of the actual amounts of ecosystem services delivered, with methods that simply give a binary indication of whether a service is provided or a score indicating to what degree it is provided, receiving less attention. For example, the blueprints developed by Crossman et al (2013) and Seppelt et al (2011b) assume quantification, despite the existence of methods fitting the latter description (e.g. Maynard et al, 2010; Durham Wildlife Trust, 2014).

This paper sets out an ecosystem services mapping method that has been developed to inform green infrastructure planning in a practical context; primarily the local government planning process in the UK. It is constructed around a set of key principles, discussed in section 4, that include:

- Privileging comprehensiveness (in terms of the range of ecosystem services considered) over quantification
- Pragmatic levels of spatial detail
- Separation of supply and demand mapping

The method is described in some detail in section 2. Some of the case studies to which the method has been applied (including Liverpool (The Mersey Forest, 2010a) and Liverpool City Region (The Mersey Forest, 2013a)) provide further detail on the version of the method used, to the extent that the outputs should be reproducible.

2. Method

The mapping method has been developed over the last seven years through discussion with stakeholders and application to a wide range of study areas. Study areas in the UK include Liverpool (The Mersey Forest, 2010a), Ayrshire (MD^2 et al, 2011), Carlisle (Rebanks Consulting et al, 2011), Liverpool City Region (The Mersey Forest, 2013a), the Hoo Peninsula in Kent, Liverpool Knowledge Quarter (The Mersey Forest, 2010b), and a site in Liverpool where part of the River Alt is to be deculverted. The process of applying the mapping method to some study areas in continental Europe is also under way as part of an EU Interreg project: the Province of South Holland in The Netherlands, and the Brussels Airport Business Region and the Campine Region in Belgium (Alterra et al, undated). These study areas range in size from 6ha to over 3 000km^2 and include both urban and rural areas.

The case studies to which the method has been applied also vary in that, for some, the mapping has been undertaken for one fixed point in time, whereas for others it has been undertaken specifically to examine the potential effects of a planned change, such as a new development on a site. As Cowling et al (2008) have pointed out, the latter can be powerful in influencing policy.

Due to the considerable differences between these study areas, it has been necessary to incorporate a degree of flexibility into the mapping method as it has evolved. However, this has been balanced against a desire to maintain a degree of compatibility between studies. This is useful because it allows comparison of study areas, with certain caveats, and because it allows adjacent studies to be concatenated to provide broader coverage and facilitate cross-boundary working (which is a requirement of UK local authorities stemming from the National Planning Policy Framework (Department for Communities and Local Government, 2012)). Compatibility is achieved partially through the consistent application of the static key principles mentioned in section 1.

The method consists of four steps. The first, referred to as typology mapping, describes the green infrastructure within the study area using a mixed land cover/land use classification. The second, referred to as functionality mapping, describes the supply of ecosystem services by the green infrastructure identified in the first step. The third, referred to as needs mapping, describes the demand for ecosystem services within the study area. The fourth and final step combines the outputs of the second and third steps to determine where demands are met and where they are not met. This final step is particularly useful for informing policy.

Study areas are typically predefined for administrative or project purposes – for example, adhering to local authority or site boundaries. In order to take into account, to a reasonable degree, supply and demand outside the study area but affecting it (identified as an important consideration by Seppelt et al (2011a)), a buffer of the predefined boundary is taken, and used as the study area for the purposes of the mapping method. The buffer distance is necessarily arbitrary, but affected by factors such as the resources available for the mapping exercise and the size of the predefined study area.

In cases where the method has been applied to assess the possible effects of planned change, the four steps are carried out twice: once for the current state of the study area, and once for the planned future state – before and after the change. This is because any change of land cover or land use is likely to affect the typology, functionality and needs of the area. The two sets of outputs can then be compared.

Within the UK, the spatial basis of the first two steps is Ordnance Survey's MasterMap Topography Layer (Ordnance Survey, 2010). In applying the method to locations outside the UK that lack MasterMap equivalents, a suitable parcel system can usually be constructed from other land cover and land use datasets. For example, in South Holland, a national 1:10 000 vector topography dataset was combined with a 'soil use' dataset.

2.1. Typology mapping

The first step of the mapping method consists of a classification of each of the land parcels as either 'not green infrastructure' or one of a list of green infrastructure types. A standard list of 18 green infrastructure types has been developed, and this is applied where possible. The list has generally been acceptable when applied within the UK, given that further distinctions within the types are made when undertaking the functionality mapping. In cases where the list is considered inadequate to describe an area's green infrastructure, however, it can be modified. Outside the UK this has proven to be often the case.

- Agricultural land
- Allotment, community garden or urban farm
- Cemetery, churchyard or burial ground
- Coastal habitat
- Derelict land
- General amenity space
- Grassland, heathland, moorland or scrubland

- Green roof
- Institutional grounds
- Orchard
- Outdoor sports facility
- Park or public garden
- Private domestic garden
- Street trees
- Water body
- Water course
- Wetland
- Woodland

Each type comes with a definition that helps to clarify its exact meaning within the mapping method. These definitions are provided in The Mersey Forest (2013a). The categories are applied hierarchically: land cover types generally override land use types. For example, a patch of woodland within a park is counted as *woodland*, not *park or public garden*. This facilitates the functionality mapping step.

The list is adapted from one developed for a green infrastructure scoping study for the East Midlands (TEP et al, 2005), which in turn was based upon a typology suggested in the British Government's now-superseded Planning Policy Guidance 17 (PPG17) (Office of the Deputy Prime Minister, 2002). This typology was derived from The Urban Green Spaces Taskforce (2002) and Dunnett et al (2002) and is still widely used by UK local authorities for their open and green space audits and strategies. The list above is designed to appeal to UK local authority planners through the familiarity of the PPG17 categories. However, it goes further than the PPG17 list, as it covers a broader range of green infrastructure types, including agricultural land and street trees. The latter in particular is deemed to be an important component of green infrastructure that was missing from a traditional green space approach. The list is also designed to be intuitive, but its primary purpose is to provide a basis for the next step, the functionality mapping.

The land parcels are classified using a range of techniques. Which techniques are used, and the degree to which each is relied upon, depends on data and resource availability and the size of the study area. The principal techniques are listed below.

- Automated use of MasterMap attributes and annotation: for example, a certain attribute value identifies all private domestic gardens
- Intersection with other vector datasets, such as local authority open space audits and tree inventories
- Automated use of remote sensing data, such as colour infrared remote imagery (which can be used to distinguish between vegetated and non-vegetated areas, e.g. private domestic gardens) and lidar height data (which can be used to distinguish between trees and other vegetation)
- Manual correction with reference to remote imagery, Ordnance Survey raster mapping, Google Street View, local knowledge, etc.

The reliance on different techniques will result in differing levels of accuracy. For example, outputs from one study that made use of the first three techniques but not the fourth were compared with those from another overlapping study that relied heavily upon the fourth technique, alongside the first and second. The former classification was found to be 91%

accurate relative to the latter in terms of the sheer number of parcels classified correctly, and 71% accurate in terms of the area classified correctly[1] (The Mersey Forest, 2013a).

Figure 1 is an example of a completed typology map.

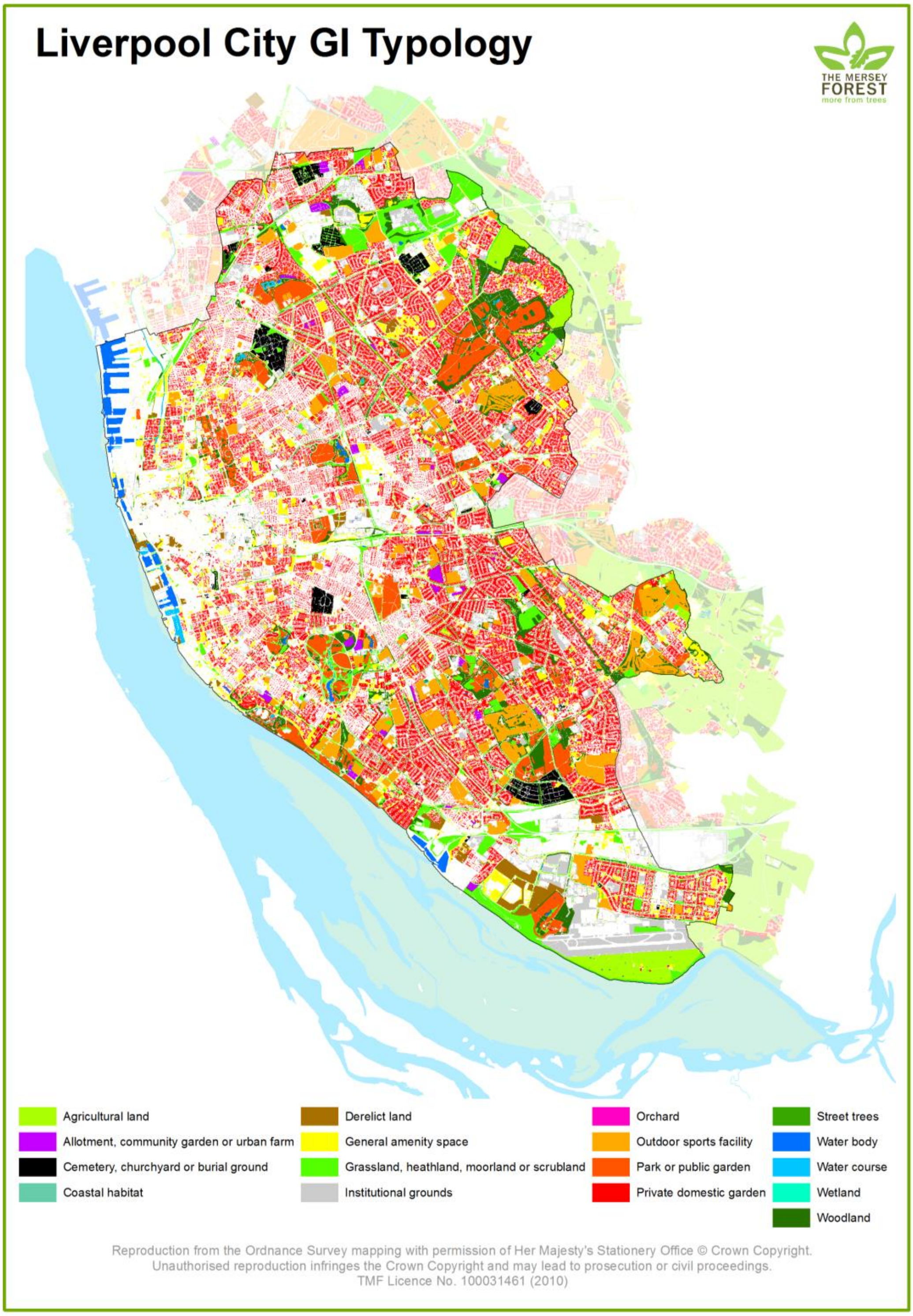

Figure 1: Liverpool green infrastructure typology map (The Mersey Forest, 2010a)

[1] Excluding the *coastal habitat* type, which was not used in the latter study.

2.2. Functionality mapping

The second step of the mapping method consists of identifying which of the parcels supply each of a list of ecosystem services (or green infrastructure functions). Again, a standard list of functions has been developed, and is used where possible. This list has evolved throughout the development of the mapping method. It currently consists of 35 functions. The list has proven generally acceptable in the UK context, notwithstanding the various issues that have prompted its evolution. The list can be modified, however, where it is considered inadequate to describe the functionality of an area's green infrastructure. This has proven to be often the case outside the UK. The standard list is given below.

- Accessible water storage
- Biofuels production
- Carbon storage
- Coastal storm protection
- Community cohesion
- Connection with local environment
- Corridor for wildlife
- Culture
- Encouraging green travel
- Evaporative cooling
- Flow reduction through surface roughness
- Food production
- Habitat for wildlife
- Heritage
- Inaccessible water storage
- Learning
- Noise absorption
- Opportunity to hear more natural sound
- Pest and disease control
- Physical movement barrier
- Pollination
- Pollutant removal from soil/water
- Providing jobs
- Recreation – private
- Recreation – public
- Recreation – public with restrictions
- Shading from the sun
- Soil stabilisation
- Timber production
- Trapping air pollutants
- Visual contribution to landscape character
- Water conveyance
- Water infiltration
- Water interception
- Wind shelter

This list was developed with reference to previous lists from: the Millennium Ecosystem Assessment (2005), the Countryside In and Around Towns programme (The Countryside Agency and Groundwork, 2005), the East Midlands Green Infrastructure Scoping Study (TEP et al, 2005), Kambites and Owen (2006), and the 'CLERE' model (Barber, 2005). It has evolved through an internship exploring the links between green infrastructure and hydrology (The Mersey Forest, 2009), and through consultation with North West England's Green Infrastructure Think Tank, a group of academics and practitioners who meet regularly to discuss issues such as these. The current list of 35 services was arrived at only in 2013; as such, many of the case studies referred to in this paper use a previous version that consisted of 28 services. The list is designed to reflect the established concerns of local authority planners without neglecting the other services that green infrastructure supplies. It bears comparison with the lists from TEEB (2010) and the Common International Classification of Ecosystem Services (European Environment Agency, 2013), although with some differences.

Like the types, each service comes with a definition that helps to clarify its exact meaning within the mapping method. These definitions are provided in The Mersey Forest (2013b), with references, where available, to provide evidence demonstrating that the service is supplied by green infrastructure.

The method used to identify which parcels supply which services is based upon a table that includes a cell per type-service combination. This is similar to the matrix proposed by MacFarlane (2007), and is a cross between the methods Martínez-Harms and Balvanera (2012) call 'look-up tables' and 'causal relationships'. The content of the table is slightly different for each study, but there are two main versions of the table that are used in different contexts.

In the first, each cell contains an 'A' for 'always', an 'S' for 'sometimes', or a dash meaning 'never'. An 'A' means that all parcels of the type in question are considered to supply the service in question to a level above a notional threshold. An 'S' means that some parcels of the type in question are considered to supply the service in question to a level above the notional threshold, and others are not, depending on other factors. These other factors are detailed in an annex to the table and involve comparison with other datasets. A dash means that no parcels of the type in question are considered to supply the service in question to a level above the notional threshold. For example, all *woodland* is considered to supply the *carbon storage* service, as it stores considerably more carbon than other vegetation types (Milne and Brown, 1995), and as such it was deemed important to emphasise this role. This implies that the threshold for this service is below the lowest level of carbon stored by a unit area of what is classed as *woodland* under this mapping method. *Grassland, heathland, moorland or scrubland* is only sometimes considered to supply the *carbon storage* service, depending on the level of carbon stored in the soil, as this may or may not be above the threshold. A spatial dataset giving this level, or a proxy, is therefore required. Parcels classed as *water body* are never considered to supply the *carbon storage* service, as the level of carbon stored per unit area is considered likely to always be below the threshold.

The thresholds are notional because their values are not defined, and may vary from study to study. Clearly it would be relatively easy to put a value on the threshold for *carbon storage*, but for many of the other services it would be much more difficult. In any case, we consider the exact values to be relatively unimportant compared to the comprehensiveness of the information the method can provide to planners and the relative ease with which it can be understood.

As an alternative, a second version of the table can be used which replaces some of the cells containing an ‘S’ with numerical estimates (between zero and one) of the likelihood that any given parcel of the type in question supplies the service in question. Use of this version of the table becomes necessary when data is not available to determine certain properties of the parcels within the study area, principally tree canopy cover. In some cases, where the study area is small and resources are plentiful, this can be determined manually (in which case the first version of the table can be used), but in other cases, unless suitable data is available, the likelihoods have to be used. This is a compromise that produces outputs that are less easy to interpret (as their binary nature is lost), but allows the method to be used in situations where resources and data are restricted. The likelihoods are based upon the outputs of studies that used the first version of the table and expert judgement. The other contents of both versions of the table, including the annex, are based upon the literature where possible and expert judgement otherwise.

A map showing where each service is supplied can be produced using the outputs of this step. The total number of services supplied by each parcel is calculated (or the total of the likelihoods if the second version of the table has been used) and presented on a ‘multifunctionality’ map. If the method is being used to assess the possible impacts of a proposed change, a map showing change in multifunctionality, that is the difference between the total number of services supplied before and after the change, can be a powerful output.

Figure 2 is an example of a completed map showing where one service is supplied: in this case *noise absorption*. Trees near noise sources, such as main roads and railways, can help to absorb the noise (Fang and Ling, 2003). Supply of this service is therefore mapped by identifying parcels with significant tree cover close to these noise sources.

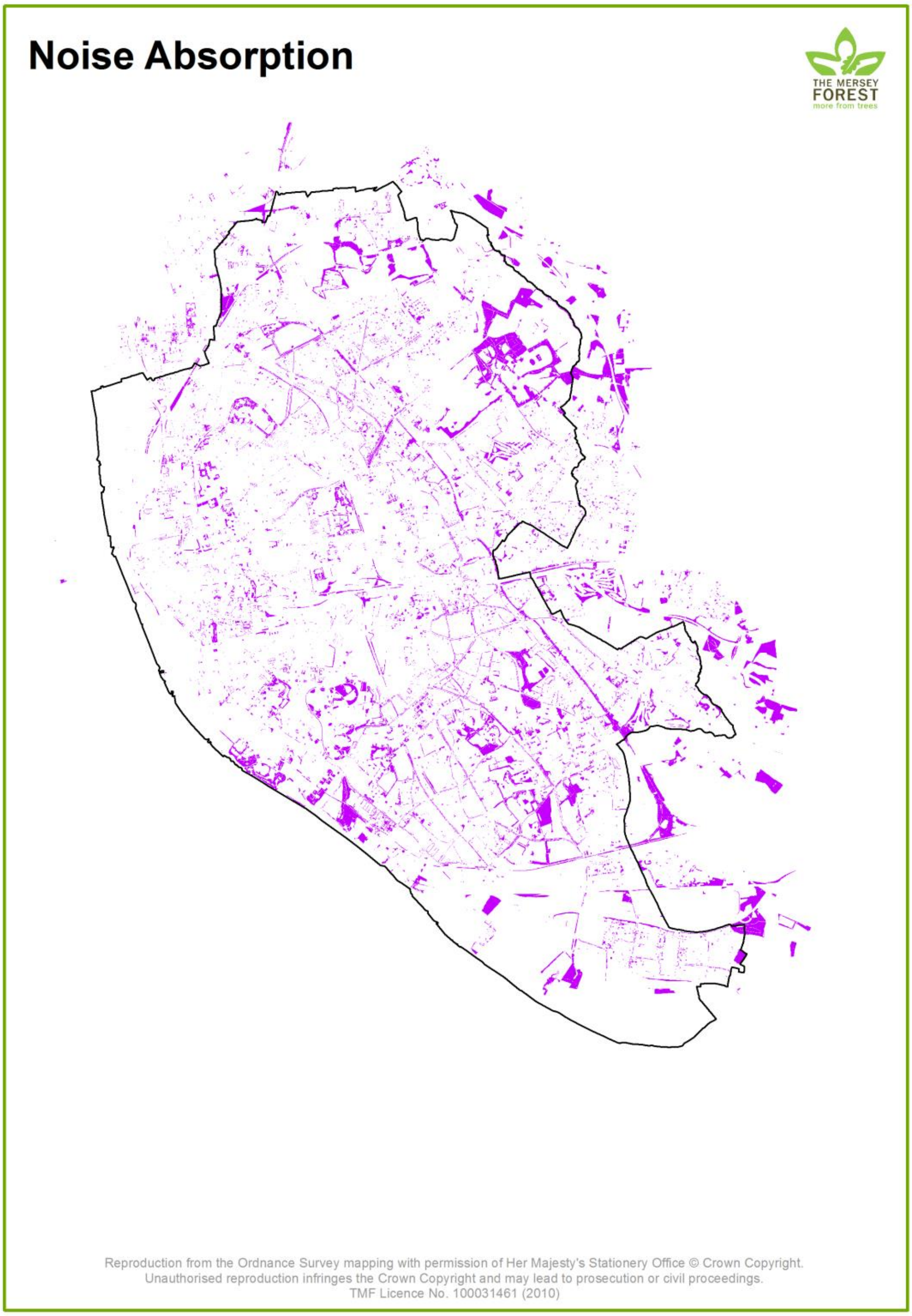

Figure 2: Liverpool noise absorption supply map (The Mersey Forest, 2010a)

2.3. Needs mapping

The third step of the mapping method consists of identifying where the greatest demand (or need) for each of the services exists within the study area. The previous step identifies where supply exists, and hence where there is a lack of supply, so this step considers only other factors that affect demand. Because these factors rarely conform to the arrangement of land cover or land use, this step departs from the parcel system of the previous two. However, the mapping is again binary: for each service, the study area is divided into parts where the demand is greatest and parts where there is less demand.

This step is where the most variation between studies is found. This is because different factors affect the demand in each location, and data availability varies. For each study, and for each of the services, the factors affecting demand are considered in consultation with the literature and previous applications of the method. The data availability for the area is reviewed, and criteria are then devised for mapping where the demand is greatest.

For example, in one study (The Mersey Forest, 2013a), when considering demand for the *noise absorption* service, it was considered that the noise that green infrastructure can help to absorb was mostly produced by main roads and railways, and that the greatest demand for absorption of that noise was before it could reach where most people live, both at the time and in the future. Therefore the locations of greatest demand for this service were deemed to be where the highest current population density and projected future population density intersected a buffer of main roads and railways. The buffer distance was based upon research from a government agency (Department for Environment, Food and Rural Affairs, 2006), but the population density threshold was more arbitrary, selected to ensure that some but not most of the study area was counted as a location of greatest need. This latter technique is a general principle used in the criteria for demand for many of the services. It helps to ensure that the outputs are useful: to say that none or all of the study area is a location of greatest need does not help planners to target interventions, choose between sites etc.

In the case of some (if not all) services, green infrastructure in locations other than where the problem is felt can help to alleviate that problem. The *noise absorption* service is an example of this: the problem is felt at the homes where people live, but green infrastructure some distance away, perhaps alongside a main road, can help to alleviate it. Flooding-related services are another example – green infrastructure many kilometres from areas at risk of flooding can sometimes help to alleviate that flooding (European Environment Agency, 2012). Within this mapping method, the demand is said to exist wherever green infrastructure is likely to be able to help (described here as the intervention catchment), not just where the problem is felt, and the demand criteria are designed to try to reflect this.

Figure 3 is an example of a completed map showing demand for one service.

Figure 3: Liverpool noise absorption demand map (The Mersey Forest, 2010a)

2.4. Needs met and not met

The fourth and final step of the mapping method consists of combining the supply and demand mapping for each service. Where supply coincides spatially with demand, the demand is said to be met, and where demand exists that does not coincide with supply, the demand is said to be not met. The intervention catchment principle described in section 2.3 means that this spatial intersection technique has some validity. Because neither supply nor demand is quantified, it is not possible to say whether there is sufficient supply in each location to meet the demand there. However, because of the threshold principle described in section 2.2, it can be assumed that the supply is a significant contribution towards the demand. The maps of demand met and not met are particularly useful because they correspond clearly to classes of action, as described in section 4.

The total number of demands met (or a sum of the likelihoods if the second version of the table has been used, as described in section 2.2) at each location is calculated and presented. Locations where many demands are met are clearly important green infrastructure assets. The total number of demands not met at each location is also calculated and presented, and highlights areas where creation or enhancement of green infrastructure could have a particular impact, if it is well designed, in terms of meeting many unmet demands. Finally, the percentage of demands met in each location is calculated and presented. Similar maps can be produced based upon subsets of the services corresponding to perceived benefits, with the same caveats described in section 2.2 – except for that now demand is incorporated.

If the method is being used to assess the possible impacts of a proposed change, maps showing change in each of the three variables described above (total demand met, total demand not met and percentage of demand met) can also be produced.

Figure 4 is an example of a completed map showing where demand is met and not met for one service.

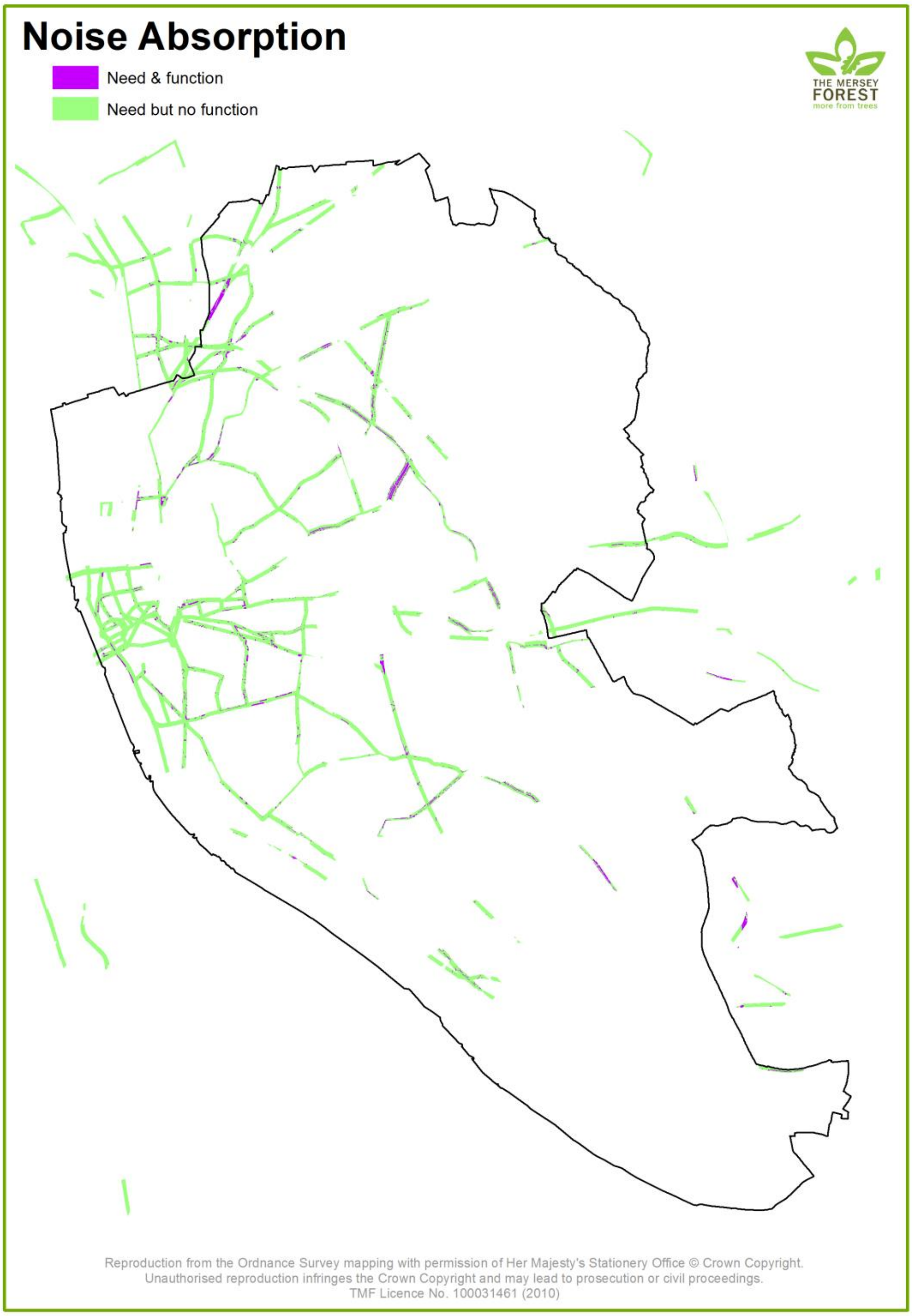

Figure 4: Liverpool noise absorption demand met and not met map (The Mersey Forest, 2010a)

3. Results

The primary output from the method is data that can be explored in a geographic information system, but maps are usually also produced. Examples of some completed maps from the Liverpool Green Infrastructure Strategy (The Mersey Forest, 2010a) are included below, showing:

- The green infrastructure typology mapping (Figure 1)
- Where one service is supplied (Figure 2)
- Where there is greatest demand for one service (Figure 3)
- Where demand is met and not met for one service (Figure 4)

4. Discussion

Many aspects of the mapping method have been determined by its primary purpose: to inform the local government planning process in the UK. In particular, it was decided at an early stage to privilege comprehensiveness (in terms of the range of ecosystem services considered) over quantification. This comprehensiveness is a key advantage of an ecosystem services approach (Haines-Young and Potschin, 2010): some well-known services (such as recreation) have been considerations of the planning system for decades (e.g. Parliament of the United Kingdom, 1919), whereas others (such as evaporative cooling) have been largely ignored (Maes et al, 2012).

It was considered unfeasible to quantify a large number of services. Instead, an approach was developed to determine whether or not each service was performed by the green infrastructure at each location. This approach, together with a needs assessment, gives planners the key information that they need to compare sites and target interventions, but also means that the method does not fit very well into the blueprints developed by Crossman et al (2013) and Seppelt et al (2011b). These blueprints could nonetheless provide useful templates and checklists for those beginning an ecosystem services mapping study. An attempt to shoehorn one application of The Mersey Forest's method into the former blueprint has been carried out, to demonstrate the issues and for the purposes of comparison with other studies, and is available on request.

The need for comprehensiveness is balanced against a need to consider each service in sufficient depth to ensure a reasonable level of confidence in conclusions drawn. A key strategy for achieving both requirements is to incorporate existing mapping where it is available and suitable, to avoid duplication of effort.

Another key principle is use of pragmatic levels of spatial detail. In urban areas, distinguishing private domestic gardens from the houses that they adjoin is valuable and achievable, whereas in rural areas, much larger areas are homogeneous in terms of their green infrastructure, and therefore a lower level of spatial detail is appropriate. Use of a vector rather than a raster framework helps to account for this variation.

A third key principle is the separation of supply and demand mapping. Key information outputs for decision-making include locations where demand for each service is already met, and locations where demand is not met. These outputs are particularly useful because they correspond very clearly to particular classes of action. In order to provide these outputs, it is important to map supply (and therefore also lack of supply) separately, as far as possible, from other aspects of demand for a service, such as the locations of people who particularly need it.

The classes of action mentioned – types of intervention for which the mapping method provides evidence – are illustrated by Figure 5.

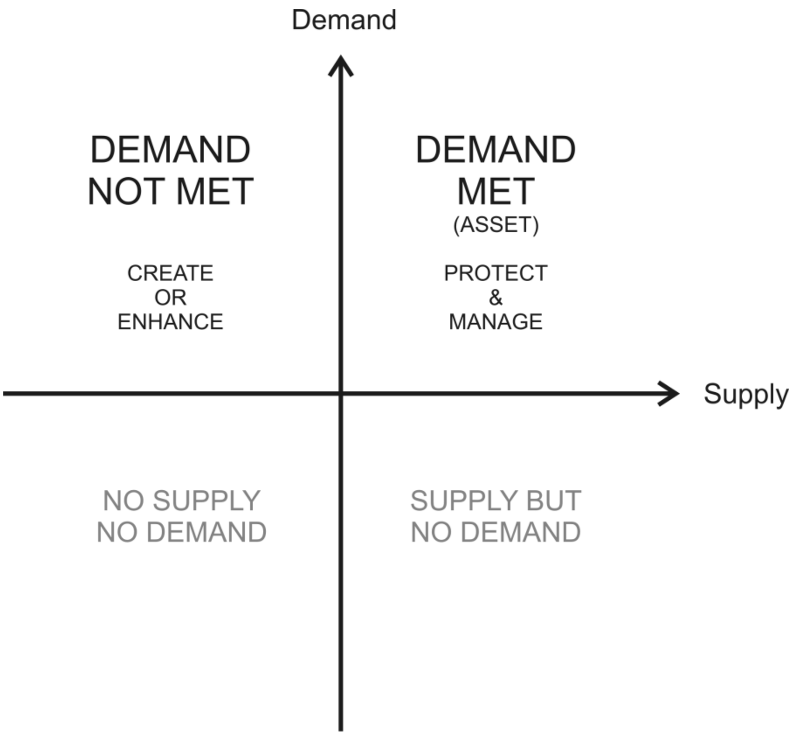

Figure 5: Where green infrastructure meets an identified demand by supplying the service, it is considered an asset in terms of that service, and should, if possible, be protected and managed so that it continues to supply the service and meet the demand. If it meets identified demand for multiple services, it is a particularly important asset.

Where an identified demand is not met (i.e. there is no corresponding supply) suitable green infrastructure should, if possible, be created, or the existing green infrastructure enhanced, to supply the service and therefore meet the demand. If demand for multiple services is not met in a particular location, the need for action is particularly pressing.

As well as providing evidence for targeting interventions in these ways, the outputs of the method can help with other planning decisions. For example, in the UK planners have to allocate sites for housing development, and the outputs can help them to choose between candidates, bearing in mind that the development might lead to loss or gain of green infrastructure both in terms of quantity and services provided. Planners also have to assess planning applications and place conditions upon development. The method provides evidence that can inform and support these decisions.

Furthermore, the method provides some of the input data for use of the Green Infrastructure Valuation Toolkit (Green Infrastructure Valuation Network, 2010), and is likely to similarly aid other valuation methods.

Some of the key advantages and disadvantages of the method are set out below.

4.1. Advantages

- **The method has been designed with a clear audience in mind**: primarily, UK local authority planners. Others who might also benefit from the evidence it provides include other UK local authority departments, local authorities elsewhere, government agencies, developers, NGOs and many others.

- **It has been designed with a clear purpose**: to provide evidence to aid decision-making. Key decisions with which it might assist include targeting and designing green infrastructure interventions, allocating land for development, and responding to planning applications.
- **It is built upon some clear principles**: privileging comprehensiveness over quantification, pragmatic levels of spatial detail and the separation of supply and demand mapping (see above), awareness of notional thresholds within supply mapping (see section 2.2), and awareness of intervention catchments and pragmatic choice of arbitrary thresholds within demand mapping (see section 2.3).
- **It is flexible**: modification of versions previously used is encouraged, allowing it to be applied to many different study areas, of different sizes and natures, in different countries, and with different data and stakeholder landscapes.
- **It considers demand for as well as supply of ecosystem services**
- **It can be understood by non-specialists** thanks to the use, as far as possible, of plain English terminology, to the binary nature of the key outputs, and to the familiarity of many categories used. Cowling et al (2008) and Seppelt et al (2011a) state that this is important for mainstreaming of the approach into policy.
- **It can help to educate non-specialists** thanks to the relative ease with which it can be understood, and to its comprehensiveness.
- **Key outputs correspond clearly to classes of action** (see above)
- **It is transparent**: the types and functions are defined, and the details of the source data and mapping processes are documented. This is particularly important when decisions based on evidence the method provided are challenged.
- **It can be used to assess the possible impacts of a planned change**
- **A basic version of the method can be carried out fairly quickly and easily**, depending on factors such as data availability, GIS expertise and the number of parcels in the study area.
- **Most of the source data required is readily available**, especially to UK public bodies.
- **There are several ways to get stakeholders involved in the process**, as described and recommended by Seppelt et al (2011a).

4.2. Disadvantages

- **The method does not attempt to quantify supply of or demand for ecosystem services**: whilst this was a conscious choice based upon documented reasoning, it is likely to mean that insufficient evidence is provided for certain decisions (Eigenbrod et al, 2010; Seppelt et al, 2011a).
- **Significant thought is often required to adapt the method to suit a new study area**, especially if the study area is outside the UK.
- **Most outputs require explanation** to avoid misinterpretation, especially when presented to non-specialists. For example, whilst multifunctionality maps are useful as a summary of the functionality mapping step and as a communication tool, users are advised not to give too much weight to them because they do not take into account the spatial variation in demand for the services, and they imply that all of the services are equally important (which they undoubtedly never are). Furthermore, users often like to group services to indicate which contribute most directly to perceived benefits of green infrastructure,

some of which they may wish to prioritise over others. The sums of these subsets can also be calculated and presented, although with the same caveats, and bearing in mind that the services and benefits are too deeply and subtly interlinked to do this rigorously.

- **Not all ecosystem services are included** in the standard list, despite the attempt at comprehensiveness, when compared with the Common International Classification of Ecosystem Services (European Environment Agency, 2013). However, Haines-Young and Potschin (2010) argue that services are contingent, so a list like the Common International Classification of Ecosystem Services cannot be universal, and should instead be treated more as a menu from which to choose.
- **Some key principles are difficult to apply consistently**, such as the separation of supply and demand mapping and the application of intervention catchments.
- **A highly accurate version of the method can be time-consuming to carry out**, especially if the study area contains a very large number of parcels and certain helpful datasets are not available.
- **Some useful source data is difficult or expensive to acquire**, such as colour infrared remote imagery of sufficient resolution.
- **Significant GIS and ecosystem services expertise is required** to carry out the method efficiently and with robustness.
- **Most source data is a proxy** in one sense or another. A study by Eigenbrod et al (2010) has demonstrated that this can result in misleading conclusions. Some parameters are anecdotal or based on expert judgement rather than empirical evidence. Regression modelling (recommended by Martínez-Harms and Balvanera (2012) for improved results based on sampled primary data) is not used.
- **Studies applying the method are not usually fully compatible or comparable with one another**, because the method is usually modified to suit the study area in question.
- **The method does not attempt to map opportunity** for green infrastructure interventions. Factors such as land ownership and funding availability may or may not allow recommended interventions (to meet an unmet demand, for example) to proceed.
- **Some important types of green infrastructure do not fit well into the parcel system** – for example, street trees and hedgerows. However, these can often be incorporated.
- **The outputs can be difficult to explore and use for those without access to a GIS or GIS expertise**, although this has been partially remedied by the creation of an online tool (The Mersey Forest, 2012).
- **The method does not take into account compatibility of services with each other** (in some cases, one area of green infrastructure cannot supply both of a pair of services). This is identified as an important consideration by Seppelt et al (2011a).

5. Conclusion

The mapping method presented in this paper is well suited to its primary purpose: to inform the local government planning process in the UK. This is evidenced by its successful application to several different study areas in the UK and the subsequent use of the outputs by planning professionals. It is also adaptable to other purposes, including outside the UK.

Many of the characteristics of the method (the primary purpose of informing the local government planning process in the UK, the consideration of demand for as well as supply of ecosystem services, the decision to privilege comprehensiveness in terms of the number of services considered over quantification, the incorporation of the flexibility necessary for application to many different study areas) help to distinguish it from the many other ecosystem services mapping methods that exist (Martínez-Harms and Balvanera, 2012; Crossman et al, 2013).

The mapping method has evolved iteratively, through application to a number of case studies. There is still considerable scope for further improvements, such as extending the standard list of services further in accordance with the Common International Classification of Ecosystem Services (European Environment Agency, 2013), and improving the criteria for mapping supply of and demand for individual services. The latter relies, to some extent, on more primary research, for example into services such as *encouraging green travel* and *noise absorption*, which seem to be less well understood (Hillsdon et al, 2009; Fang and Ling, 2003).

It would also be an improvement to incorporate some primary data on quantities of ecosystem services into particular applications of the method, for assessment of error and/or to improve the reliability of outputs (Seppelt et al, 2011a; Nelson and Daily, 2010; Martínez-Harms and Balvanera, 2012; Eigenbrod et al, 2010).

There are some services (notably *corridor for wildlife* and *pest and disease control*) where it would be useful for the primary research to be synthesised for non-specialist use and input into green infrastructure mapping. Widely available, up-to-date guidance would seem to be key in the transfer of knowledge from science to practice.

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