EcoServ-GIS v3.3

Technical Report: "Accessible Nature experience Service"

1. Ecosystem Service Definition and Description

<u>Short definition</u>:

Areas where people benefit from opportunities to experience and enjoy natural places and landscapes within their living, working, and commuting space.

<u>Long definition</u>:

Areas where people have opportunities to experience and enjoy natural places and landscapes within their living, working, and commuting space. The capacity of the natural environment to provide the service is mapped by identifying public accessibility status and scoring areas by their perceived level of naturalness. The demand (need) for the service is mapped by estimating the number of people likely to travel to an area, using site size and proximity indicators, together with estimates of the relative need for the health related benefits, based on health scores and population density.

<u>Descriptive text</u>:

People use greenspace for walking and recreation. Most frequent visits are local, but people may travel further to use larger sites. People gain various health benefits from recreation in the natural environment, both in terms of physical health and mental health. The benefits may be higher in more natural environments, such as areas with tree cover and water.

<u>Service benefits description</u>

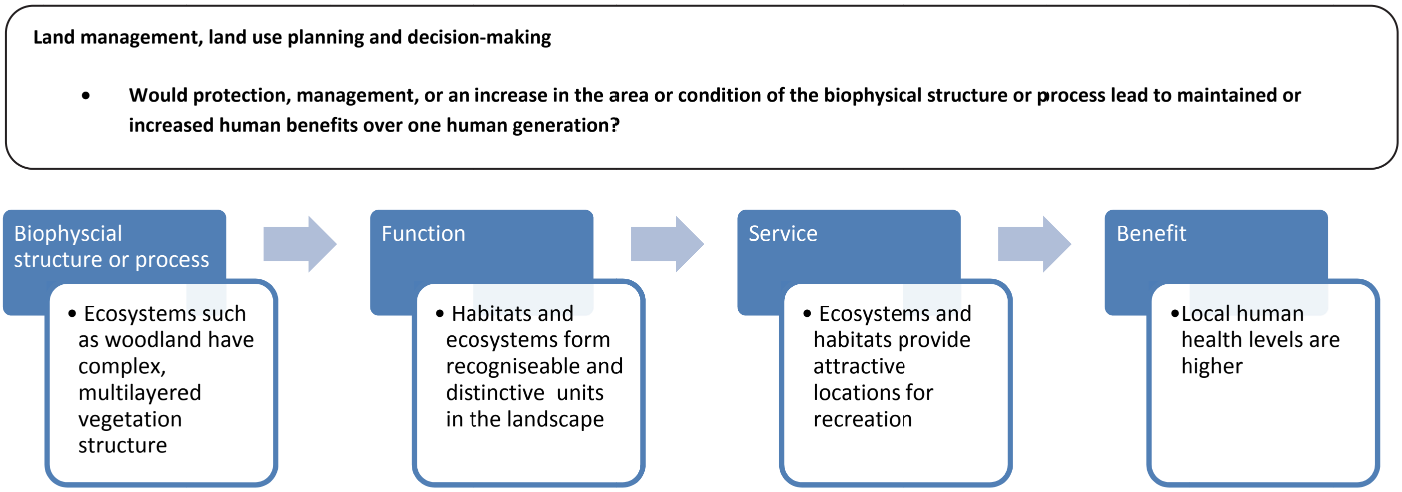
This service reflects the opportunities for people to experience semi-natural, natural habitats and greenspaces within their daily or weekly lives. The service focuses on accessible areas close to where people live by using distances that represent local travel, e.g. walking, jogging or short trips by bicycle, or car. The link between the environment and the human benefit focuses on frequent visits. These are most likely near to where people live or work. Infrequent, or long-distance visits are not considered within this service definition. Areas that are further than the region scale distance are therefore not considered to deliver this service, even if they are accessible.

This service focuses on opportunities for experiencing ecosystems through a level of engagement e.g. via walking, cycling, jogging, or viewing these at a close scale rather than longer distance views of natural habitats, which is examined in the aesthetics service. The focus of the service is on regular access rather than specialist trips to view particular sites or species, which are covered by other services (e.g. tourism, wildlife watching).

The activity by which people benefit from this service includes informal access via walking, cycling, dog-walking, or jogging in semi-natural habitats or greenspace and also by organised or formal events such as weekly health walks, park runs or walking or jogging groups.

2. Service Cascade

As this toolkit is aimed at a county to regional scale the focus of land management and decision making is local. A timescale of one human generation (20 - 30 yrs.) is set within which to consider, assess or measure the impacts of land use planning decisions and management. This is logical in relation to the long-term planning decisions of local authorities, health boards and infrastructure planning projects.



3. Literature review

Cultural ecosystem services are important to well-being and are typically more easily understood, appreciated and valued by people compared to more obscure services, such as carbon storage (Andersson et al. 2014). Urban localities hold areas that provide ecosystem services that are important to local residents' quality of life, such as recreation and cultural values (Bolund & Hunhammar 1999).

Well-designed urban areas, achieved through active planning or interventions in neighbourhoods towns and cities can lead to a greater quality of life, including mental and physical health of the residents (Barton 2009). There is now substantial support in the academic (Jorgensen & Gobster 2010; Haines-Young & Potschin 2010; Clark et al. 2014), policy (Balfour & Allen 2014; Faculty of Public Health 2010; Aked et al. 2008), and agency (CABE 2010; Greenspace 2011; Forest Research 2010; Greenspace Scotland 2008; Dempsey et al. 2007; LUC 2004), literature of the benefits to human health of greenspace provision, access and use, although the exact benefits, and beneficiaries may differ between populations and localities, and causal mechanisms can be complex (Miller & Morrice 2014).

Although this service focuses on the health benefits for residents of access to nearby nature for recreation, studies have also suggested a positive financial impact e.g. on residential house prices near parks or urban greenspace (Jim & Chen 2010; Kong et al. 2007). A 2008 review in Scotland of the links between greenspace and health (Croucher et al. 2008) reported a number of summary findings:

- A positive relationship between greenspace and general health, the relationship held across different socio-economic groups.
- People who use greenspace the most usually live nearby.
- Determinants of use of sites include attractiveness and site quality.
- Sites must be of sufficient size, be accessible and well connected to residential areas to be of most benefit and support use by high volumes of people.
- Site attractiveness can provide an additional incentive to continue with exercise programmes or regimes.

- A link between lower stress levels and access to urban greenspace. (Potential factors important for stress reduction may include: outdoor activity and exercise, natural daylight, sense stimulation and the aesthetic experience).
- Lack of evidence or consensus on the mechanisms of the broader health benefits, or the links to different types of greenspace.

Another review in England, also noted the following points and recommendations (Faculty of Public Health 2010):

- Greenspace has a positive impact on mental and physical health.
- Local authorities should provide more accessible greenspaces and open-air leisure facilities in which children, families, adults and older people can safely play and exercise.
- Local strategic partnerships, especially those in urban areas, should maximise the use of available greenspace for health-promoting activities.
- GPs should consider providing advice about physical activity in greenspaces as an alternative or adjunct to medication for patients with milder forms of depression or anxiety.
- Exercise prescription schemes in general practice could usefully be extended to cover supervised physical activity in greenspaces.
- Programmes, such as *Walking for Health*, which encourage physical activity in greenspaces and natural environments should continue to be fully supported.

A broad review of Green Infrastructure benefits (Forest Research 2010) noted that "good quality, accessible open space and infrastructure can provide many potential health and well-being benefits", and that significant benefit categories included:

- Improvements in life expectancy and reduced health inequality.
- Improvements in levels of physical activity and health.
- Promotion of psychological health and mental well-being.

Guidance in Scotland indicates a number of features of greenspace that are considered to promote physical activity (and thus health) (Greenspace Scotland 2008): Distance from residence, Ease of access, Size, Connectivity, Attractiveness, Multi-use.

A wide range of additional research in the area of greenspace accessibility, health, spatial analysis and planning exist. The following insights were used to help construct the current GIS service model:

Site attractiveness, naturalness and accessibility

- A number of features of "naturalness" are important to local urban park users, e.g. richness of bird and plant species, biological diversity and natural design (Bertram & Rehdanz 2014).
- A study across four cities in France and Portugal found consensus in priority values for park users of "contact with nature" and to "enhance health and well-being" amongst the reported benefits of users' access to greenspace (Madureira et al. 2015).
- There is evidence that site features including aesthetics promote use by people, but support is less clear, for example, than the impact of accessibility in promoting use (Bauman & Bull 2007).
- A Swiss study found a relationship between number of land use types within a 1 km cell and increased visitation, which the researchers interpreted as diverse landscapes being more attractive to people (Kienast et al. 2012).

Site attractiveness, naturalness, biodiversity and human benefits

- Recent review indicates the positive effect of natural environment settings on well-being compared to similar levels of activity in ”synthetic” environments (Bowler et al. 2010). Such benefits are separate from the additional pull factors of natural greenspace on length or frequency of site use.
- Questionnaire surveys in Finland found a positive association between reported well-being and participation in nature-based recreation (Korpela et al. 2014).
- Research in urban parks indicated measures of well-being were positively associated with perceived biodiversity levels in the parks (mainly species richness), and that for plants perceived richness was related to measured richness levels (Fuller et al. 2007).
- In Italy results from a self reported study found that higher natural settings (higher biodiversity level) was associated with a higher perceived restorativeness of visits to greenspace (Carrus et al. 2015).
- Perceived naturalness scores have been used to study *wildness* in Scotland, averaged across 250 m cells to account for how local landscape pattern impacts on how individuals may experience their landscape (Carver et al. 2011).
- Studies have examined links between public well-being and measured species richness in riparian greenspace sites and found no correlation, illustrating the complexity of linking site features of naturalness, species richness or broader biodiversity measures to well-being (Dallimer et al. 2012). Interestingly however, the study found a positive correlation between public perceived species richness and resulting well-being at greenspace sites.
- In Holland examination of street "greenery" found positive relationships at the street and neighbourhood level with self reported mental and physical health levels (particularly for stress) (De Vries et al. 2013).
- The Mappiness study in the UK examined the association between self-reported well-being and location, and found higher well-being levels in green and natural habitats compared to urban environments, although the respondents were not necessarily representative of the UK population (MacKerron & Mourato 2013).
- The public may hold different levels of perception of site naturalness or biodiversity compared to professional groups or specialists (Hofmann et al. 2012). In particular woodland habitats, and degree of canopy closure at sites are noted by the general public as characteristic "natural" features of greenspace (Hofmann et al. 2012; Dallimer et al. 2012).
- Research of public parks in Scandinavia showed that observers felt that parks were more restorative if they were more generally green, had a cover of trees and shrubs, and were larger (Nordh et al. 2009). This study of small pockets parks, less than 3,000 m^2 (0.3 ha) highlights the importance of small urban greenspace.
- Reviews have highlighted the difficulty of summarising the influence of biodiversity *per se* on human health, as compared to the general benefits of greenspace or the outdoors (Clark et al. 2014).
- In Australia, public open space in high socioeconomic neighbourhoods contained more features likely to promote physical activity amongst children compared to open spaces in more deprived neighbourhoods (Crawford et al. 2008).
- The relationship of mental health to biodiversity levels is less clear than the links to greenspace in general (Dean et al. 2011).

Greenspace use is affected by site accessibility and desirability

- Research across four European cities indicated parks are considered important by local residents for their recreation service (Bertram & Rehdanz 2014).
- Urban greenspace users in Holland placed most value on the ecosystem subservice of aesthetic appreciation, with other high scoring subservices including: recreation, air quality control and social setting (Buchel & Frantzeskaki 2014).
- Different user groups exist for greenspaces, and visits may be motivated by different reasons (Conedera et al. 2015).
- In Britain most visits to parks are by foot (69%), followed by cars (25%) (Greenspace 2007). Most journeys by foot were short <10 min.

- Neighbourhood greenspace availability "was positively associated with likelihood of reporting full physical, occupational, and social participation" in a study of the influence of local land use characteristics and features on activity levels in disabled adults using two scales of analysis (neighbourhood 800 m, community 8 km) (Botticello et al. 2014).
- Reviews indicate that physical activity levels are linked to accessibility, proximity and ease of walkability (Bauman & Bull 2007).
- Research in Bristol illustrated how user reported frequency of greenspace use declined with distance (Coombes et al. 2010).
- Some studies have used complex spatial models to include site-specific distance decay factors based on site interest levels (Giles-Corti & Donovan 2003). Scores were based on expert opinion of features present within greenspace sites, with a high weighting given to site size.
- Many studies have indicated that use and access of sites for recreation reduces with travel distance (Giles-Corti & Donovan 2002; TNS 2014; Natural England 2015a; Nielsen & Hansen 2007).
- A large study in England found that recreational walking was positively associated with % of greenspace (excl. gardens) at the local (approx 1.7 km), 5 km, and 10 km scales (Lachowycz & Jones 2014).
- Frequency, or likelihood, of recreation visits is often influenced by site size, larger sites being more regularly or consistently used (Giles-Corti et al. 2005).
- In Denmark, frequency of use of urban greenspace was related to distance. The authors found that after 100 m from larger urban parks, typical summer use frequency dropped rapidly with distance (Nielsen & Hansen 2007).
- In rural areas in England there is higher recreational physical activity, and recreational walking, compared to urban areas, the increased activity in these greener areas is not just related to more active rural jobs (Rind & Jones 2011).

Societal need for the benefits of access to nature varies spatially

- A large study in England found that mortality from all causes, and from circulatory disease, differs between populations with different exposure levels to greenspace. Physical environment can influence health inequalities (Mitchell & Popham 2008).
- Recent work in Scotland showed that mothers' perceived distance from nearby greenspace is associated with length of TV viewing in children of 6 yrs old (Aggio et al. 2015). Children in the most distant groups >20 min from greenspace also tended to have lower mental and physical health scores than those in the nearest group <5 min to greenspace. Because sedentary behaviour can be detrimental to health then this is of concern. Distances were self reported but are approximately <5 min (<300 m) compared to >20 min (> 1,200 m).
- In New Zealand, both access to useable greenspace and increased proportion of greenspace in the larger neighbourhood were associated with decreased anxiety / mood disorder counts, as reported to doctors (Nutsford et al. 2013).
- Several studies have examined greenspace quality and type, in addition to coverage or area. In Australia, researchers examined the number, proportion, type of greenspace within 1,000 m network distance of residents homes, and assessed relationships to mental and physical health. Physical health was measured but activity and mental health were self-reported. The greenness, size and type of greenspace were inversely related to cardio metabolic risk (Paquet et al. 2013). The study is of interest in noting that it is not necessarily the number or proportion of nearby sites that is important to people, but the characteristics of those sites. In this case the greenness and the presence of sporting facilities. The authors re ran analysis at 500 m and 1,600 m. Results were similar at the 1,600 m scale but were not fully repeated at the 500 m buffer (Paquet et al. 2013).
- There is most demand for greenspace in the central areas of municipalities where areas are surrounded by dense housing (La Rosa 2014).

Societal need for the benefits of access to nature varies between different populations

- In Sweden research has illustrated how the demand for the benefits of physical and visual access to greenery extends to the workplace environment, where male workers were shown to have more positive workplace attitude and reduced stress levels with increased greenery (Lottrup et al. 2013).
- In England research found that there was a relationship between greenspace occurrence and reduced cardiovascular mortality, but only amongst the most deprived areas of the community, and the relationship could not be explained just by increased levels of recreational walking (Lachowycz & Jones 2014).
- Work in Holland illustrates the complexity of health-environment relationships. 15 out of 24 disease clusters examined had lower than expected rates in areas with more greenspace within 1 km of homes (Maas et al. 2009). The authors stress the beneficial importance of greenspace close to homes. The relationship was shown to be particularly important for children and lower socioeconomic groups (Maas et al. 2009). The relationship was strongest in slightly urban areas, and not apparent in very strongly urban areas.
- Other studies in Holland found similar positive relationship between self reported perceived health levels and the occurrence of greenspace at 1 km and 3 km radius, again stronger impacts being shown in more deprived socio-economic groups (Maas et al. 2006).
- An interesting study in Philadelphia studied the impact of a greening programme on urban vacant lots over 10 yrs and found positive impacts on local health levels, and reduced crime levels (Branas et al. 2011).
- In targeting action, reviews have noted there is greatest potential health benefits of greenspace in areas with the greatest number of people in lower socio-economic groups (Forest Research 2010).

Site management and ecosystem service planning

- There is now increasing interest and support for the active promotion of the benefits of nature to support health and well-being (Carpenter 2013).
- Examination of recreational access areas in relation to green infrastructure has been mapped for use in city scale planning (Caspersen & Olafsson 2010).
- Accessibility to greenspace varies, areas have different resources in terms of service supply and demand (Balfour & Allen 2014).
- Reports have noted that green infrastructure should be improved or created, especially in areas of greatest “need” (Forest Research 2010).
- There is now policy support for more accessible greenspace to address health (Balfour & Allen 2014).
- Levels of greenspace have varied in cities over time, both up and down (Dallimer et al. 2011), and therefore there are opportunities to influence availability of this changing resource, via land use planning.
- Likely future trends in outdoor recreation use in Scotland suggest that any success in increasing participation is likely to require intervention, that recreation activities will be concentrated into hotspots, and there will be a key need to “provide quality outdoor recreation opportunities, infrastructure and services, particularly in proximity to places of work and residence” (Brown et al. 2010).
- In Scotland shorter distance categories of recreation visits have increased in importance over time (<3.2 and 3.2 to 8 km). Long distance trips are less frequent and local use has become more important (Brown et al. 2010).
- The impacts of greenspace can be presented in terms of cost avoided, or explicit health treatment benefits. Recent research showed that every 1% increase in the proportion of useable or total green space (within 3 km) was associated with a 4% lower anxiety or mood disorder treatment rate (Nutsford et al. 2013). Similarly every 100 m decrease in distance to the nearest useable green space resulted in a 3% lower anxiety or mood disorder treatment rate (Nutsford et al. 2013).

Information on the demand for accessible recreation locations is available in Britain (Greenspace 2007), England (Natural England 2015a) and Scotland (TNS 2014). Data are from 2013-2014 for Scotland (Sc) and England (En).

- Across Britain surveys indicated that 92% of respondents visited parks and greenspaces, 70% of which were regular visitors (Greenspace 2007).

- Reasons for park visits included to relax, for peace and quiet or to view or enjoy natural surroundings or wildlife. These were reported more frequently than visits to keep fit, or improve health (Greenspace 2007).
- Of visits to the natural environment (greenspace, opens spaces, the wider countryside and coast):
    - 64% (En) to 66% (Sc) were on foot.
    - 28% (En) to 27% (Sc) were by car/van.
    - 68% (En) to 60% (Sc) were within 2 miles (3.2 km) of start point.
    - 83% (En) to 85% (Sc) were within 5 miles (8 km) of start point.
    - 58% (En) to 50% (Sc) of adults visited the natural environment at least once a week.
    - Following their visit 80% (En) to 49% (Sc) reported feeling closer to nature.
    - Parks in towns and cities are a frequent destination 27% (En), 41% (Sc).
    - Woodland and forest are a key destination .
    - In England the proportion of visits within towns and cities is increasing.
    - Upland, protected areas or nature reserves formed a minority of visits.
        - Mountain / moors / hill: 2% (En), 7% (Sc).
        - Wildlife area / nature reserve: 4% (Sc) .
    - Motivation for visits included to enjoy scenery or wildlife 17% (Sc), to enjoy scenery 20% (En), to enjoy wildlife 13% (En).
    - Higher socioeconomic groups indicated the greenspaces in their area were within easy walking distance, and of a high enough standard, compared to lower socioeconomic groups.

Several previous studies have mapped the ecosystem service of recreation, access to nature or accessible nature (Herzele & Wiedemann 2003; East Midlands Regional Assembly & Partners 2006a; Kienast et al. 2012; Peña et al. 2015; Paracchini et al. 2014). However, the majority of existing research has examined demand or supply in isolation and few attempt to predict the flow of benefits. A good overview of the issues needed to consider when assessing greenspace access is presented by (Herzele & Wiedemann 2003). The importance of urban greenspace has been recognised at a government level, for example in Scotland with the production of national greenspace mapping (AECOM 2011). Recent research highlights how it is important to consider both the supply and demand of cultural ecosystem services (Peña et al. 2015).

In the East Midlands mapping for the *Public Benefits System* scored areas of land for desirability for greenspace creation, or management. High scores were given to areas where the local population had a high proportion of young or elderly residents because these are most impacted by their immediate locality, due to reduced mobility levels (East Midlands Regional Assembly & Partners 2006b). Similarly this system allocated high scores to areas that were in the highest 25th percentile for deprivation scores and also mapped reported health levels to aid targeting (East Midlands Regional Assembly & Partners 2006b).

In Switzerland a model was generated to map recreation suitability at the local scale, and this was used to derive guidance for landscape managers. Network distances between 1 km^2 cells and residences were created, using topography and accessibility via trails among a wide range of potential predictors of reported visitation. This study found an interesting relationship between higher number of land use types within a cell and increased likelihood of visitation, which the researchers interpreted as diverse landscapes being more attractive to people (Kienast et al. 2012). In a rare example of time quantification the researchers noted this analysis for a typical town would take approximately 6 months of landscape researcher time to complete. The study concluded that to be used effectively that attractive greenspace should be within 5 to 10 min walk or cycle (Kienast et al. 2012).

In the EU a system has been used to examine the recreation ecosystem service at a continental scale (Paracchini et al. 2014). The method examined potential demand and supply and assessed accessibility measures. At this scale close to home trips were considered to be <8 km and maximum day trips were defined as <80 km (Paracchini et al. 2014). Recreation potential was mapped using indicators of naturalness, with for example, coastal areas being given high importance. The study illustrated a miss-match between supply and demand in certain countries, but not in others.

Studies that have examined accessibility and benefits of greenspace have used a wide range of distance, connectivity or proximity measures together with variable definitions of greenspace, site types or area. A particular issue that emerges is whether the benefits link most to overall levels of greenness in the local environment (not necessarily fully accessible), or to specific accessible areas, such as the nearest useable greenspace. Many studies examine the proportion of total greenspace within a distance buffer. It is then unclear how much of this resource is actually accessible to people. Only several health studies have actually assessed useable and accessible greenspace e.g. (Nutsford et al. 2013; Aggio et al. 2015; Nielsen & Hansen 2007).

Caution must be used in the interpretation of the associations between greenspace, access and health. Many factors inter-relate and the results of studies are often strongly influenced by the methods chosen. For example in Stoke a negative relationship was found between use and access distance to recreational greenspace (>2 ha) in sunnier weather, but a positive relationship during wetter weather (Cochrane et al. 2009). This was interpreted that in those areas with poor greenspace access levels, the residents may be prepared to walk further to access sites outside their area in times of good weather, but to stay more locally when the weather was bad (Cochrane et al. 2009). A recent government project in Scotland found no evidence of a relationship between the amount of greenspace in urban neighbourhoods and mortality or measures of morbidity. The exception was men living in deprived urban areas, where higher amounts of local greenspace were associated with a lower risk of mortality (Miller & Morrice 2014). This Scottish study also found no relationship to mental wellbeing, however "regular use of woods and forests appeared to be more protective of mental health than exercising in the gym or streets" (Miller & Morrice 2014).

In summary, greenspace can be beneficial to people by encouraging physical activity, both within greenspace itself but potentially also in the wider community, it may also be associated with other physical and mental health benefits which again may be related both to access within accessible greenspace sites, but also to general neighbourhood or local greenness levels. Pathways to explain the wider benefit of inaccessible greenspace include stress reduction and related community effects. Several studies indicate there is most demand for access to nature in deprived socio-economic communities (Maas et al. 2009; Miller & Morrice 2014; Mitchell & Popham 2008). The implications are complex, because use and access to greenspace is known to differ between different socio-economic groups (Kabisch & Haase 2014) (see also: Community Cohesion Technical Report). Research has reported higher covers of vegetation, i.e. greener neighbourhoods, being related to higher socio-economic conditions (Pauleit et al. 2005; Pham et al. 2012). The quality of greenspace sites may also differ between areas such that certain neighbourhoods may experience multiple environmental deprivation. A final point relates to the issue of the inclusion of gardens. Gardens, as a form of greenspace, have received mixed research (Cameron et al. 2012), but the occurrence of gardens is known to vary between different types of housing stock and therefore the relative balance and importance of gardens versus other forms of greenspace to health and well-being is likely to vary. Studies have variously included or excluded gardens in their measures of greenspace links to health.

Methods used within previous accessibility studies

Existing literature have used various methods with which to assess or map the resource or demand for accessible nature. These are summarised below. The main factors that vary are: the types of land considered to be greenspace, minimum size thresholds at which sites are considered able to deliver benefits to people, travel distance used to identify catchment areas or zones of benefit within which people are most likely to access sites, methods of mapping accessibility, and methods of mapping beneficiaries (e.g. households or mapped zones). Finally different methods have been used to categorise variations between sites, e.g. in attractiveness, quality, and naturalness.

Types of greenspace. In England accessibility analysis typically excludes areas of allotments, farm land, golf courses and school playing fields, but includes all remaining areas of semi-natural habitat or greenspace (Comber et al.

2008). In Scotland almost all land is legally accessible, but studies tend to focus on certain categories of greenspace, for example as mapped within the Greenspace Scotland map (AECOM 2011). Academic research has used a range of definitions, with both the inclusion or exclusion of private gardens.

Site size. Thresholds have been informed by studies of typical urban sites and are estimated sizes at which different levels of benefit may be expected to occur. Guidance in Wales applies a minimum site size of 2,500 m^2, (0.25 ha) which is 50 x 50 m, easily within the range of small urban parks that could be used, for example, by dog walkers. Academic studies have used different minimum patches sizes to illustrate areas likely to be suitable for recreation. In Norway a threshold of 5,000 m^2 (0.5 ha) was used (Koppen et al. 2014), in Holland 600 m^2 (0.06 ha) (Maas et al. 2009; Maas et al. 2006) and in New Zealand both 500 m^2 (0.05 ha) and 200 m^2 (0.02ha) (Nutsford et al. 2013; Richardson et al. 2013). In England a cut off of 2 ha is normally used by Local Authorities to assess accessibility standards, although this may be varied locally (Handley et al. 2003). Research indicates that there are probably more attractive features present in larger urban greenspace sites (Schipperijn et al. 2013).

Accessibility mapping. Koppen et al. outline the main steps involved in accessibility mapping (Koppen et al. 2014). This may include simplistic buffer analysis using straight-line distance or more complex network analysis along known, or predicted, travel routes (La Rosa 2014). Early advice recommend more detailed distance analysis (Harrison et al. 1995), but this was rarely applied. Buffering is the main method that has been applied. Comparative analysis has shown that accessibility quantifications differ if network analysis instead of buffer analysis is used (Koppen et al. 2014; de Vries & Goossen 2002). In the Netherlands the two measures were highly correlated (0.9) indicating use of simple distance would have been acceptable (de Vries & Goossen 2002). Recent work in Italy also highlighted the two measures were highly correlated and noted that simple Euclidean distance may be suitable, considering the additional data and analysis requirements of network analysis (La Rosa 2014). When network analysis has been used to calculate distances to greenspace along the road network it has been from origin points of homes (Barbosa et al. 2007), or from postcode units (Coombes et al. 2010). Some studies have carried out detailed analysis to identify "walkable" networks, to assess greenspace connectivity, e.g. by digitising detailed access points (Cochrane et al. 2009). This research then mapped different classes of greenspace as, “restricted access” (greenspace, but with no public access or no obvious legal use), “unrestricted access” (freely accessible, and e.g. with mapped access points), and an intermediate category of “limited access” (Smith & Davey 2008; Cochrane et al. 2009). Recent work has identified types of greenspace users and used least-cost analysis in order to map likely accessibility (Moseley et al. 2013). This work used proximity analysis to weight the catchment zones around sites by their levels of quality, and user profiles to drive the least-cost analysis. Results indicated that network analysis for leisure users gave a provision area less than one third the value given by Euclidean buffer analysis (Moseley et al. 2013).

Site accessibility, usability and proximity indicators. Studies have used different distances and methods within which to consider site accessibility. A target distance may be used to calculate all the nearby greenspace resource within a buffer zone, to assess accessibility to the nearest greenspace site, or to show what proportion of the population has an accessible greenspace resource within this distance. For example, 300 m distance relates approximately to a 5 min walk and this has been used to indicate likely local use. In Europe longer distance accessibility targets have been set, such as 15 min walk, or 900 m distance (Barbosa et al. 2007). In Australia parents considered 800 m from homes a reasonable distance for their children to travel (Crawford et al. 2008). In Belgium a study used 5 km as a maximum distance that could be covered by walking or cycling (De Clercq et al. 2007). Such measures are used to estimate catchment areas or “home ranges” of local residents within which frequent use of greenspace may occur. Historical ranges of children's activity have been reported from under 100 m around homes, up to 1,136 m (Mathews, 1987) in (Harrison et al. 1995). Early work initially recommended minimum accessible distances of 500 m, but these were reduced down to 280 m to account for the use of sites by children (Harrison et al. 1995). In London areas of deficiency of greenspace have been identified where areas are more than 1 km walking distance from metropolitan or borough quality sites (Handley et al. 2003).

Of the health research examining accessibility a range of distances have also been applied. Research examining activity levels in Bristol used a 800 m network distance (Coombes et al. 2010). In Holland, positive health measures were associated with greenspace cover at 1 and 3 km buffer scales (Maas et al. 2009; Maas et al. 2006). Work in England has examined greenspace cover within census zones. The area of these census zones can be converted to an estimated radius distance, in order to allow these to be compared to studies using buffer distances. The mean estimated radius for LSOA zones is 723 m, and for MSOA zones 1,728 m. In England there is an association between % cover of greenspace and likelihood of recreational walking at MSOA (1,728 m), 5 and 10 km scales (Lachowycz & Jones 2014). Separate research also reported an association of higher physical activity levels related to % greenspace within MSOA zones (1,728 m) (Mytton et al. 2012). Previous research in England also showed positive association of health characteristics with % greenspace cover at the LSOA (723 m) scale (Mitchell & Popham 2008).

The accessibility distance measures may also be used in combination with different site area thresholds, to allow an additional range of proximity measures to be mapped. Larger sites may attract visitors from a longer distance, and these have been assessed using 2, 5 or 10 km distances (Natural England 2010).

Location of beneficiaries. Several studies examining the “recreation” ecosystem service have used zonal models of accessibility from post code areas e.g. (Baerenklau et al. 2010). These models map the benefits of greenspace back to areas of users. Other studies have used the exact location of households, or samples of typical households as point data, rather than zones e.g. (Barbosa et al. 2007). Further studies have used zonal areas from the population census, e.g. Output Areas (OA), typically using the centre point for distance or density calculations, e.g. (Comber et al. 2008; Cochrane et al. 2009). The use of zones is likely to be acceptable and similar to household point mapping for small zones in cities, but becomes problematical with large zones, or in rural settings. In such situations the use of a centre point coordinate to represent the accessibility distance or area of greenspace for all residents within the zone becomes less reliable. Other approaches include the overlay of hexagons to divide the landscape into units of analysis for landscape metrics and socio economic analysis (De Clercq et al. 2007).

Type of beneficiaries. Mapping work has noted that access to greenspace statistics are useful, not just for the whole of society, but are needed for different sectors of society, to be of most use for planners (Barbosa et al. 2007). Whilst academic work often includes an investigation of the variability of greenspace with socio-economic group, the setting of access standards has been uniform across population types.

Site quality, attractiveness, biodiversity or naturalness. Many approaches do not attempt to estimate site attractiveness, instead using proxies such as site size to indicate likely interest levels. It is difficult to select a method that can be generalised and used in all areas when representing naturalness as an attractive site trait for all potential users. For example, research has shown that different landscape types may be valued differently in core urban, versus rural-urban, landscapes (Cho et al. 2008). However a number of studies do measure visitors or public perception of features that are attractive or conducive to visits or recreation use, e.g. (Goossen & Langers 2000). These areas of research use preferences for particular habitats or landscape types, e.g. woodland, moorland etc compared to those that are disliked, such as urban areas or industry, to assign scores to sites or landscapes. The likely levels of nature or wildlife present within a site can be a motivating reason for visits to sites or areas (Bird 2004; TNS 2014; Natural England 2015a).

Greenspace assessment for prioritisation and gap analysis. In order to assess access levels between different areas a number of standards have been developed for use by local authorities. These set minimum acceptable standards for the occurrence of accessible greenspace, using site area thresholds and minimum access distances. Such quantification of accessible greenspace has a relatively long history (Harrison et al. 1995). Accessible greenspace standards have been developed in England (Comber et al. 2008; Handley et al. 2003; Mckernan & Grose 2007; Natural England 2010), Scotland (GS & SNH 2013) and Wales (CCW 2006). Other work in the Netherlands produced a GIS model of recreation visits to areas and allowed indication of areas with an undersupply or recreation or nature areas (de Vries & Goossen 2002). Standards are similar between the countries of the UK. In Wales (CCW 2006), the guidance advices:

- 2 ha of accessible greenspace per 1,000 population.
- No person should live more than 300 m from their nearest area of natural greenspace (0.25 ha threshold).
- At least one accessible 20 ha site within 2 km of home.
- One accessible 100 ha site within 5 km of home.
- One accessible 500 ha site within 10 km of home.

Research acknowledges that the 2 ha size limit was arbitrary and that ideally all sites would be included (Harrison et al. 1995). There is much debate over the appropriate distance threshold and minimum site area used in such assessments. In Scotland 400 m network distance is recommend, reduced to 300 m if using buffer analysis (GS & SNH 2013). Similarly a default site area of 0.2 ha is recommend in Scotland, but some areas such as Fife have a applied a lower threshold of 0.1 ha (GS & SNH 2013). The larger site area and distance thresholds are intended to capture the greater benefit that may lie in larger greenspace sites, and the greater willingness of residents to travel further to access such sites.

Table 1. Studies examining health links to greenspace

Reference	Location	Analysis (N = network, B = buffer)	Unit type (Z = zones, P = points)	Popn Age	Units N=individuals Z = zones	GS type	GS Thresholds (Ha)			GS Distance bands search radius (km)				GS measures: CD,, %, S,Q	Impact A,M,P	Health measure R,M
							<1	1-50	> 50	<1	1 to 10	10plus	Nearest			
(Aggio et al. 2015)	Scotland	N	P	<6	N 3,586 (Z 10)	U*	-	-	-	0.5	1.2		Y	D	A,M,P	R
(Cochrane et al. 2009)	England	N,B	P,Z	>18	N 761	U		2		0.2,0.4,0.6,0.8	1			D	A	R
(Coombes et al. 2010)	England	N	P	>16	N 6,803	U*		2		0.8			Y	D	A,P	R
(de Vries & Goossen 2002)	Holland	N	P,Z	mn 51	N 1,641 (Z 20)	T	-	-	-	0.5				%,Q	M,P	R
(Lachowycz & Jones 2014)	England	B	Z	>18	N 165,424, (Z 6,781)	T*	+			MSOA	MSOA, MSOA+5	MSOA+10		%	A	M
(Maas et al. 2006)	Holland	B	P	all	N 250,782	T	0.06				1, 3			%	P	R
(Maas et al. 2009)	Holland	B	P	all	N 345,143	T	0.06				1, 3			%	M,P	M
(Mitchell & Popham 2008)	England	B	Z	<retired	N 40,816,236	T*	+			LSOA	LSOA			%	P	M
(Mytton et al. 2012)	England	-	Z	26 -58	N 31,049	T*	+			MSOA	MSOA	MSOA		%	A	R
(Nielsen & Hansen 2007)	Denmark	N	P	18-80	N 1,200	U				0.05, 0.1, 0.3	1, 2, 5	20, >20	Y	D	M,P	T
(Nutsford et al. 2013)	New Zealand	N,B	Z	>15	N 7,552,(Z 3,149)	U*,T*	0.05			0.3	3		Y	D,%	M	M
(Paquet et al. 2013)	Australia	N	P	>18	N 3,754	U	0.07				1			C,%,S,Q	P	M+R
(Richardson et al. 2013)	New Zealand	-	Z	>15	N 8,517, (Z 1,009)	T*	0.02			CAU				%	A,M,P	R

U = Useable (accessible) greenspace, T = Total greenspace, * Excludes gardens, + very small area threshold of 0.0005 ha. Greenspace measure: C =count, D = distance, % percentage cover, S = size, Q = quality. Population impact assessed: A = physical activity, M = mental health, P = physical health. Health measure: R = self reported, M = measured or physician assessed. MSOA (Eng) radius (m) 306 - 18,954, mean 1,728, 80% < 2,376 LSOA (Eng) radius (m) 76 - 14,756, mean 723, 80% < 832 CAU mean area ~ 0.5 ha, estimated typical radius ~ 40 m

Table 2. Summary of accessibility and health impacts

Reference	Types greenspace	Accessible only?	Scales - search radius (km) Local <1	Landscape 1 to <10	Region > 10	Activity and health impacts	Stronger impact In deprived communities?
(Aggio et al. 2015)	not gardens	Yes	x*			Children in worst GS access area had more TV time (sedentary behaviour) compared to those in highest GS area. Children in worst GS access area had lower general health and mental health compared to those in highest GS area	Yes
(Coombes et al. 2010)			x*			People more likely to visit nearby greenspace. Residents of more walkable and less socioeconomically deprived neighbourhoods more likely to visit greenspace, and less likely to be overweight or obese. More frequent greenspace users less likely to be overweight or obese.	Yes
(Lachowycz & Jones 2014)	not gardens	No		x*	x*	Higher % GS leads to more recreational walking. Recreational walking not linked to reduced mortality or to circulatory disease in general. However amongst deprived areas significantly lower mortality in greenest compared to least green areas.	Yes
(Maas et al. 2009)	All	No		x*		% GS leads to reduced morbidity	Yes
(Maas et al. 2006)	All	No		x*		% GS leads to increased perceived health, particular impact of socioeconomic groups and age (old and young)	Yes
(Mitchell & Popham 2008)	not gardens	No	x*			Populations exposed to greener environments also enjoy lower levels of income deprivation related health inequality.	Yes
(Mytton et al. 2012)	not gardens	No	x*	x*		% GS associated with increased physical activity	-
(Nielsen & Hansen 2007)	All	Yes	x	x	X	Access to gardens or short distance to greenspace associated with less stress and lower likelihood of obesity	-
(Nutsford et al. 2013)	not gardens	Both	x	x*		Proportion of total and useable greenspace in 3 km and distance to nearest useable greenspace associated with anxiety / mood disorder treatment. No effect of 300m buffers.	-
(Paquet et al. 2013)	All	Yes		X*		Quality of sites within 1 km related to lower risk of cardio metabolic health risk	-
(Richardson et al. 2013)	not gardens		X*			GS associated with physical activity. Zone greenness, GS associated with reduced cardio vascular disease or poor mental health.	-

x = scale relationships examined, *main significant impact scale

4. Summary of constructing the GIS mapping service model

Sufficient information was available in the literature and sufficient detailed GIS data was available to build a logic based model of the service, however a number of approximations and assumptions had to be made. The main literature identified rules used to build the models were:

Capacity

- The frequency, or likelihood, of site use may be linked to site attractiveness, or site area as a proxy.
- The accessibility and connectedness of sites will affect their use and value to people.
- Naturalness or diversity features of a site may enhance the benefit of visits, or be a motivating factor for users to visit sites.
- Perceived biodiversity levels may be linked to reported well-being levels at greenspace sites.
- Perceived naturalness scores can be attributed to habitat types to indicate public perception of experience levels near, or within, such habitats.
- There are thresholds of site size, below which there is reduced, or no, capacity for the service, however the potential importance of very small pocket parks in urban areas should not be underestimated.

Demand

- Parks and urban greenspace sites are particularly important for people.
- The demand for accessible nature is highest at short distances, near where people live, and declines with travel distance.
- Ideally demand mapping will use access points and detailed accessibility information.
- Ideally network analysis rather than buffer analysis would be used to map demand.
- Most people travel to use greenspace sites on foot.
- Distance buffers can be used to assess the catchment population, and hence demand for individual sites.
- Site size can be used as a proxy for site attractiveness, likely occurrence of significant features and likelihood of longer distance travel by people.
- There is a higher societal need for accessible nature benefits in neighbourhoods with lower socio-economic conditions or higher levels of deprivation.
- Ideally demand mapping would not use uniform standards, but would adapt these to local socio-economic characteristics, such as age, mobility, health, and access to transport.

Building the service model involved the following stages:

- Capacity
  - Mapping site accessibility.
  - Selecting indicators of service capacity.
  - Identifying thresholds for site capacity.
- Demand
  - Selecting indicators of service demand.
  - Choosing site attractiveness and functionality thresholds.
  - Choosing demand catchment scales.
  - Modelling user types.
  - Weighting demand indicators.

Mapping site accessibility

Areas of "Accessible" greenspace are mapped in order to indicate the areas where the service is most likely to occur. These are legally publicly accessible areas in England and Wales, and indicate those areas of most likely public use in Scotland. Private land, or land where access is not actively promoted, is considered to block the flow of this service because members of the public are not able, or likely, to access the site. Accessible areas are:

- 20 m either side of linear routes.
    - Public Right of Way (England and Wales) or Core Path (Scotland).
    - Pavements (modelled from MasterMap, with areas along Motorways and Dual Carriageways removed).
    - Long distance walking route (GB).
    - Sustrans cycle route (GB).
    - Forestry Commission recreation route (GB).
- Publicly accessible areas / areas promoted for public use.
    - Country parks (England and Scotland), data not available for Wales.
    - Countryside Rights of Way access (England and Wales).
    - Local Nature Reserves, National Nature Reserves (GB).
    - Beaches and 100 m swim distance from them.
    - Accessible woodlands ("Woodlands for People") mapped by the Woodland Trust.
- All areas of Green Infrastructure labelled as "accessible" during the creation of the BaseMap models (see BaseMap Technical Report).
    - Typically: Playgrounds, general amenity greenspace, cemeteries, parks and public gardens and other areas mapped as accessible by Local Authority Open Space Surveys or Greenspace Scotland map.

Selecting indicators of site capacity

Protected area status, or measures of conservation importance (e.g. SSSSI status) were not used as an indicator of accessible nature capacity because the general public may not be sensitive to the differences between sub types of rare habitats. Recent work in England tested the network of protected sites in different tiers against several measures of a coherent ecological network, one of which included measures of accessibility. Analysis showed the importance of Local Nature Reserves and Local Wildlife Sites in being accessible within urban areas whilst a lower percentage of other protected site categories (SSSI, AONB etc) occurred in, or near to, urban areas (Lawton et al. 2010).

Measures of perceived naturalness were selected to map site capacity. Natural habitats are scored based on results from two tranquillity and wilderness mapping studies which collected survey data on the public's perceived naturalness of different land cover types in England (Jackson et al. 2008) and Scotland (Carver et al. 2011; Carver et al. 2008), and applied these to Land Cover 2007 data habitat categories for mapping. We averaged the habitat scores from the two studies and assigned scores to the closest matching habitat categories identified in the BaseMap (See "Naturalness" field, and habitat link table in the Toolkit). Areas classified as a mixture of habitat types were assigned the lowest naturalness score of any habitat present.

Several studies indicate that more diverse, natural, or higher biodiversity areas are important motivating factors for site use, or give higher benefits to people (Bertram & Rehdanz 2014; Bauman & Bull 2007; Bowler et al. 2010; Fuller et al. 2007; Carrus et al. 2015). Perceived naturalness scores were used because studies indicate that the public gain well-being benefits from habitats that are perceived to be more natural, or of higher biodiversity (Dallimer et al. 2012; Fuller et al. 2007).

Accessible greenspace areas are identified and analysis is applied to "sites" above a user defined area threshold. Naturalness scores are analysed to derive an indicator that represent naturalness at the site, and within a focal distance, to capture visitors experience of the nearby local environment. Focal analysis sums the scores of all cells within the selected local distance (default 300 m) for all areas of greenspace. This represent a typical local experience score that a person may experience as they undertake a short distance walk within the site. A 300 m distance relates to a short 5 min walk, once within a site. Non greenspace areas do not receive a capacity score. The focal search score and the cell based patch score are combined. The resulting score is standardised and represents the unrestricted accessible nature capacity. The same analysis is then conducted for all areas, rather than just accessible areas, to create scores for all greenspace areas - the restricted accessible nature capacity. Greenspace sites are mapped as all semi-natural habitats excluding water, sea and private gardens, these settings can be altered by the user.

Identifying thresholds for service capacity

An area threshold is applied to sites because small sites may not have the capacity to deliver the benefits of the service to people. A small area threshold of 0.05 ha (500 m^2) is used because small pocket parks may be important sources of accessible nature in built up areas, and cumulatively these may contribute to neighbourhood character. This is smaller than the thresholds currently used in most accessibility analysis. The parameter can be altered by toolkit users to match local conditions.

Selecting indicators of service demand

The literature review indicated that key determinants of demand for the service were: site attractiveness, site proximity or distance and local population characteristics.

Analysis was conducted to create 3 indicator types, each repeated at three spatial scales, to capture the different characteristic of use of local, versus more distant greenspace areas. The individual indicators and the way the indicators are combined across spatial scales can be altered by the user, although recommended defaults are applied.

Previous work indicates that analysis methods can result in different forms of demand maps. For example data can be attributed to either trip sources (homes), or to destination areas (greenspaces), e.g. the number of people within a set distance of a greenspace can be attributed to each greenspace. The later approach is recommended when the aim is to analyse and understand the demand for greenspace areas (La Rosa 2014).

Indicators for population density, local mean population health scores and distance to the nearest access points or footpaths are then calculated at each of three spatial scales, with the results applied back to the following three scales of greenspace. Population size and general health scores from the Index of Multiple Deprivation (IMD) are used to indicate relative societal need or demand for the service. We do not refer to conscious demand for the health benefits of the service, we simply note that in areas of higher population or where general health is poorer that if people had access to semi-natural areas for recreation that there would be a higher general benefit to the population than in either areas of lower population or where health levels are currently high. As such the method does focus on marginal change in human benefits and not on maintaining the current health level of good health areas.

In order to account for limitations in both the mapping rules that identify domestic buildings and the reliability of the population size and Multiple Index of Deprivation statistics at low population density, thresholds are applied to the

Local, Landscape and Region population measures. Defaults are > 50, > 500, and > 1000. These can be modified by users.

Separate site access indicators are created for the three scales of greenspace site. A selection and modification of the data used to map publicly accessible areas are used to map each access indicator score as a proxy measure for travel demand to each type of site. For local scale greenspace sites, the areas will mainly be accessed by people on foot. A distance analysis from all pavements, surfaced paths, PROW / CORE paths and Sustrans cycle routes is mapped (default 600 m). The landscape scale analysis assumes that some site users may walk to the site whilst others will arrive by vehicle. Analysis examines the transport stop location (XY stops data) and also a dataset that generates a proxy for access points to parks, country parks or areas of the countryside. This data is generated by finding points of intersection between surfaced roads and any PROW / CORE paths, Sustrans cycle routes, FC recreation routes, or long distance paths. These are proxies for the locations of car parks, lay-bys or visitor centres at which people may park, or alight from public transport, before walking in the countryside. The method is likely to overestimate these sites. Users can add local data by replacing the XY stops dataset with point data on car park locations, or these can be merged with the XY stops data. The default landscape travel distance is 2.4 km. The same analysis is conducted for region scale analysis, again using a default walking distance of 2.4 km (from the car park or access point). The access distance scores are masked to the mapped greenspace sites at each analysis scale. All scores are then inverted on a 1 to 100 scale, with 100 representing the areas very close to the access route or access point.

Choosing site attractiveness and functionality thresholds

Three categories of greenspace are mapped in order to represent sites that are used locally, e.g. by walking or more distant sites that are likely to be accessed by cycling or vehicles or public transport.

Greenspace is identified as all areas of the BaseMap excluding gardens, water, sea, built up areas, infrastructure, paths and pavements. Agricultural areas are retained. Site area is identified in order to allow sites to be selected by size category. Analysis dissolves boundaries between adjacent green areas, leaving sites split only by roads or built up areas. This allows smaller urban greenspace sites to be identified, although rural areas often remain classified as several very large contiguous "sites" with this method. This method is then used to separately identify *local*, *landscape* and *region* scale greenspace sites. Default sizes applied are: 0.1 ha, 10 ha and 100 ha. Each category includes all sites above the size threshold, therefore the three data layers will overlap in many areas.

Choosing demand catchment scales

Guidance for setting accessibility standards for Local Authorities often use a short distance catchment of 300 m, from buffer analysis, to show that all populations should have access to a greenspace site within 5 min walk. This distance is considered too fine a resolution and too simplistic to use to assess the accessible nature resource at a local scale, where people may have a choice of several nearby sites, rather than just use their nearest site. Available evidence on typical travel distances was used to set the three (local, landscape, region) catchment analysis distances. Most trips to parks, greenspace or to access the natural environment are over short distances. The information resulting from Natural England's Monitoring of Engagement with the Natural Environment (MENE) study used questionnaires with estimated distance bands to track visits (Natural England 2015b). The data from 2011-2014 was downloaded and analysed. The survey used distance ranges, the midpoints of these have been used to map the cumulative occurrence of trips, split by transport types, and comparing all source locations, to those trips from home. The analysis indicates almost 90% of trips by walking are less than 2.4 km, whilst almost 70% of trips by car are less than 12.8 km.

In England, health research found recreational walking was positively associated with total % of greenspace (excl. gardens) at the local (1.7), 5, and 10 km scales (Lachowycz & Jones 2014), and with increased physical activity at the

1.7 km scale (Mytton et al. 2012). Also in England a large study showed the health benefits of greenspace cover across LSOA census areas, mean radius of 723 m (Mitchell & Popham 2008). Studies reporting associations between mental health and greenspace at very short scales < 500 m have been variable and contradictory (Nutsford et al. 2013; Aggio et al. 2015). The majority of studies examining health benefits have measured the % cover of greenspace at local scales greater than 500 m, typically up to 1, or 3 km radius.

The insight from this range of studies was used to set the scales of analysis for demand catchment mapping at: *local* 0.6 km, *landscape* 2.4 km, *region* 12.8 km.

This equates to travel time estimates of local scale: a 10 min walk or 3 min cycle, landscape scale: a 30 min walk, 9 min cycle or 4 min drive, and region scale: a 15 - 20 min drive or 48 min cycle.

Trip analysis. Cumulative analysis, reference % within each trip type. (England MENE, all data 2011-2014).

Distance bands Km (mid point)	On foot From home	By car / van From home
0.8	60.1	7.3
2.4	89.7	28.0
6.4	98.9	53.8
12.8	99.9	69.8
24.8	100	81.9

Trip analysis. Cumulative analysis, reference % against total of all visit records. (England MENE , all data 2011-2014).

Distance bands	On foot		By car / van		All transport	
Km (mid point)	All	From home	All	From home	All	From home
0.8	37.9	36.6	2.2	2.0	40.1	38.6
2.4	56.6	54.5	8.2	7.6	64.8	62.1
6.4	62.6	60.1	15.7	14.7	78.3	74.8
12.8	63.3	60.7	20.4	19.0	83.7	79.7
24.8	63.3	60.8	24.1	22.3	87.4	83.1

The following distances were selected to map the different scales of demand

Catchment scale	Distance (radius) (km)	Site threshold (ha)	Proportion of population affected	Travel method	Weighting
Local	0.6	0.1	~100%	On foot	0.6
Landscape	2.4	10	~65%	On foot / vehicle	0.3
Region	12.8	100	<10%	Vehicle	0.1

Score weighting – Accessible Nature service

The scores for each spatial scale are combined to give most weighting to local scale factors, and only minor influence to region scale factors, to match the literature on greenspace site usage.

5. Spatial occurrence and service flows

This service is provided by areas of natural and semi-natural habitat. The flow of the service is in-situ, people benefit from the habitat and semi-natural areas if they are within (or directly adjacent) to the area. The mapping of the flows is dependent on the identification and mapping of accessible areas. Private, or inaccessible, land is considered to block the flow of the service as general members of the public are not able to access the site lawfully or easily in order to benefit from the service.

6. Ideal Data

The ideal data with which to map the service would be locally collected site measurements, at a relevant local spatial scale, compared to reference measures at a national scale. Data would be recently collected and updated regularly. Scientific research would be available which measures the impact of marginal changes in the extent, composition or condition of the natural capital asset on the level of the service delivered to people, and the benefits experienced. There would be detailed data on the number per socio-economic category, age or other suitable classification category of people who could benefit from the service, along with research on how changes in these social characteristics alter their relative levels of service demand over time. Finally there would be data on how levels of human use impact ecosystem condition.

In order to reliably map the service the following information would be required:

Capacity

- The type, location, extent, condition, quality and management status of greenspace and semi-natural habitats.
- The extent to which greenspace and semi-natural sites encourage use, repeat visits or activity levels.

Demand

- The number of people who visit each site, for how long and with what frequency.
- The societal need for the health benefits (age, socio-economic group and health status of the visitors).

Service Flows and benefits

- The long term health benefits of the use and activity levels within sites, compared to activity levels in other similar areas with less natural habitats or vegetation cover.

7. Proxies for ideal data

In the absence of ideal data, assumptions have been made, and proxies used, including accessibility status, distance and population size, to infer the levels of use that could be present in each site. The cumulative time spent in a site or area is assumed to be linked to its accessibility distance. If sites area accessible and nearby then they are assumed to be accessed and used. Data on the accessibility of all patches of greenspace is unavailable. A number of datasets are therefore combined to form an estimate of the areas that are accessible based on the best available information. Population size is calculated from the BaseMap by summing household population predicted to be present within mapped domestic buildings. Focal scales based on typical travel distances are used to represent the potential population that could travel to a site. The distance from the nearest access points or access routes are also used to indicate the likelihood of use, with areas that are further from paths or transport stops being assumed to receive fewer visitors.

Capacity

- The type, location, extent, condition, quality and management status of greenspace and semi-natural habitats.
  - *Type, location, extent*: BaseMap: A combination of local data and several (optional) national datasets including: OS MasterMap, priority BAP habitats, LCM 2007, local and national nature reserves, combined with Local Authority Open Space Survey / Green Infrastructure Survey (or equivalent).

- *Condition*, *quality and management*: No consistent, reliable information .
- The extent to which greenspace and semi-natural sites encourage use, repeat visits or activity levels.
  - A score is assigned to each habitat type in the link table "naturalness" data field. This is used to represent the relative "perceived naturalness" capacity of each habitat.
  - This value is considered an approximation of the aesthetic value of the site and is predicted to be linked to attractiveness, repeat usage, enjoyment levels and health benefits.
  - Focal sum analysis is used to represent the cumulative value of natural areas within a local search radius.

Demand

- The number of people who visit each site, for how long and with what frequency.
  - Number of people likely to use a site is calculated using several indicators.
    - Indicator of site accessibility is used to indicate sites that are more likely to be use by the public. In England and Wales these are legally accessible sites. In Scotland these include areas that would be expected to be more frequently used than the general countryside (identified from the Greenspace Scotland map).
    - 3 scales of greenspace site size are used to indicate likely site use, with longer distance travel only being likely for larger sites.
    - Local walking distance (local scale) (default 0.6 km).
    - Short distance drive / cycle ride (landscape scale) (default 2.4 km).
    - Long distance drive (region scale) (default 12.8 km).
    - Distance to closest Access points (Paths, Public Right of Way or Transport Stop).
  - Site visit length or frequency.
    - Frequency of use is assumed to relate to site access distance and site size.
- The age, socio-economic group and health status of the visitors.
  - Health score (IMD) (mean) of people.
    - Local scale distance (default 0.6 km).
    - Landscape scale distance (default 2.4 km).
    - Region scale distance (default 12.8 km).

Service Flows and benefits

- The long term health benefits of the use and activity levels within sites, compared to activity levels in other similar areas without less natural habitats or vegetation cover.
  - Spatial overlay of capacity and demand is used to indicate potential flow and benefits of the service.
  - Ranking by quintiles is used to identify areas of relative high priority, improvement areas and gaps.

8. Limitations to the model and potential future improvement (where relevant)

There are limitations in the range of data used to map greenspace site habitat type. This can lead to differing levels of accuracy and detail within data derived from different Local Authorities. Ideally a detailed categorisation of site type would include quality and management status, using a consistent method, with comprehensive coverage.

A future proxy could be developed to indicate how management status or site quality influence both the level of use by people and any resulting benefits. For example, lower quality sites, with vandalism, fires or litter may be used less frequently. This would require further development.

The model is limited by variability and gaps in the data used to map accessibility. Assumptions are made that distance to sites is an accurate predictor of levels of use. Linear distance is used and could be replaced by more accurate travel distance mapping (network, or least cost analysis). The presence of areas that could block actual use of sites, such as wide rivers or buildings is not currently included. The cut off distances used to model potential use levels are also open to interpretation and would benefit from further justification and refinement at a local level.

The model assumes that mean health scores can be used to represent the likely health benefits of access and recreation in natural habitats. However, not all reasons for low health may benefit from such recreation, and certain health conditions may benefit more. The use of health data related to specific conditions or illnesses could add more reliability to future versions of the method.

The link between perceived naturalness and potential health benefits is currently simplistic and could be explored further. In particular, the influence that site size and condition or the variety of habitats present has on potential health benefits could be explored. The use of the local scale cumulative naturalness sum score to represent nearby greenspace value would benefit from further justification.

Limitation	Impact
Source data	Habitat mapping is often only available at the broadest level. Fine scale variations in population demographics are masked. There may be errors in the classification of households.
Literature	A wide range of research exists to inform the map rules.
Mapping rules transferability	Ideally more factors would he used to estimate the health benefits of sites, rather than naturalness type. Further clarification of the impact of greenspace site size on visitation levels, and further clarification of the variability of public perception of habitat type naturalness would be useful.
Study area extent	N/A
Landscape composition	N/A
Buffer zone impacts	N/A
Landscape pattern	N/A
Topography	Topography will impact on the capacity of habitats in terms of its likelihood of visitation, but also in links to potential health benefits through calorific expenditure. These are not currently included in the model.

9. Final List of Indicators

Indicators with a suffix of _IndC or _IndD are saved in the Indicators Geodatabase.

Indicator name	Indicator Type	Description
Accessible_IndC	Capacity	An amalgamation of all accessibility datasets. All areas that are legally accessible or where public access is promoted or likely.
AccessPoints_IndD	Demand	Proxy for the location of greenspace access points. These area all areas where linear access routes meet surfaced roads. These may represent access points to parks or the beginning of paths into the countryside from car parks, lay-bys or visitor centres.
BaseMap_Accessible_Greenspace_IndC	Capacity	All accessible greenspace areas
BaseMap_Accessible_IndC	Capacity	The BaseMap_FINAL data clipped to show only accessible areas
BaseMap_Greenspace_ALL_IndC	Capacity	All greenspace areas (accessible, non accessible and unknown)
Greenspace_landscape_IndD	Demand	Greenspace sites above the landscape scale site area threshold
Greensapce_local_IndD	Demand	Greenspace sites above the local scale site area threshold
Greenspace_region_IndD	Demand	Greenspace sites above the region scale site area threshold
Landscape_Greenspace_AREA_SUM_IndC	Capacity	The area (ha) of greenspace in the landscape search neighbourhood
Landscape_Health_Scores_IndD	Demand	Mean health scores (IMD) within the landscape search neighbourhood
Landscape_Naturalness_Mean_IndC	Capacity	Mean naturalness score for greenspace sites within the landscape search neighbourhood, mapped to greenspace sites only
Landscape_Naturalness_Mean_Unr_IndC	Capacity	Mean naturalness score for accessible greenspace sites within the landscape search neighbourhood, mapped to accessible greenspace sites only
Landscape_Naturalness_SUM_IndC	Capacity	Sum of naturalness score for greenspace sites within the landscape search neighbourhood, mapped to greenspace sites only
Landscape_Naturalness_SUM_Unr_IndC	Capacity	Sum of naturalness score for greenspace sites within the landscape search neighbourhood, mapped to accessible greenspace sites only

Indicator name	Indicator Type	Description
Landscape_popn_threshold_IndD	Demand	Population density above the landscape scale threshold
Local_Greenspace_AREA_SUM_IndC	Capacity	The area (ha) of greenspace in the landscape search neighbourhood
Local_Health_Scores_IndD	Demand	Mean health scores (IMD) within the local search neighbourhood
Local_Naturalness_Mean_IndC	Capacity	Mean naturalness score for greenspace sites within the local search neighbourhood, mapped to greenspace sites only
Local_Naturalness_Mean_Unr_IndC	Capacity	Mean naturalness score for accessible greenspace sites within the local search neighbourhood, mapped to accessible greenspace sites only
Local_Naturalness_SUM_IndC	Capacity	Sum of naturalness score for greenspace sites within the local search neighbourhood, mapped to greenspace sites only
Local_Naturalness_SUM_Unr_IndC	Capacity	Sum of naturalness score for greenspace sites within the local search neighbourhood, mapped to accessible greenspace sites only
Local_Popn_Threshold_IndD	Demand	Population density above the local scale threshold
Log10_Land_Popn_IndD	Demand	Log10 conversion of the landscape scale population density (above threshold)
Log10_Local_Popn_IndD	Demand	Log10 conversion of the local scale population density (above threshold)
Log10_Regn_Popn_indD	Demand	Log10 conversion of the region scale population density (above threshold)
Min_Distance_Landscape_Access_Inv_Score_IndD	Demand	Score (1 - 100) representing proximity to access points, landscape scale greenspace sites (high score, close proximity)
Min_Distance_Local_Access_Inv_Score_IndD	Demand	Score (1 - 100) representing proximity to access points or routes, local scale greenspace sites (high score, close proximity)
Min_Distance_Region_Access_Inv_Score_InD	Demand	Score (1 - 100) representing proximity to access points, region scale greenspace sites (high score, close proximity)
Min_Distance_to_Access_IndD	Demand	No longer used
Min_Distance_to_Access_Landscape_IndD	Demand	Minimum distance to access points (landscape scale greenspace sites)
Min_Distance_to_Access_Local_IndD	Demand	Minimum distance to access points or routes (local scale greenspace sites)
Min_Distance_to_Access_Region_IndD	Demand	Minimum distance to access points (region scale greenspace sites)
Pavements1_IndC	Capacity	Pavements (predicted) mapped from the BaseMap_FINAL data, excluding areas along motorways or dual carriageways
Region_Health_Scores_IndD	Demand	Mean health scores (IMD) within the region search neighbourhood
Region_popn_threshold_IndD	Demand	Population density above the region scale threshold
Site_Health_scores_IndD	Demand	Mean health scores (IMD) within the site search neighbourhood (25 m)
Site_Naturalness_Score_IndC	Capacity	Naturalness score per cell (greenspace sites)
Site_plus_Local_Landscape_Naturalness_Mean_IndC	Capacity	Combined scales naturalness score (mean)
Site_plus_Local_Naturalness_Mean_IndC	Capacity	Combined scales naturalness score (mean)
Site_plus_Local_Naturalness_Mean_Unr_IndC	Capacity	Combined scales naturalness score (mean) - accessible greenspace sites
Site_plus_Local_plus_Landscape_Naturalness_ Mean_Unr_IndC	Capacity	Combined scales naturalness score (mean) - accessible greenspace sites

Note - a number of indicators have been retained from earlier versions of the model, although these are no longer all used in the calculation of final capacity or demand.

Detailed GIS Analysis steps

Model: 1AccessibleNatureCapacity

Models the availability of greenspace and semi-natural areas and scores areas by their perceived level of naturalness.

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles geo database and folders (mainly required during model testing rather than the final models).
- All Access Submodels - identify and map accessible areas.
    - PRoW / Core Paths, CRoW, NNR, LNR, Woods4People, FC recreation routes and GI_Beach data is clipped to the study area.
    - All linear access routes (non road routes) are buffered by 20 m to represent areas which can be experienced from these routes.
    - Accessible areas of the sea are identified by buffering beaches by 100 m and then erasing features of the buffer zone which overlap the land, leaving an area which stretches 100 m from land.
    - Areas within the BaseMap marked as accessible from Local Authority Open Space surveys are selected and copied out to form a new feature layer.
    - Pavements are selected from the BaseMap and buffered by 20 m to identify areas which are experienced from these routes. The mapping predicts which areas are likely to be pavements, but may also map areas of sealed surface near roads. Any areas that might represent the central reservation of dual carriageways or motorways are removed using buffer analysis of these road types.
    - Accessibility layers are merged and union applied. Data is saved as an indicator "Accessible_IndC"
    - This data is used to clip the BaseMap to show accessible areas of the BaseMap "BaseMap_Accessible_IndC". Areas of greenspace are selected from this to create "BaseMap_Accessible_Greenspace_IndC"
    - Areas of greenspace are also selected from the BaseMap to create "Basemap_Greenspace_IndC"
- Submodels conduct focal statistics of the site naturalness. The same analysis, in two separate submodels, is conducted for all greenspace areas, and for accessible greenspace areas (with a suffix of "Unr")
    - A raster dataset is created from the relevant greenspace dataset, based on Naturalness score.
    - Conversion to feature class and back to raster data, and extract by mask is used to create a dataset above a user defined threshold of greenspace sites.
    - This raster is multiplied by 10 to give the "Site_Naturalness_Score_IndC".
    - Focal statistics analysis is conducted at a local scale to derive sum naturalness scores "Local_Naturalness_SUM_IndC" and "Local_Naturalness_SUM_Unr_IndC"
    - Data is extracted by mask to the user defined extent (default SA_buffer). Threshold analysis is undertaken of the naturalness raster data to remove small sites below a user defined threshold.
    - The score for all greenspace areas is re-scaled to 1 to 100 and saved as "Accessible_Nature_Capacity". Areas of NoData are coded as 0, this is saved as "Accessible_Nature_Capacity_0_100".
    - The score from all accessible greenspace areas is re-scaled to 1 to 100, and saved as "Accessible_Nature_CapacityUnrestricted".
    - Areas of value = 0 are extracted from "Accessible_Nature_Capacity_0_100" and these are added to "Accessible_Nature_CapacityUnrestricted", this is saved as "Accessible_Nature_CapacityUnrestricted_0_100"
- A sub model converts the raster data to vector shapefiles. The values are grouped into simplified categories, e.g. 1-10 (10), 10-20 (20), 20-30 (30) etc.

Model: ES2AccessibleNatureDemand

This model estimates the societal demand (need) for opportunities to access and enjoy natural landscapes across the study area by estimating the number of people likely to travel to an area for this activity and their need for the related health benefits.

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles geo database and folders (mainly required during model testing rather than the final models).
- Submodels run to create the Indicator scores.
- Access distance demand indicators
    - Access_Points_IndD is created from analysis of the intersection between surfaced roads and linear access routes.
    - Min_Distance_to_Access_Local_IndD is created from the minimum distance to any OS path, pavement, PROW or Core path route. A local maximum search distance is applied (default 600 m).
    - Min_Distance_to_Access_Landscape_IndD is created from the minimum distance to any XY transport stops, or Access Points data. A landscape maximum search distance is applied (default 2400 m).
    - Min_Distance_to_Access_Region_IndD is created from the minimum distance to any XY transport stops, or Access Points data. A landscape maximum search distance is applied (default 12800 m).
- Greenspace area thresholds
    - Features selected from the BaseMap_FINAL , (NOT HabBroad = 'Built up areas') AND (NOT HabBroad = 'Garden') AND (NOT HabBroad = 'Railway') AND (NOT HabBroad = 'Roads') AND (NOT HabBroad = 'Pavement') AND (NOT HabBroad = 'Path') AND (NOT HabClass = 'Sea') AND (NOT HabClass = 'Water')
    - Converted to raster and back based on single value field in order to dissolve adjacent boundaries.
    - Three datasets created based on site area selections.
    - Greenspace_local_IndD where default > 0.1 ha, Greenspace_landscape_IndD where default > 10 ha, Greenspace_region_IndD where default > 100 ha.
- Access distance scales
    - the min access distance scores are masked to each greenspace site scale, the distances are re-scaled to 1 to 100, then inverted so high scores represent close proximity.
    - Min_Distance_Local_Access_Inv_Score_IndD, Min_Distance_Landscape_Access_Inv_Score_IndD, Min_Distance_Region_Access_Inv_Score_IndD.
- Indicators population density
    - Analysis of the Popn_socioec_points data creates population density datasets.
    - Focal sum analysis of population at each of three user defined scales: local, landscape, region.
    - These values are masked by the relevant scale of greenspace site, to only produce population density data for greenspace sites.
    - Thresholds are applied at each scale to only show population density for areas that do not have sparse populations. Defaults: 50, 500 and 1,000.
    - Local_popn_threshold_IndD, Landscape_popn_threshold_IndD, Region_population_threshold_IndD
- Indicators health scores
    - Analysis of the Popn_socioec_points data creates health score datasets.
    - Focal mean analysis of population is applied at three user defined scales: local, landscape, region.
    - These values are masked by the relevant scale of greenspace site, to only produce health score data for greenspace sites.
    - Thresholds are applied at each scale to only show health score data for areas that do not have sparse populations. Defaults: 50, 500 and 1,000.
    - Local_health_scores_IndD, Landscape_health_scores_IndD, Region_health_scores_IndD
- Rescaled indicators

  - Indicators are re-scaled onto a 1 to 100 scale.
- Weighting indicators
  - Weighting analysis is conducted in two stages.
  - Initially indicators are combined to create a single score illustrating demand at each of the user defined scales: local, landscape and region.
  - The main indicators can optionally be weighted by users, as they contribute to each analysis scale.
  - Once each scale score has been created (local, landscape, region) these can also be weighted before they are summed and rescaled to give the final demand score.
  - The default values for combination of each scale score are local: 0.6, landscape: 0.3 and region: 0.1
- Final score and export
  - Extract by mask is applied (default = Study Area buffer).
  - Values are re-scaled onto a 1 to 100 scale.
  - Datasets (raster) saved as AccessibleNature_Demand .
  - A submodel converts the raster data to vector shapefiles. The values are grouped into simplified categories, e.g. 1-10 (10), 10-20 (20), 20-30 (30) etc.

Model: ES3AccessibleNature Flows

The capacity and demand data are converted to quintiles and overlaid to identify benefitting areas and gaps

The service flow model is the same for each service

- Defaults are set for cell size and extent, but can be altered by the user.
- Sub models delete all previously run data from Scratch, Outputs, Indicators, Shapefiles Geodatabase and folders (mainly required during model testing rather than the final models).
- Sub model takes the separate capacity and demand datasets and produces the following datasets for either the Study Area of the Study Area plus buffer.
  - Capacity quintiles based on area and value.
  - Demand quintiles based on area and value.
  - All areas where there is some level of demand.
  - When the quintiles are calculated for capacity these are only created for areas with Demand > 0.
- The service occurrence, demand and quintiles data are combined to create two sets of benefitting area data:
  - Ecosystem Service Benefiting Areas (ESBA) and gaps.
  - Ecosystem Service Benefiting Areas (ESBA) and gaps - prioritised.
- Ecosystem Service Benefiting Areas occur where Demand > 0 and Capacity > 0.
- Service Gaps occur where Demand > 0 and Capacity = 0.
- The prioritised data are defined by selecting the highest quintile (5) as high demand or high capacity, this allows the following categories to be produced:
  - A1 - Service Benefiting Area - High Demand (Q=5) and High Capacity (Q=5).
  - A2 - Service Benefiting Area - High Demand (Q=5) and Low Capacity (Q=1).
  - A - Service Benefiting Area - other (Demand Q>0<5 and Capacity Q>0).
  - B1 - Service Gap - High Demand (Demand Q=5 and Capacity Q=0).
  - B - Service Gap (Demand Q>0<5 and Capacity Q=0).
  - C1 - Restricted Service - High Demand (Demand (Q=5) and Capacity (Q>0 but restricted).
  - C - Restricted Service - other (Demand (Q>0<5) and Capacity (Q>0 but restricted).
- The ESBA and ESBA - prioritised datasets are each comprised of a single dataset to facilitate their use in later zonal statistics analysis.
- A sub model identifies "GI assets" by masking the service capacity maps to illustrate only those areas where there is a level of demand.

- A sub model exports the raster files to shapefiles. An optional patch area threshold allows small areas to be removed during the conversion process (default shape area > 200 m^2).

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