EcoServ-GIS v3.3

Technical Report: "Local climate regulation service"

1. Ecosystem Service Definition and Description

<u>*Short definition*</u>:

Controlling local temperatures & reducing the urban heat island effect

<u>*Long definition*</u>:

Places within urban areas where the cover of woodland vegetation helps to lower temperatures during times of extreme heat events. This model calculates the capacity for this service as the proportion of the landscape that is covered by woodland, trees or scrub within a local neighbourhood window around each focal cell (default 200 m). Demand for the service occurs within urban areas and is graded by the proportion of manmade surfaces in a local neighbourhood window (default 200 m) and the proportion of the local population that may be at a high risk of health impacts from extreme heat events.

<u>*Descriptive text*</u>:

Temperatures within urban areas are often warmer than surrounding areas because of the relative amount of impervious, manmade surfaces. Heat waves pose a threat to human health. This is particularly a problem in areas with high population densities with high concentrations of the elderly or very young. Habitats, particularly woodlands, help to reduce temperature maxima through direct shading and increased evapotranspiration.

<u>Service benefits description</u>

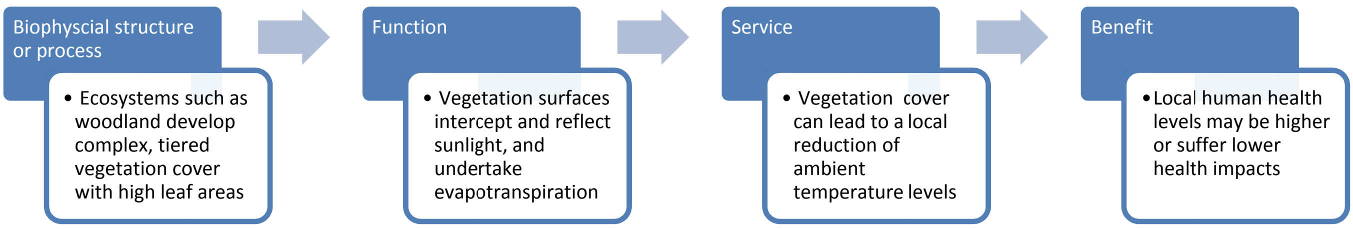
This service occurs mainly in large urban areas where the urban heat island effect is experienced. People benefit from this service where houses, or areas near houses, occur close to areas of tree cover. People can benefit from the resulting lowered temperatures in these areas. The potential benefits to the health of people are considered to be highest where local populations are of lower current health levels, or are older, or very young. Temporally this service will only occur when extreme heat waves occur, the occurrence and frequency of which are likely to vary spatially across the UK.

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 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 large infrastructure projects.

Land management, land use planning and decision-making

- **Would protection, management, or an increase in the area or condition of the biophysical structure or process lead to maintained or increased human benefits over one human generation?**



3. Literature review

Local climate regulation is a recognised ecosystem service in urban areas (Bolund & Hunhammar 1999). Land use has a large impact on local climate because surface types differ in their rates of net radiation absorption and their influence on the amount of water that is absorbed or enters into surface runoff or evapotranspiration (Kalnay & Cai 2003; Foley et al. 2005; Gill et al. 2007). A large proportion of people in the UK reside in urban areas (England: 81 %, Wales: 66 %, Scotland: 81%, based on census area urban / rural classifications) (Pateman 2010), and urban areas continue to expand at a faster rate than other types of land use (Antrop 2004). As opposed to the USA, where cities have tended to grow "outward", creating vast regions of urban sprawl, in the UK urbanisation has tended to involve increasing the density of buildings and people per unit area, often resulting in the loss of urban greenspace (Dallimer et al. 2011). These built-up areas experience different local climates compared to rural areas because of the relative amount of impervious, man-made surfaces compared to unsealed areas with vegetation (Gill et al. 2007). Temperatures within these urban areas are often one or two degrees warmer than surrounding countryside. Global climate change is likely to amplify these differences (Gill et al. 2007; Bowler et al. 2010).

The positive impact of greening, urban vegetation or parks has been investigated in several cities around the world (Edward et al. 2011; Dugord et al. 2012; Doick et al. 2014; Chang et al. 2007; Gill et al. 2013; Shashua-bar & Hoffman 2000; Skelhorn et al. 2014; Zhang et al. 2014; Kong, Yin, Wang, et al. 2014). For example studies in the subtropics have also shown that parks can lead to cooler conditions in cities, and have suggested an interesting correlation to park size, noting that smaller parks may not consistently hold the same benefits as larger parks , e.g. sites less than 2ha (Chang et al. 2007). Recent work has confirmed positive impacts of urban greenspace in a UK context (Hall et al. 2012; Armson et al. 2012; Doick et al. 2014). The following literature insights informed model construction:

Capacity

- Recent research of the impact of predicted climate change on typical English domestic buildings indicated that shading is the most appropriate strategy to help reduce the impacts of future overheating via climate change (Gupta & Gregg 2012).
- Positive design-led planning can aid human health in cities (Barton 2009).
- Modelling work indicates that increased tree planting could partly help maintain lower temperatures as climate change occurs in a UK (Hall et al. 2012) and an American city (House-Peters & Chang 2011).
- Natural and semi-natural habitats can reduce urban temperature maxima over small scales (Shashua-bar & Hoffman 2000) and several studies show the positive impacts relate to both forest patch size and cumulative local area e.g. (Kong, Yin, James, et al. 2014).
- The effectiveness of natural cooling by greenspace is improved by increased tree cover, and this is likely to be strongest at small scales, e.g. 200 to 400 m (Merbitz et al. 2012).
- Building and man-made surface densities are positively correlated with temperature maxima (Merbitz et al. 2012; Tratalos et al. 2007).
- Merbitz et al (2012) found that surface sealing was most strongly related to temperatures at the 200 m, rather than 400 m buffer scale.
- Tratalos *et al.* (2007) reported a positive relationship between urban density and increasing temperatures in UK cities, with roughly a 4 degree Celsius rise difference between areas with <10 addresses per hectare, compared to areas with ~20 addresses per hectare.
- A study in Manchester, UK showed that tree shading had an impact on air temperatures during summer days and that parks were cooler than nearby urban areas (Armson et al. 2012).
- Urban grassland and tree cover can help ameliorate the urban heat island effect and both together are preferable to either in isolation (Armson et al. 2012).
- Park daytime temperatures in smaller parks (<3 ha) were shown to be correlated with level of tree cover (lower temperatures) and paved areas (higher temperatures) in a study in Taipai (Chang et al. 2007).
- A study in a London park has shown that urban heat island night time temperature can be reduced both within and adjacent to parks. The cooling effects can extend up to 100 m from the park (Doick et al. 2014).
- In Berlin benefits were related to greenspace size and reduced temperatures to distances over 50 m from site boundaries (Dugord et al. 2012).

Demand

- Higher temperatures can cause thermal discomfort and heat waves pose a risk to human health (Forest Research 2008; Kleerekoper et al. 2011).
- Areas with high population densities are more at risk and older people are more vulnerable to health problems associated with heat waves (Department of Health 2010; Tomlinson et al. 2011) .
  Research in Berlin used population density and age characteristics (elderly >= 65, young <= 6) to illustrate areas at risk of extreme heat events (Dugord et al. 2012). Study also showed that size of areas of industrial and commercial space caused higher temperatures (Dugord et al. 2012). Degree of soil sealing was a good predictor of temperatures (Dugord et al. 2012).

  Although broad trends in the urban heat island effect are well known, more evidence is needed to establish the exact levels to which greenspace cools the surrounding area and how this is affected by habitat composition, structure and configuration at different scales (Bowler et al. 2010; Kleerekoper et al. 2011).

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 large number of approximations and assumptions had to be made. The main literature identified rules used to build the models were:

Capacity

- The proportion of the local landscape that is covered by woodland and trees can be used to indicate capacity for affecting the local climate (using a focal statistics window, default 200 m).
- The benefits of woodland and trees occur in the areas beneath the tree canopy and in nearby adjacent areas.
- There are likely to be density dependence and threshold effects of woodland patch size on the local climate regulation benefits.
- Wider benefit buffers are modelled around larger capacity sites.

In the absence of data to separately indicate the beneficial impact of different woodland types, all woodland scattered trees and scrub are considered to have capacity to deliver the service. A focal sum calculation of all nearby cells within a set neighbourhood distance was used to capture the value of both patches and scattered smaller sites of woodland and trees. To reflect the wider transfer of benefits from larger sites the following buffer distances were applied, within which the focal sum scores are masked. Prior to the following analysis all woodland and trees sites are buffered by 4 m, then dissolved, in order to capture the occurrence of contiguous sites that would otherwise be divided by narrow paths, tracks or streams.

Patch size (m^2)	Patch size (ha)	Buffer distance (m)
<= 20000	2	20
> 20,000 <= 50,000	2 to 5	40
> 50,000 <=100,000	5 to 10	80
> 100,000	> 10	100

It is acknowledged that these buffer distances, although inspired by the available literature, are essentially arbitrary. Ideally the model would also include analysis of the broader cover of greenspace in addition to woodland and trees but this is not currently implemented.

Demand

- Urban area boundaries are used to locate the areas where the service may occur.
- Census statistics are used to map population occurrence, and the relative proportion of the population in old or very young population bands.

5. Spatial occurrence and service flows

This service is provided by areas of natural or semi-natural woodland habitats. The flow of the service is considered to be both in-situ, and within an adjacent buffer zone around these habitats, to account for the positive impact of regulated local air temperatures. The benefits would largely be experienced therefore where people are at home, or walking within, or adjacent to, an area of greenspace. Currently the model includes all spatial areas and is not limited to publicly accessible areas.

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 woodland, trees and scrub.
- The extent to which air temperatures are reduced by the levels of vegetation currently present.

Demand

- The number of people who reside at, or visit each site, for how long and with what frequency.
- The age, socio-economic group and health status of residents / visitors.
- The levels of air temperature spikes experienced at each locality during heat waves, and levels of variation spatially and temporally.

Service flows and benefits

- The long-term health benefits of the reduced air temperature levels compared to residing or undertaking recreation in other similar areas without vegetation.
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7. Proxies for ideal data

In the absence of the full range of ideal data to map the service, assumptions have been made, and additionally proxies have been used to represent selected elements of the ideal set of data.

Capacity

- The type, location, extent, condition, quality and management status of woodland, scrub and trees.
  - *Type, location, extent: BaseMap*: A combination of local data and several (optional) national datasets including: OS MasterMap, LCM 2007, priority BAP habitats, 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 air temperatures are reduced by the levels of vegetation cover currently present.
  - The relative cover of beneficial habitats is used as a proxy for the local capacity of the service.
  - A maximum distance beyond the habitat boundary is used to represent the distance at which benefit might occur outside the habitat boundary. This ranges from 20 to 100 m based on patch size.

Demand

- The number of people who reside at, or visit each site, for how long and with what frequency.
  - Number of people within local scale walking distance (default 300 m).
- The age, socio economic group and health status of the visitors.
  - Proportion of the local population at higher risk of health impacts is calculated (Age > 65 or < 10).
- The levels of air temperature spikes experienced at each locality during heat waves, and levels of variation spatially and temporally.
  - The location of large urban areas are used to identify areas where the urban heat island may occur. Default > 1,000 ha.
  - The cover of made surfaces is used as a proxy for the likelihood of an extreme heat wave event leading to high air temperatures.

Service flows and benefits

- The long-term health benefits of the reduced air temperature levels compared to residing or undertaking recreation, in other similar areas without vegetation.
  - 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)

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 classification of households
Literature	There were relatively few published sources on which to base the mapping rules, more information on the relationship between patch size and air temperatures levels would be useful
Mapping rules transferability	Ideally specific locations of different illness hotspots would be included rather than age risk
Study area extent	Very small study areas may not contain the large urban areas in which the urban heat island is expected to occur
Landscape composition	In rare cases of upland or entirely arable landscapes there may be no areas of mapped capacity
	Building height in urban areas will impact air temperatures and areas of health risk
Buffer zone impacts	N/A
Landscape pattern	N/A
Topography	Topography will impact capacity due to its influence on air circulation, but it is not currently included in the models.

9. Final List of Indicators

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

Indicator Name	Type	Description
LocalClimate_Regulatory_Demand_IndD	Demand	Relative score indicating temperature threat based on the proportion of man-made cover
LocalClimate_Societal_Need_IndD	Demand	Relative score indicating the societal need for local climate regulation based on proportion of very old and very young population (age risk > 65 and <10)

Detailed GIS Analysis steps

Model: ES1_LocalClimateCapacity

Estimates the capacity of an ecosystem to cool the local environment and cause a reduction in urban heat maxima.

- 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).
- Model takes the BaseMap and creates a feature layer.
- From the BaseMap, woodland, trees are made into a feature layer.
- Converts the feature class to a raster, based on constant1 field, Output is saved to scratch.
- Output cell size is taken from SA010 or SA050, set by user.
- Focal Statistics calculates the number of tree cells within 200 m.
- Neighbourhood shape set to circle and Neighbourhood settings set to 200 m radius. These settings capture the impact of trees over very local scales. The statistic is set to SUM.
- Euclidean distance calculates a distances from the woodland features.
- The features class of woodlands, trees and scrub is buffered by 4 m then dissolved (to allow for small divisions within wood areas, e.g. by stream or paths).
- A series of analysis creates buffers zones of increasing distance from patches of different class size. This allows for an increased influence of big woodland patches or parks. The separate buffers are then merged to one area of influence.
- The focal SUM score of woodland, trees and scrub cover is masked by the merged buffer analysis file to only return focal scores for the areas within set distances of patches.
- Extract by mask is applied (default Study Area buffer).
- Values are re-scaled onto a 1 to 100 scale. A version of the dataset with No Data replaced by 0 is created.
- Datasets (raster) saved as LocalClimate_Capacity and LocalClimate_Capacity_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: ES2_LocalClimateDemand

Estimates societal demand and regulatory need across space for ecosystems that can reduce temperature maxima

- 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).
- Sub Model creates a feature layer from the urban shapefile.
- Urban areas are selected. Users can select an alternative urban boundary file if required.
- Creates a new selection of urban areas which intersect with the Study Area buffer.
- Creates a 200 m buffer around urban areas.
- Urban area threshold selection is applied (default > 1,000 ha) (10 km^2).
- Used to select those urban areas where urban heat island effect may be expected to occur.
- Sub model creates focal population sum at local neighbourhood scale (default 200 m)
- Local threshold is applied, so only areas of population density are mapped above a minimum threshold (default > 50).
- Sub model examines mean age risk score in local neighbourhood (default 200 m).

- The population score and age risk scores are multiplied to give an age risk weighted population score, this is then masked to show results for areas within the urban areas previously selected.
- The score is then masked to show only those areas within 250 m of land or houses.
- Proportion of man-made surfaces within local search distance is calculated (default 200 m).
- This results in two indicators scores.
  - Societal need (age risk weighted population score) (1 to 100).
  - Regulatory demand (man-made surface proportion cover) (1 to 100).
- The two scores for societal need and regulatory demand can be weighted (default 1).
- Two scores are summed.
- Extract by mask is applied (default Study Area buffer). Values are re-scaled onto a 1 to 100 scale.
- Datasets (raster) saved as LocalClimate_Demand.
  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: ES3LocalClimateFlows

The capacity and demand data are converted to quintiles and overlaid to identify benefiting 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 benefiting 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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