Land-cover scores for ecosystem service assessment

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Summary

This note describes a simple method for mapping ecosystem services based on scoring different types of land cover from 0 to 5, depending on their ability to supply different services. We have applied this approach to the Bicester area, by adapting a matrix of land-cover scores generated from a study in Warwickshire, Coventry and Solihull (WC&S). This note describes how the scores were generated in the initial study and how they have been modified for Bicester, providing explanation and justification for the scores. It presents some example results and considers the next steps. The scores derived for Bicester are shown in Tables 3 and 4 of Appendix 1, and the ecosystem service maps generated from these scores are shown in Appendix 2. We are continuing to refine the scores as part of a new eco-metric tool that is being developed by Natural England (release expected in late 2019).

Background to the approach

The land-cover score approach was first presented in a paper by Burkhard et al (2012). It is sometimes known as the Burkhard approach or the Matrix approach. It involves developing a matrix of scores for the ability of different types of land cover to provide different ecosystem services, then using these scores to produce maps of each ecosystem service. For Burkhard's initial study, scores were generated using the expert knowledge of the authors, but the intention was that this approach could subsequently be refined by using biophysical data or models to improve the scores. The land cover maps in the Burkhard study were based on the CORINE datasets, and were therefore restricted to relatively broad land cover classes (e.g. coniferous forest, natural grassland, water bodies). Every area within each of these classes received the same score.

The technique was subsequently extended by Kopperoinen et al (2014), as the GreenFrame approach. This strengthens the derivation of land cover scores by supplementing expert knowledge with that of local stakeholders. More detailed land cover maps were created using a wide variety of GIS datasets to reflect themes such as water quality or the presence of conservation areas. This allowed a distinction between water bodies with high or low water quality, for example.

The land-cover scoring technique has now been applied in a number of studies worldwide, and is recognised as an effective first-cut method of rapidly mapping a wide range of ecosystem services. However, the accuracy of the technique depends on the resolution of the land cover maps available and the reliability of the scores (Jacobs et al 2015).

Natural England are currently developing an eco-metric approach to growing natural capital, which includes the development of a matrix of scores. This has the potential to offer an improved set of scores that brings in additional biophysical evidence, e.g. on carbon storage.

The land cover scores derived from the WC&S study

We applied a land cover scoring approach to a case study of Warwickshire, Coventry and Solihull (WC&S) as part of the EU-funded OpenNESS project (Operationalisation of natural capital and ecosystem services). The approach was well suited to WC&S because a detailed Phase 1 Habitat and Biodiversity Assessment survey (HBA) was available.

We held a workshop in January 2015 attended by 14 local stakeholders and experts including planners, ecologists and people with agricultural interests. After presenting a brief overview of the approach, we asked them to score 16 key land cover classes from the HBA based on the capacity of the land cover to deliver each ecosystem service, using a six-class system (i.e. from 0 to 5) where zero is no delivery capacity and 5 is very high delivery capacity. Median stakeholder scores were used (with some adjustments, see Appendix 1) to create a summary matrix for these key land cover classes (top part of Table 1, Appendix 1). As well as scoring individual services, we created average scores for all regulating services, all provisioning services, all food provisioning services and all cultural services (see the last four columns). These scores were then used as the basis for deriving a full set of scores to include the other 26 land cover classes in the WC&S HBA survey (lower part of Table 1, Appendix 1).

These scores were then applied to the HBA layer within a Geographic Information System (we used ArcGIS) to generate maps of each individual service or of groups of services, which can be produced at any scale from the WC&S area down to field/farm-scale resolution of the HBA. Although the method is very simple and is based largely on expert judgement, stakeholders found these maps very useful for demonstrating and visualising the provision of ecosystem services in WC&S.

Adapting the land cover score matrix for Bicester

For Bicester, we adapted the matrix of scores derived for WC&S by:

- Modifying the range of ecosystem services to reflect those of interest in Bicester;
- Modifying some of the existing scores in the WC&S matrix and creating scores for the new ecosystem services added for Bicester, based on the results of a systematic literature review;
- Extending the range of land cover classes to include the different types of green infrastructure within the Bicester area, and generating appropriate scores for these. A new category of eutrophic standing water was also added.

The new scores for Bicester are shown in Tables 3 and 4, Appendix 1.

Range of ecosystem services

The ecosystem services of most interest in Bicester were identified by project partners during the kick-off meeting. As a result, the range of services in the WC&S matrix was modified by:

- Removing “timber provision”;
- Replacing “traditional crops” with “urban food” (covering allotments, food grown in private gardens and community farms/gardens / orchards);

- Adding “sense of place”, “wildness”, “noise regulation” and “microclimate regulation” (cooling, shading and sheltering).

Modifying the scores and creating new scores for extra services

Although the WC&S workshop provided a useful set of initial scores, it did not allow time for the scores to be consolidated and cross-checked by the stakeholders. Some of the stakeholders were not familiar with the concept of ecosystem services, and for many their expertise applied only to a subset of the services. For some services and land cover classes, the different stakeholders in the workshop generated a range of very different scores, indicating a high degree of uncertainty and/or differences in interpretation. In addition, the stakeholders at the workshop interpreted the “urban” ecosystem as including both hard-standing areas (roads, buildings, car parks etc.) and gardens, whereas in order to examine the fine detail of green infrastructure in Bicester we need to make a distinction between these “grey” and “green” areas.

We therefore reviewed all the scores and modified some, based on the findings of a recent systematic review of the literature on the links between natural capital and ecosystem services (Pérez-Soba et al, 2015; Smith et al, 2017). This review covered 780 papers (60 for each of 13 ecosystem services) and was used to develop a typology linking different natural capital attributes (such as the area of different ecosystem types, or the abundance or diversity of different species) and the ecosystem services that they underpin. It was therefore very useful in increasing our understanding of the ways in which different types of land cover affect the ability of ecosystems to deliver different services. We also incorporated knowledge gained from ecosystem service mapping in Warwickshire and Essex as part of the OpenNESS project, including participatory workshops where stakeholders identified the areas that they felt were important for providing different ecosystem services, and analysis of Flickr photos to see what types of habitats were important for aesthetic value, recreation, or interaction with wildlife (reports available on request).

The results of this review were used to compile a justification for the scores used in this study, which is presented in Appendix 1. This also includes the justification for the new scores created for the extra ecosystem services added for Bicester (see above).

Extending the land cover classes to include green infrastructure

GIS maps of land cover within Bicester have been compiled from the following sources:

- The Habitat and Land Use Study (a Phase 1 survey carried out by Thames Valley Environmental Records Centre) provided under license from Cherwell District Council (CDC)
- A map of publically owned land within Bicester (the “Grounds layer”)
- Individual trees and groups of trees within public spaces (the “Tree survey”), provided by CDC based on a survey by Bicester Town Council
- The Open Space survey carried out by CDC in 2011, which was used to identify playing fields and other sports facilities, and allotments.

For several hundred polygons in the Habitat and Land Use study, the Phase 1 Habitat type was blank or marked as ‘unidentified’ or ‘not applicable’. In these cases, the land cover was determined from alternative data such as the BAP Habitat.

Ecosystem service scores for additional land cover classes were derived by extrapolating scores from similar land cover classes assessed in the WC&S study. Scores and justifications are provided in Appendix 1.

Interpreting the ecosystem service maps

Appendix 2 contains a selection of maps for some of the services that were identified as being important for Bicester:

- Cultural services (average score across all 6 services)
- Regulating services (average score across all 10 services)
- Provisioning services (max of the 3 food provision services)
- Water provision
- Flood protection
- Water quality regulation
- Habitat
- Recreation

It is important to remember that this is a fairly simplistic approach to evaluating and mapping ecosystem services. The scores are subjective; they have not been checked by local stakeholders; and they do not take account of local variations within land cover classes, e.g. the difference between two patches of broad-leaved woodland, etc. Nevertheless, the maps can be a very useful tool for helping to visualise the distribution of ecosystem services within an area, and for stimulating discussions with stakeholders and policymakers.

Examination of these maps reveals certain issues.

1. Much of the land surrounding Bicester is arable or improved grassland, which is of high value for food provision but relatively low value for all the regulating and cultural services. The majority of the regulating and cultural services are provided by a relatively small number of areas of woodland and semi-natural grassland, including the areas around the airfield in the north-east; Gavray meadows; Graven Hill and Bignell Park.
2. There is a notable lack of land that provides flood protection, especially upstream of the town. The map shows that the playing fields within the town provide quite a large permeable area. Similarly, there is a lack of areas providing water quality regulation.
3. For wildlife habitat, the map starts to reveal the outline of some key networks of semi-natural land and woodland that could be valuable for connecting habitats. This includes a string of high scoring areas along the Langford Brook, connecting into Gavray meadows and then to patches of grassland further out to the south-east in the Ray valley.
4. To improve connectivity, attention could focus on improving the links from this network to the other green areas at Bignell Park and the airfield. The railway embankments also offer a potential link between Gavray meadows and Bure Park nature reserve, and out to link up with new Green Infrastructure in the North-west Bicester eco-town.
5. The map of recreational value highlights the importance of the parks, play areas, playing fields and allotments within the town. These appear to be quite evenly distributed, although some of these areas (e.g. school playing fields or private sports clubs) are of course not freely accessible to everyone.

Refining the maps to include quality indicators and local knowledge

Local project partners identified a number of places where the maps could be refined to reflect local variations from the standard scores:

- Stratton Audley quarry was mapped as a quarry in the Phase 1 survey but is now a local wildlife site with a mosaic of habitats, with improved value for wildlife habitat and cultural services.
- Several areas have historic interest, including Bicester airfield and various ancient monuments, and should receive higher scores for some of the cultural services.
- The airfield was mapped as 'improved grassland' but is not grazed, so we set the livestock value to zero.

To reflect these points in a more systematic way across the whole area, we decided to apply a second layer of scoring based on designations such as nature reserves, wildlife sites, NERC S41 habitats, ancient trees and "archaeological constraints", including Bicester airfield and scheduled ancient monuments. This was superimposed as a top layer, replacing the scores for Phase 1 habitats in those areas designated as having high historic or nature value. For areas with a high historic value, the scores for intellectual, spiritual and sense of place were all increased to the maximum value of 5. For areas with a nature-based designation, all the cultural scores and also the wildlife habitat score were set to 5.

Future work

The maps could be improved by:

- Validating the land-cover scores with local experts.
- Modifying the scores to reflect ecosystem condition, e.g. two patches of woodland may deliver different levels of service, depending on condition and species.
- Comparing the ecosystem service maps with those generated using other approaches, e.g. EcoServ-GIS.

A new tool being developed by Natural England (the "eco-metric") is also developing a matrix of land cover scores, incorporating a wide-ranging review of different evidence. When tested and released, this could provide a more robust set of scores for future work. It will also provide multipliers to reflect the impact of habitat condition or quality and spatial location, which would be very useful for refining the maps to reflect local conditions.

References

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Appendix 1: Justification for the land cover scores developed for Bicester

This appendix presents justification for the land cover scores developed for Bicester. It describes:

- How the scores for Warwickshire, Coventry and Solihull (WC&S) were compiled;
- How the WC&S scores were then adjusted to reflect additional expert knowledge;
- How additional scores were derived for new ecosystem services and new types of land cover and green infrastructure for Bicester.

Deriving land cover scores for WC&S

At the stakeholder workshop in WC&S run as part of the OpenNESS project (see main text), the 14 expert stakeholders in each assigned their own scores to 16 key land cover classes, for each ecosystem service. We generated overall scores from these individual scores as follows.

- Where the range (difference between highest and lowest scores) of scores from all 14 stakeholders was 1.0 or less, the median stakeholder score was used.
- Where the range was greater than 1.0, the median score from just the 8 ecologists was used.

Scores for these 16 key land cover classes are shown in the top part of Table 1.

The next step was to extrapolate the scores for the 16 key land cover classes to the other 29 land cover classes in the Habitat and Biodiversity Audit (HBA) survey for WC&S. The criteria used to derive these additional scores are shown in Table 2. Generally this involved equating the score to that of a similar land cover class, or taking the average of two similar land cover classes. For example, a score for coniferous semi-natural woodland was derived as the average of the scores for broad-leaved semi-natural woodland and coniferous plantation. In some cases, the score was based on a single similar land cover class and adjusted to reflect differences between the two land cover classes, based on expert opinion (Dr Pam Berry). For example, scores for sphagnum bog, acid/neutral flush, basin mires and swamps were derived by slightly adjusting the scores for marsh / marshy grassland. Scores for these 26 additional land cover classes are shown in the lower part of Table 1.

Table 1. Matrix of scores for ecosystem service supply from different land cover classes for WC&S

Stakeholder scores for key land cover classes

HABCODE	DESCRIPTION	Recreation	Aesthetic	Spiritual	Intellectual	Pollination	Pest control	Species habitat	Climate regulation	Air quality	Flood protection	Water purification	Erosion control	Intensive crops	Traditional crops	Livestock	Water supply	Timber provision	Provisioning	Provisioning (Food)	Regulating	Cultural
A111	Broad-leaved semi-natural woodland	5.0	5.0	5.0	4.5	5.0	4.0	5.0	5.0	5.0	4.5	4.0	5.0	0.0	0.0	0.5	1.0	4.0	1.1	0.2	4.7	4.9
A112	Broad-leaved plantation	4.5	4.0	3.0	3.0	3.5	3.0	3.5	4.0	4.0	4.0	4.0	4.0	0.0	1.0	0.0	1.0	4.5	1.3	0.3	3.8	3.6
A122	Coniferous plantation	3.0	2.5	1.5	3.0	2.0	2.0	2.0	2.5	3.0	3.0	2.5	3.5	0.0	0.0	0.5	0.5	5.0	1.2	0.2	2.6	2.5
A21	Dense/continuous scrub	2.0	2.0	2.0	3.0	4.5	3.5	4.0	4.0	3.0	3.0	3.0	3.0	0.0	0.0	2.5	0.0	2.0	0.9	0.8	3.5	2.3
B11	Unimproved acidic grassland	3.5	4.5	3.0	4.0	5.0	4.0	5.0	3.0	3.0	3.0	3.0	4.0	0.0	0.0	3.0	0.0	0.0	0.6	1.0	3.8	3.8
B21	Unimproved neutral grassland	4.0	4.0	3.0	4.0	5.0	4.0	5.0	3.0	3.0	3.0	3.0	4.0	0.0	0.0	3.0	0.0	0.0	0.6	1.0	3.8	3.8
B31	Unimproved calcareous grassland	3.5	4.5	3.0	4.0	5.0	4.0	5.0	3.0	3.0	3.0	2.5	4.0	0.0	0.0	3.0	0.0	0.0	0.6	1.0	3.7	3.8
B4	Improved grassland	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.5	2.5	1.5	0.0	5.0	0.0	0.0	1.3	2.2	1.4	1.0
B5	Marsh/marshy grassland	3.0	4.0	3.0	4.0	5.0	3.5	5.0	3.0	3.0	4.0	4.0	4.0	0.0	0.0	3.5	1.0	0.0	0.9	1.2	3.9	3.5
C31	Tall ruderal	1.5	2.0	1.5	2.5	5.0	4.0	4.0	3.0	2.5	2.0	2.5	3.0	0.0	0.0	1.5	0.5	0.0	0.4	0.5	3.3	1.9
D5	Dry heath/acid grassland mosaic	3.0	4.5	4.0	4.0	5.0	3.5	5.0	3.5	3.0	3.0	3.0	3.5	0.0	0.0	2.5	0.0	0.0	0.5	0.8	3.7	3.9
G1	Standing water	4.0	5.0	5.0	4.0	2.5	2.0	5.0	2.5	2.0	2.5	3.5	0.5	0.0	0.0	1.0	5.0	0.0	1.2	0.3	2.6	4.5
J11	Arable	1.0	1.0	0.5	1.0	1.0	1.0	0.5	1.5	1.0	1.0	1.0	1.0	5.0	4.0	1.0	0.0	0.0	2.0	3.3	1.0	0.9
J12	Amenity grassland	2.5	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.5	0.0	0.0	1.0	0.0	0.0	0.2	0.3	1.4	1.3
J4	Bare ground	1.0	1.0	0.0	0.5	1.0	1.0	3.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6
URB	Urban	3.0	2.0	1.5	1.0	1.5	1.0	1.5	0.5	1.0	1.0	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.9

Derived scores for other land cover classes (see Table 2; exceptions to general rules shown in red text)

A121	Coniferous semi-natural woodland	4.0	3.8	3.3	3.8	3.5	3.0	3.5	3.8	4.0	3.8	3.3	4.3	0.0	0.0	0.5	0.8	4.5	1.2	0.2	3.6	3.7
A131	Mixed semi-natural woodland	4.5	4.4	4.1	4.1	4.3	3.5	4.3	4.4	4.5	4.1	3.6	4.6	0.0	0.0	0.5	0.9	4.3	1.1	0.2	4.2	4.3
A132	Mixed plantation	3.8	3.3	2.3	3.0	2.8	2.5	2.8	3.3	3.5	3.5	3.3	3.8	0.0	0.5	0.3	0.8	4.8	1.3	0.3	3.2	3.1
A22	Scattered scrub	2.0	2.0	2.0	3.0	4.5	3.5	4.0	4.0	3.0	3.0	3.0	3.0	0.0	0.0	2.5	0.0	2.0	0.9	0.8	3.5	2.3
A31	Broad-leaved parkland/scattered trees	3.8	3.0	3.0	2.5	1.0	2.0	2.3	2.5	2.5	3.0	3.0	3.3	0.0	0.5	0.5	0.5	2.3	0.8	0.3	2.4	3.1
A32	Coniferous parkland/scattered trees	2.8	1.8	1.3	1.8	1.0	1.5	1.5	1.8	2.0	2.5	2.3	3.0	0.0	0.0	0.8	0.3	2.5	0.7	0.3	1.9	1.9
A4	Recently felled woodland	1.0	1.0	0.0	0.5	1.0	1.0	1.0	0.0	0.0	1.0	3.3	0.0	0.0	0.0	0.0	0.8	0.0	0.2	0.0	0.9	0.6
A5	Orchard	4.5	4.0	3.0	3.0	3.5	3.0	3.5	4.0	4.0	4.0	4.0	4.0	0.0	3.0	0.0	1.0	4.5	1.7	1.0	3.8	3.6
B12	Semi-improved acidic grassland	3.5	4.5	3.0	4.0	5.0	4.0	5.0	3.0	3.0	3.0	3.0	4.0	0.0	0.0	3.0	0.0	0.0	0.6	1.0	3.8	3.8
B22	Semi-improved neutral grassland	4.0	4.0	3.0	4.0	5.0	4.0	5.0	3.0	3.0	3.0	3.0	4.0	0.0	0.0	3.0	0.0	0.0	0.6	1.0	3.8	3.8
B32	Semi-improved calcareous grassland	3.5	4.5	3.0	4.0	5.0	4.0	5.0	3.0	3.0	3.0	2.5	4.0	0.0	0.0	3.0	0.0	0.0	0.6	1.0	3.7	3.8
B6	Poor semi-Improved grassland	2.5	2.5	2.0	2.5	3.0	2.5	3.0	2.0	2.0	2.5	2.3	3.3	0.8	0.0	4.0	0.0	0.0	1.0	1.6	2.6	2.4
C11	Continuous bracken	1.5	2.0	1.5	2.5	5.0	4.0	4.0	3.0	2.5	2.0	2.5	3.0	0.0	0.0	1.5	0.5	0.0	0.4	0.5	3.3	1.9
C32	Non-ruderal	1.5	2.0	1.5	2.5	5.0	4.0	4.0	3.0	2.5	2.0	2.5	3.0	0.0	0.0	1.5	0.5	0.0	0.4	0.5	3.3	1.9
E11	Sphagnum Bog	2.0	4.0	3.0	4.0	4.0	3.5	5.0	3.5	3.0	4.0	4.0	4.0	0.0	0.0	1.5	1.5	0.0	0.6	0.5	3.9	3.3
E21	Acid/neutral flush	2.0	4.0	3.0	4.0	4.0	3.5	5.0	3.5	3.0	4.0	4.0	4.0	0.0	0.0	1.5	1.0	0.0	0.5	0.5	3.9	3.3
E32	Basin Mire	2.0	4.0	3.0	4.0	4.0	3.5	5.0	3.5	3.0	4.0	4.0	4.0	0.0	0.0	1.5	1.5	0.0	0.6	0.5	3.9	3.3
F1	Swamp	2.0	4.0	3.0	4.0	4.0	3.5	5.0	3.5	3.0	4.0	4.0	4.0	0.0	0.0	1.5	1.5	0.0	0.6	0.5	3.9	3.3
F22	Inundation vegetation	2.0	4.0	3.0	4.0	4.0	3.5	5.0	3.5	3.0	4.0	4.0	4.0	0.0	0.0	1.5	1.0	0.0	0.5	0.5	3.9	3.3
G2	Running water	4.0	5.0	5.0	4.0	2.5	2.0	5.0	2.5	2.0	2.5	3.5	0.5	0.0	0.0	1.0	5.0	0.0	1.2	0.3	2.6	4.5
I21	Quarry	1.0	1.0	0.0	0.5	1.0	1.0	3.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6
I22	Spoil	1.0	1.0	0.0	0.5	1.0	1.0	3.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6
I24	Refuse tip	1.0	1.0	0.0	0.5	1.0	1.0	3.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6
J112	Allotments	2.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.5	0.0	4.0	0.0	0.0	0.0	0.8	1.3	1.4	1.8
J13	Ephemeral/short perennial	1.5	2.0	1.5	2.5	5.0	4.0	4.0	3.0	2.5	2.0	2.5	3.0	0.0	0.0	1.5	0.5	0.0	0.4	0.5	3.3	1.9
J14	Introduced shrub	1.5	2.0	1.5	2.5	5.0	4.0	4.0	3.0	2.5	2.0	2.5	3.0	0.0	0.0	1.5	0.5	0.0	0.4	0.5	3.3	1.9

Revising the scores for Bicester

For the Bicester study, some further adjustments were made to the WC&S scores based on further evidence from the OpenNESS project, including a systematic literature review of 780 papers (Smith et al., 2017) as well as experience from ecosystem service mapping in the WC&S and Essex case studies.

Summary of findings from the literature review

Our revision of the stakeholder scores was informed largely by the findings from the literature review, which are summarised here. The review identified four main pathways (A to D) by which natural capital influences the delivery of different bundles of ecosystem services, as shown schematically in Figure 1. The pathways are:

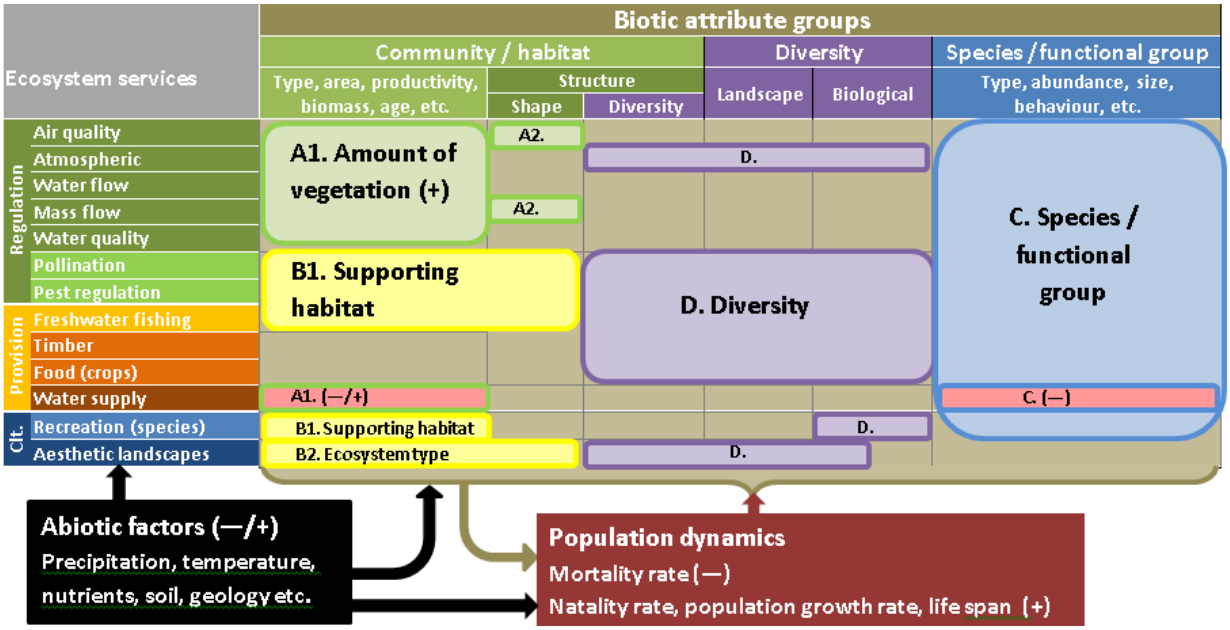
A. Amount of vegetation. For a bundle of regulating services, the most important factor is the physical amount of vegetation present. Vegetation stores carbon, absorbs pollution from the air, intercepts rainfall and delays the passage of floodwater, protects the soil from erosion, and filters out pollution from water. Therefore woodland tends to provide the highest level of these services, and older and larger trees often provide a greater service than small trees or shrubs. Well-established permanent grassland can provide a moderate level of service, as it can store carbon in the soil and can provide good protection from soil erosion. For the service of water supply, however, the impact of vegetation can often be negative, as trees absorb water from the soil which can reduce groundwater and surface water supplies. However, this can be partly offset by the beneficial impact of woodland on soil infiltration rates.

B. Presence of supporting habitat for beneficial organisms. For pollination and pest control, the presence of suitable habitat to support the beneficial organisms that provide the service (e.g. pollinating insects such as bees, and pest predators such as bats, wasps and beetles) is critical. The level of service delivered depends on the proximity to high-quality semi-natural habitat such as woodland or wild flower areas. A sub-category of this pathway (B2) refers to the importance of particular ecosystem types (water and woodlands) for aesthetic value.

C. Characteristics of particular species or functional groups. Most services depend to some extent on the presence of particular species or functional groups (such as trees, or pollinating insects), and on particular characteristics such as species size or behaviour.

D. Diversity (both biological and structural / physical diversity). Many services are delivered better by more diverse ecosystems. For example, woodlands containing mixed ages and species of trees tend to be more productive and thus store more carbon, because trees with a variety of heights and root depths can exploit different resource niches (in terms of light, water and nutrient availability). Structural diversity is also important for aesthetic value, and for providing good habitats for wildlife including beneficial insects (i.e. with shelter and over-wintering sites). In addition, more biodiverse ecosystems are more resistant to environmental change, and thus can continue to deliver a better level of service into the future.

Figure 1: Schematic diagram of the links between natural capital attributes and ecosystem services



Revising the scores for cultural ecosystem services

Cultural services to be assessed for Bicester are:

- physical recreation (e.g. playing sport, walking, running, cycling, boating)
- aesthetic value (the enjoyment gained by experiencing the sights, sounds and smells of nature)
- spiritual value (the emotional connection to natural areas, or their spiritual significance)
- intellectual (e.g. use of the area for education, research and informal learning)
- sense of place (what makes an area special or distinctive, including historic significance, local culture and personal history, e.g. local food, landscapes associated with famous painters or writers, or just people's favourite places)
- wildness (the opportunity to experience nature in or close to its natural state).

The last two of these (sense of place and wildness) are new services identified as being important for Bicester, so new scores have been created for these services as described later in this section.

For the first four of these services, the WC&S stakeholders assigned the highest values to semi-natural broad-leaved woodland, which scored 5.0 in all categories except intellectual, where it scored 4.5. Broad-leaved plantation scored a little less in all categories, and coniferous plantation less still. The scores for scrub were similar to those for coniferous plantation: a little lower for recreation and aesthetic value but higher for spiritual interaction, presumably because scrub can be more 'natural' than plantation.

These findings are in accordance with the literature review of the ecosystem characteristics that influence aesthetic value, which found that forests are amongst the most highly valued ecosystems, and that structural diversity increases aesthetic value. Natural forests tend to be more structurally diverse than plantations, which is consistent with the higher scores awarded by the stakeholders.

All types of unimproved grassland (including marsh / marshy grassland and dry heath/ acid grassland mosaic) also scored quite highly, between 3.0 and 4.5 for the four cultural services assessed – lower than broad-leaved woodland but similar to broad-leaved plantation. While lacking the large-scale structural complexity of natural woodland, unimproved grassland offers good opportunities for recreation and can

provide high levels of aesthetic value and diversity at a smaller scale, especially when flowering plants are present. Improved grassland, in contrast, scored only 1.0 for all four services, presumably reflecting its uniform and uninteresting appearance and general lack of access for recreation. Similarly, arable land had low scores of 0.5 to 1.0. Tall ruderal (weedy) vegetation, typical of waste ground, received fairly low scores of 1.5-2.5.

Standing water (lakes and ponds) received high scores of 4.0-5.0, again in agreement with the literature review which found that water features add to the aesthetic value of landscapes. We added a new category of eutrophic standing water as this was included in the Phase 1 habitat survey for the Bicester area, and assigned lower scores than for standing water to reflect the reduced aesthetic value of water that has algal blooms. There is support for this in the literature review. We also assumed that there would be a lower recreational value as water with algal blooms may not be safe or pleasant for swimming or boating.

For amenity grassland, we made some changes to the stakeholder scores. We increased the recreation value of amenity grassland from 2.5 to 3.0, as this type of land is often used for recreation (walking, playing ball games, picnicking, etc). The score could be increased further, but there is a difficulty in that the term is also used to describe relatively small patches of grassland such as verges, which are less useful for recreation. However, the use of the more detailed green infrastructure datasets for Bicester (see next section) help to overcome this issue, as playing fields can be separated out from general amenity grassland and given a higher score for recreation.

The scores for allotments were generally increased, based on the high value assigned to allotments in the participatory workshop in Essex. The score for recreation was increased from 2.0 to 5.0; aesthetic value from 1.0 to 2.0; and spiritual and intellectual value from 2.0 to 3.0.

Broad-leaved parkland with scattered trees is given the same score as for amenity grassland for cultural services. However, our analysis of Flickr photos for Warwickshire and Essex revealed that this was one of the most popular habitats in terms of the number of photographs taken per hectare, indicating a high aesthetic value. The score was therefore increased from 3.0 to 4.0 for broad-leaved parkland, and from 1.8 to 2.5 for coniferous parkland. The spiritual value of coniferous parkland was also increased slightly, from 1.3 to 2.5.

Bare ground, as expected, received low scores of 0.0 to 1.0. For the urban category, the WC&S stakeholders scored the overall mix of houses, roads, hard areas and gardens, so there were some fairly high scores (1.0 to 3.0). For Bicester, the urban category is taken to include only buildings and hard areas and all scores were therefore set to zero. Gardens are mapped and scored separately, using OS MasterMap.

We generated new scores for the two additional cultural ecosystem services: sense of place, and wildness. Wildness was scored on the degree of human influence on each land cover class: natural woodland, grassland, marshes and water were scored at 5.0; semi-natural woodland, parkland, plantations and scrub at 3.0 to 4.0; improved grassland at 2.0; and arable land and amenity grassland at 1.0. ‘Sense of place’ reflects local distinctiveness and personal attachments to places. The scoring largely followed the wildness scores, because more natural habitats tend to be more locally distinctive, but with some exceptions. For example, amenity grassland scored only 1.0 for wildness but 3.0 for sense of place, because our participatory mapping workshops in Warwickshire and Essex showed that even fairly uninspiring patches of grass could have personal significance for the local people who use them regularly, e.g. to walk the dog or play games. Allotments and orchards are highly managed and therefore only scored 1.0 and 2.0 for wildness, but they scored 5.0 for sense of place, because our workshops found that local food production is important for distinctiveness. Semi-improved grassland also scored only 2.0 for wildness but 3.5 for sense

of place, because evidence from the workshops showed that these areas (e.g. rough pasture along rivers) often contribute to local character and are important to local people.

Revising the scores for regulating services

The regulating services assessed for Bicester are:

- Pollination
- Pest control (via beneficial organisms such as wasps, beetles, bats and birds)
- Habitat for wildlife (this underpins many of the other services)
- Climate regulation (via carbon sequestration and storage)
- Air quality regulation (via absorption and adsorption of pollution onto plant material)
- Flood protection
- Water purification (via filtration of water through vegetation and soil)
- Erosion control
- Microclimate regulation (cooling and shading by vegetation, and cooling by water)
- Noise regulation

The last two of these — microclimate and noise regulation — are additional services that were not addressed in the WC&S study, so new scores have been generated for these services.

For the first eight services, the WC&S stakeholders assigned the highest values to semi-natural broad-leaved woodland, which scored 4.0 to 5.0 for all regulating services. Broad-leaved plantation scored a little less, and coniferous plantation lower still. Scrubland scored higher than coniferous plantation for all services except soil erosion. The unimproved grassland habitats, heathland and tall ruderal vegetation scored as highly as broad-leaved plantation (4.0 to 5.0) for pollination, pest regulation and habitat provision, and around 2.5 to 3.0 for most of the other regulating services.

For pollination, pest control and habitat provision, the scores appear reasonable as the grassland habitats are likely to include flowering plants that can sustain beneficial insects. For the other services, however, there appear to be some inconsistencies. The literature review showed that the main factor influencing the supply of this bundle of regulating services (atmospheric, air and water quality, flood and erosion regulation) is the amount of biomass in the ecosystem, so that forests tend to perform best followed by scrub and then grassland.

For climate regulation, coniferous plantation was given a very low score of 2.5, lower than scrub (4.0) and grassland (3.0). This is not supported by the evidence in the literature review, which finds little difference between carbon storage in coniferous and deciduous forests, because other factors such as tree age, tree size and growth rate are more important, but does find much lower carbon storage in grassland and scrub than in forests. We have therefore increased the score for coniferous plantations to 4.0, decreased the score for scrub to 3.5, and decreased the score for grasslands to 2.0, except for marshy grassland (as more carbon can be stored in the soil if it is peaty) and heath / acid grassland mosaic (as heathland vegetation can store more carbon than grassland, and the soil may be peaty), which were set to 2.5 and 3.0. The review does support the higher figure (5.0) for semi-natural forests than for plantations, because biological and structural diversity is associated with higher carbon storage. The score for arable is decreased from 1.5 to 1.0 to match improved grassland, because there is no evidence for higher carbon storage in arable soils.

Similarly, there are inconsistencies in the scores for air quality regulation. From the literature review, the dominant attribute is leaf area, so that larger trees and denser canopies are more effective at filtering out air pollution. There is little evidence that grassland would have a significant impact, so the score for

coniferous plantation has been increased from 3.0 to 4.0 and the scores for unimproved grassland have been reduced from 3.0 to 1.5.

Some changes were also made to the scores for flood protection. The review identified four mechanisms by which vegetation provides flood protection: improving soil infiltration so that more rainwater soaks into the ground; drying out the soil through evapo-transpiration; intercepting rainwater which then evaporates before reaching the ground; and (to a lesser extent) physically delaying the passage of floodwater (e.g. trees or woody debris on a floodplain, or saltmarshes on the coast). Fast-growing conifers are amongst the most effective trees for drying out the soil, so the score for coniferous plantations was increased from 3.0 to 4.0, and the scores for grassland were reduced from 3.0 to 1.5, with heath / grassland mosaic and marshy grassland being given slightly higher scores of 2.0.

For water purification, the low score of 2.5 for coniferous plantations was allowed to stand. The use of fertilisers and pesticides in plantations can have a negative impact on water quality, and cultivation of the soil and construction of forest tracks can lead to soil erosion and runoff that also decreases water quality. Runoff from conifer plantations can be acidic, which could be why the stakeholders assigned lower score to coniferous than broad-leaved plantations. The relatively high scores for unimproved grassland (3.0) were also allowed to stand as the evidence suggests that permanent grassland can effectively filter out pollutants. However these scores could be subjected to further scrutiny – for example, it is not clear why calcareous grassland was assigned a lower score (2.5). For soil erosion, the high scores (4.0) for unimproved grassland are acceptable as well-established grassland can be fairly resistant to erosion.

Improved grassland, arable land and amenity grassland score around 1.0 for most services, with improved and amenity grassland scoring a little more (1.5 to 2.5) for the soil and water regulation services, which is reasonable. Bare ground was given a surprisingly high score (3.0) for habitat, but this was allowed to stand as it could include rocky cliffs or caves. For allotments, we increased the scores for pollination, pest control and habitat from 1.0 to 2.0 because allotments contain flowering plants as well as a reasonable degree of structural diversity, which is important for providing shelter and food for beneficial insects.

Scattered scrub is set to the same scores as dense scrub. However, because there will be less biomass in these ecosystems the scores for atmospheric regulation, flood protection, erosion protection and air quality regulation should be slightly lower, so they were reduced by half a point.

The stakeholder scores for standing water are interesting. A score of 5.0 for habitat is understandable, but scores of 2.0 to 2.5 have also been provided for a number of other services. Water habitats can support beneficial insects such as dragonflies, which supports the scores of 2.5 and 2.0 for pollination and pest regulation. For climate regulation, carbon storage would presumably depend on the thickness and composition of sediments on the lake bed. The stakeholder score of 2.5 might therefore be possible if there were thick, peaty deposits, although this might not be the case for an old gravel pit. However, in the absence of any evidence from the review, this score was allowed to stand. For air quality, it is difficult to see how the stakeholder score of 2.0 could be justified, except that pollution particles deposited on the water surface would not be at risk of being remobilised by the wind. The score has therefore been reduced to 1.0. For flood protection, a lake that is already full of water is of no use for flood protection, although the associated depression in the ground may contain some space for additional water storage. The score has therefore been reduced from 2.5 to 1.5. For water purification, the score was 3.5. This was allowed to stand although it will be highly dependent on the existence of aquatic vegetation such as reeds which can act to purify the water that enters the lake.

New scores were created for noise and microclimate regulation. For both of these services, the benefit will be largely restricted to trees, with a lower impact from scrub and little impact from other land cover types, though water can contribute to cooling. All forest habitats were therefore assigned scores of 5.0 for both services; scrub scored 3.0; water and wetland scored 2.0 for microclimate regulation and zero for noise; and grassland scored 1.0 for microclimate regulation (as there will be some benefit from evapotranspiration) and zero for noise.

Revising the scores for provisioning services

It is relatively easy to assign scores to the provisioning services. Clearly arable land scores 5.0 for intensive crop provision, and most other land cover classes score zero, although improved grassland scored 1.5 as it can produce hay crops for animal feed. Poor semi-improved grassland had been set to 0.8 as it was taken to be the average of improved grassland and unimproved grassland, but this was changed to zero for consistency.

For urban food, orchards and allotments were changed to score 5.0 (increased from the stakeholder scores of 3.0 and 4.0 for 'traditional crops'). Broad-leaved or mixed woodland and scrub received low scores of 0.5 to 1.0 to reflect the potential for wild food (e.g. mushrooms and blackberries), and standing and running water received scores of 1.0 to reflect the potential for fishing. For livestock, improved grassland scored 5.0 and most other types of grassland scored 3.0, with some types of semi-natural woodland and scrub also receiving low scores to reflect the potential for limited stocking (e.g. of pigs). Amenity grassland scored 1.0, but this was changed to zero as urban grassland is not usually grazed. We decreased the score for coniferous plantations from 0.5 to zero and the score for dense scrub from 2.5 to 2.0 as it was not clear how these ecosystems could support livestock.

For water supply, the stakeholders assigned a high score (5.0) to standing water and low or zero scores to other land cover classes. In fact, the literature review showed that ecosystems that allow rainwater to infiltrate into the ground can improve water provision, compared to hard surfaces. Certain land cover types have good infiltration, such as natural grassland or natural forest, but trees and shrubs also soak up water through evapo-transpiration and thus can reduce the supply of both groundwater and surface water. Fast-growing conifer plantations are amongst the most water-hungry ecosystems, though for natural deciduous forests the net impact can be beneficial due to improved infiltration. The scores were therefore revised to set broad-leaved semi-natural woodland to 2.5 and coniferous plantation to 0.5, with natural grassland at 2.5, improved grassland (which may be subject to compaction by grazing animals) at 1.5 and arable land at 1.0. Wetlands were set to score 3.0 as they can store water for later release, and thus help to maintain base flows throughout the year.

In the WC&S study, the score for 'all provisioning services' was based on the average across all provisioning services, in the same way as the average for all regulating and cultural services. However, this seems inappropriate as land can generally only be used for one type of crop or livestock production. For example, if the assessment covers intensive crops, urban food and livestock then an arable field will score 5.0 for intensive crops but zero for urban food and livestock, giving an average score of 5.0/3 = 1.7, even though the land is actually giving a very high level of food provision. We therefore adopted the approach of basing the overall provisioning score on the maximum score out of all the crop or livestock provisioning services. Water supply is different as it can occur in parallel with the delivery of crop and livestock provisioning services: water can soak into the ground in pasture and arable fields, thus replenishing groundwater supplies. However, including water supply within the overall provisioning score would require an arbitrary decision over what weight to apply for water provision compared to food provision, so we have decided to provide separate maps of water supply rather than including it with the other provisioning services.

Table 2 Assumptions regarding derivation of ecosystem service scores for land cover classes. Based on the WC&S study, with changes highlighted in yellow (most scores for water provision were also changed).

HABCODE	DESCRIPTION	Assumption
A111	**Broad-leaved semi-natural woodland**	**Median Stakeholder value**
A112	**Broad-leaved plantation**	**Median Stakeholder value**
A121	Coniferous semi-natural woodland	Set to average of semi-natural broad-leaved woodland (A111) & coniferous plantation (A122)
A122	**Coniferous plantation**	**Median Stakeholder value (**scores for climate, air quality and flood protection increased to 4.0; score for livestock reduced to 0)
A131	Mixed semi-natural woodland	Set to average of broadleaved (A111) & coniferous (A121) semi-natural woodland
A132	Mixed plantation	Set to average of broadleaved (A112) & coniferous (A122) plantation
A21	**Dense/continuous scrub**	**Median Stakeholder** value (climate regulation reduced from 4.0 to 3.5)
A22	Scattered scrub	Set to A21 (some scores decreased (climate, air, flood, water purification) or increased (water provision and livestock) to reflect lower amount of woody vegetation)
A31	Broad-leaved parkland/scattered trees	Set to amenity (J12) for cultural; average (J12 + broadleaf plantation (A112) for others. (Set to average of amenity and broadleaved woodland; increased to 5.0 for recreation, aesthetic value and sense of place to reflect findings of Flickr photo analysis for WC&S; reduced slightly for climate, air, flood, noise and increased for water prov. as less than 50% tree cover)
A32	Coniferous parkland/scattered trees	Set to amenity (J12) for cultural; average (J12 + conifer plantation (A122)) for others (Set to average of amenity and coniferous woodland; score increased for aesthetic and spiritual value to reflect findings of Flickr photo analysis for WC&S); other small adjustments)
A4	Recently felled woodland	Set to J4 (bare ground) with reduced habitat (3-->1) and soil-related variables set to those of A132 (mixed plantation) (Water purification decreased from 3.3 to 2.0 as the amount of vegetation is reduced, and felling usually disturbs the soil and increases sediment runoff)
A5	Orchard	Set to A112 with modified food provision (A112 = BL plantation) (Changed from 3.0 to 5.0)
B11	**Unimproved acidic grassland**	**Median Stakeholder value** (scores decreased for climate, air, flood)
B12	Semi-improved acidic grassland	Set to B11 (unimproved) (scores decreased slightly for cultural ES (except recreation), habitat and pollination and increased slightly for livestock)
B21	**Unimproved neutral grassland**	**Median Stakeholder value** (scores decreased for climate, air, flood)
B22	Semi-improved neutral grassland	Set to B21 (scores decreased slightly for cultural ES (except recreation), habitat and pollination and increased slightly for livestock)
B31	**Unimproved calcareous grassland**	**Median Stakeholder value** (scores decreased for climate, air, flood)
B32	Semi-improved calcareous grassland	Set to B31 (scores decreased slightly for cultural ES (except recreation), habitat and pollination and increased slightly for

HABCODE	DESCRIPTION	Assumption
		livestock)
B4	**Improved grassland**	**Median Stakeholder value**
B5	**Marsh/marshy grassland**	**Median Stakeholder value** (scores decreased for climate, air, flood)
B6	Poor semi-improved grassland	Set to mean of B4 and B22 (Improved and Neutral grassland (small adjustments))
C11	Continuous bracken	Set to C31
C31	**Tall ruderal**	**Median Stakeholder value** (decreased slightly for climate, air, flood; increased for water provision (infiltration))
C32	Non-ruderal	Set to C31
D5	**Dry heath/acid grassland mosaic**	**Median Stakeholder value** (decreased slightly for climate, air, flood)
E11	Sphagnum Bog	Set to B5 with some expert modification (Pam) to reflect differences (climate increased to 5 as peat soil stores large amounts of carbon)
E21	Acid/neutral flush	Set to B5 with some expert modification (Pam) to reflect differences
E32	Basin Mire	Set to B5 with some expert modification (Pam) to reflect differences
F1	Swamp	Set to B5 with some expert modification (Pam) to reflect differences
F22	Inundation vegetation	Set to B5 with some expert modification (Pam) to reflect differences (climate reduced to 2.5 as not necessarily on peaty soil – may be just on gravel)
G1	**Standing water**	**Median Stakeholder value**
G2	Running water	Set to G1 (standing water)
I21	Quarry	Set to J4 (bare ground) (all ES reduced to zero except flood protection 0.5, assuming working quarry)
I22	Spoil	Set to J4 (bare ground) (set to I21 (quarry)
I24	Refuse tip	Set to J4 (bare ground) (set to I21 (quarry)
J11	**Arable**	**Median Stakeholder value** (climate reduced from 1.5 to 1; water supply increased from 0 to 1 as soil is permeable (but growing crop absorbs water))
J112	Allotments	Set to J12 (amenity) with increased food provision and more intellectual /spiritual interactions. (Changed: recreation increased from 2.0 to 5.0; aesthetic increased from 1.0 to 2.0; spiritual and intellectual increased from 2.0 to 3.0; pollination, pest control and habitat increased from 1.0 to 2.0; water supply increased from 0 to 1.0.)
J12	**Amenity grassland**	**Median Stakeholder value** (recreation increased to 3; water supply increased from zero to 2 as permeable)
J13	Ephemeral/short perennial	set to C31 (tall ruderal)
J14	Introduced shrub	set to C31 (tall ruderal) Set to dense scrub but with lower recreation, spiritual, intellectual and habitat, and higher aesthetic (assuming introduced for ornamental reasons)
J4	**Bare ground**	**Median Stakeholder value**
URB	**Urban**	**Median Stakeholder value** (changed to zero as only hard surfaces)
	Hedgerows	Set to A11
	Hedgerows with trees	Set to A11
	Lines of trees	Set to A11

HABCODE	DESCRIPTION	Assumption
	Arable with scattered trees	Set to mix of A31 (parkland with scattered trees) and arable

The revised scores for Bicester are shown in Table 3, with the new services, new land cover classes and modified scores shown in red text.

Table 3. Matrix of scores for ecosystem service supply from different land cover classes for Bicester

Changes from WC&S matrix (Table 1) shown in red text

HABCODE	DESCRIPTION	Recreation	Aesthetic	Spiritual	Intellectual	Sense of Place	Wildness	Pollination	Pest control	Habitat	Climate regulation	Air quality	Flood protection	Water purification	Erosion control	Microclimate	Noise	Intensive crops	Urban food	Livestock	Water supply	Food provision (max)	Regulating (av)	Cultural (av)
A111	Broad-leaved semi-nat. woodland	5.0	5.0	5.0	4.5	5.0	5.0	5.0	4.0	5.0	5.0	5.0	4.5	4.0	5.0	5.0	5.0	0.0	2.0	0.5	2.0	2.0	4.8	4.9
A112	Broad-leaved plantation	4.5	4.0	3.0	3.0	4.0	4.0	3.5	3.0	3.5	4.0	4.0	4.0	4.0	4.0	5.0	5.0	0.0	1.0	0.0	1.0	1.0	4.0	3.8
A122	Coniferous plantation	3.0	2.5	1.5	3.0	3.0	3.0	2.0	2.0	2.0	4.0	4.0	4.0	2.5	3.5	5.0	5.0	0.0	0.0	0.0	0.5	0.0	3.4	2.7
A21	Dense/continuous scrub	2.0	2.0	2.0	3.0	3.0	3.0	4.5	3.5	4.0	3.5	3.0	3.0	3.0	3.0	2.0	3.0	0.0	1.0	2.0	1.0	2.0	3.3	2.5
B11	Unimproved acidic grassland	3.5	4.5	3.0	4.0	5.0	5.0	5.0	4.0	5.0	2.0	1.5	1.5	3.0	4.0	1.0	0.0	0.0	0.0	3.0	2.5	3.0	2.7	4.2
B21	Unimproved neutral grassland	4.0	4.0	3.0	4.0	5.0	5.0	5.0	4.0	5.0	2.0	1.5	1.5	3.0	4.0	1.0	0.0	0.0	0.0	3.0	2.5	3.0	2.7	4.2
B31	Unimproved calcareous grassland	3.5	4.5	3.0	4.0	5.0	5.0	5.0	4.0	5.0	2.0	1.5	1.5	2.5	4.0	1.0	0.0	0.0	0.0	3.0	2.5	3.0	2.7	4.2
B4	Improved grassland	1.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	2.5	1.0	0.0	1.5	0.0	5.0	1.5	5.0	1.1	1.3
B5	Marsh/marshy grassland	3.0	4.0	3.0	4.0	5.0	5.0	5.0	3.5	5.0	2.5	1.5	2.0	4.0	4.0	2.0	0.0	0.0	0.0	3.5	3.0	3.5	3.0	4.0
C31	Tall ruderal	1.5	2.0	1.5	2.5	2.0	2.0	5.0	4.0	4.0	2.5	2.0	1.5	2.5	3.0	1.0	0.0	0.0	0.0	1.5	2.5	1.5	2.6	1.9
D5	Dry heath/acid grassland mosaic	3.0	4.5	4.0	4.0	5.0	5.0	5.0	3.5	5.0	3.0	2.0	2.0	3.0	3.5	1.0	0.0	0.0	0.0	2.5	2.0	2.5	2.8	4.3
G1	Standing water	4.0	5.0	5.0	4.0	5.0	5.0	2.5	2.0	5.0	2.5	1.0	1.5	3.5	0.5	2.0	0.0	0.0	1.0	1.0	5.0	1.0	2.1	4.7
G1E	Standing water - eutrophic	2.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	3.0	2.5	1.0	1.5	1.5	0.5	2.0	0.0	0.0	0.0	0.5	3.0	0.5	1.6	2.8
J11	Arable	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	0.0	5.0	0.0	1.0	1.0	5.0	0.9	0.9
J12	Amenity grassland	3.0	1.0	1.0	0.5	3.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.5	1.0	0.0	0.0	0.0	0.0	2.0	0.0	1.3	1.6
J4	Bare ground	1.0	1.0	0.0	0.5	0.0	0.0	1.0	1.0	3.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.7	0.4
URB	Urban - hard surfaces	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Derived scores for other land cover classes (see Table 2; changes to WC&S scores shown in red text)

A121	Coniferous semi-natural woodland	4.0	3.8	3.3	3.8	4.0	4.0	3.5	3.0	3.5	4.5	4.5	4.3	3.3	4.3	5.0	5.0	0.0	0.0	0.5	1.3	0.5	4.1	3.8
A131	Mixed semi-natural woodland	4.5	4.4	4.1	4.1	4.5	4.0	4.3	3.5	4.3	4.8	4.8	4.4	3.6	4.6	5.0	5.0	0.0	1.0	0.5	1.6	1.0	4.4	4.3
A132	Mixed plantation	3.8	3.3	2.3	3.0	3.5	3.5	2.8	2.5	2.8	4.0	4.0	4.0	3.3	3.8	5.0	5.0	0.0	0.5	0.0	0.8	0.5	3.7	3.2
A22	Scattered scrub	2.0	2.0	2.0	3.0	3.0	3.0	4.5	3.5	4.0	3.0	2.5	2.5	2.5	3.0	2.0	1.0	0.0	0.5	2.5	1.5	2.5	2.9	2.5
A31	Broad-leaved parkland/scat. trees	5.0	5.0	3.0	2.5	5.0	3.0	3.0	2.5	3.0	2.5	2.5	3.0	3.0	3.8	3.0	2.0	0.0	1.0	1.0	2.5	1.0	2.8	3.9
A32	Coniferous parkland/scattered trees	5.0	4.0	2.5	2.0	4.5	3.0	2.3	2.0	2.3	2.5	2.8	3.1	2.6	3.4	3.0	2.0	0.0	0.0	1.0	1.6	1.0	2.6	3.5
A4	Recently felled woodland	1.0	1.0	0.0	0.5	0.0	0.0	1.0	1.0	1.0	0.0	0.0	1.0	2.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	0.0	0.7	0.4
A5	Orchard	4.5	4.0	3.0	3.0	5.0	2.0	3.5	3.0	3.5	4.0	4.0	4.0	4.0	4.0	4.0	2.0	0.0	5.0	0.0	2.0	5.0	3.6	3.6
B12	Semi-improved acidic grassland	3.5	4.0	3.0	3.5	4.0	3.5	4.5	4.0	4.5	2.0	1.5	1.5	3.0	4.0	1.0	0.0	0.0	0.0	3.5	2.5	3.5	2.6	3.6
B22	Semi-improved neutral grassland	4.0	4.0	3.0	4.0	4.0	3.5	4.5	4.0	4.5	2.0	1.5	1.5	3.0	4.0	1.0	0.0	0.0	0.0	3.5	2.5	3.5	2.6	3.8
B32	Semi-improved calcareous grassland	3.5	4.5	3.0	4.0	4.0	3.5	5.0	4.0	4.5	2.0	1.5	1.5	2.5	4.0	1.0	0.0	0.0	0.0	3.5	2.5	3.5	2.6	3.8
B6	Poor semi-Improved grassland	3.5	2.5	2.0	2.5	3.5	3.0	3.0	2.5	3.0	1.5	1.3	1.3	2.3	3.3	1.0	0.0	0.0	0.0	4.0	2.0	4.0	1.9	2.8
C11	Continuous bracken	1.5	2.0	1.5	2.5	2.0	2.0	5.0	4.0	4.0	2.5	2.0	1.5	2.5	3.0	1.0	0.0	0.0	0.0	1.5	2.5	1.5	2.6	1.9
C32	Non-ruderal	1.5	2.0	1.5	2.5	2.0	2.0	5.0	4.0	4.0	2.5	2.0	1.5	2.5	3.0	1.0	0.0	0.0	0.0	1.5	2.5	1.5	2.6	1.9
E11	Sphagnum Bog	2.0	4.0	3.0	4.0	5.0	5.0	4.0	3.5	5.0	5.0	1.5	2.0	4.0	4.0	2.0	0.0	0.0	0.0	1.5	3.0	1.5	3.1	3.8
E21	Acid/neutral flush	2.0	4.0	3.0	4.0	5.0	5.0	4.0	3.5	5.0	3.5	1.5	2.0	4.0	4.0	2.0	0.0	0.0	0.0	1.5	3.0	1.5	3.0	3.8
E32	Basin Mire	2.0	4.0	3.0	4.0	5.0	5.0	4.0	3.5	5.0	3.5	1.5	2.0	4.0	4.0	2.0	0.0	0.0	0.0	1.5	3.0	1.5	3.0	3.8
F1	Swamp	2.0	4.0	3.0	4.0	5.0	5.0	4.0	3.5	5.0	3.5	1.5	2.0	4.0	4.0	2.0	0.0	0.0	0.0	1.5	3.0	1.5	3.0	3.8
F22	Inundation vegetation	2.0	4.0	3.0	4.0	5.0	5.0	4.0	3.5	5.0	2.5	1.5	2.0	4.0	4.0	2.0	0.0	0.0	0.0	1.5	3.0	1.5	2.9	3.8
G2	Running water	4.0	5.0	5.0	4.0	5.0	5.0	2.5	2.0	5.0	2.5	1.0	1.5	3.5	0.5	2.0	0.0	0.0	1.0	1.0	5.0	1.0	2.1	4.7
I21	Quarry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0
I22	Spoil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0
I24	Refuse tip	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0
J112	Allotments	5.0	2.0	3.0	3.0	5.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.5	2.0	1.0	0.0	5.0	0.0	1.0	5.0	1.8	3.2
J13	Ephemeral/short perennial	1.5	2.0	1.5	2.5	3.0	2.0	5.0	4.0	4.0	2.5	2.0	1.5	2.5	3.0	1.0	0.0	0.0	0.0	1.5	2.5	1.5	2.6	2.1
J14	Introduced shrub	1.0	2.5	1.5	2.0	2.5	1.5	4.5	3.5	3.0	3.5	3.0	3.0	3.0	3.0	2.0	3.0	0.0	1.0	0.0	1.0	1.0	3.2	1.8
J11X	Arable and scattered trees	1.0	3.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	4.5	0.0	0.0	1.0	4.5	1.9	2.2

Deriving scores for additional urban land cover classes

The Habitat and Land Use Study covered the large areas of green space within Bicester, but we supplemented this with two additional data sources: the "Grounds layer", which covered every patch of publicly owned green space including small verges, and the Open Space Review, which identified both public and private open space including sports facilities, allotments, cemeteries and churchyards, etc. Scores for these new land cover classes, presented in Table 4, were mainly based on the scores already generated for similar land cover classes from the habitat survey (described above).

Grounds layer

- Housing: all scores were set to zero (this covers buildings and hard surfaces: gardens are mapped separately).
- Grass: this includes very small areas such as grass verges, as well as larger areas such as playing fields. Playing fields were identified separately, based on the Open Space dataset (see below), and the remaining grass was set to score the same as amenity grassland.
- Hard areas: all set to zero
- Hedges: broadly the same as scrub, but higher aesthetic value (4.0 vs 2.0), spiritual value (3.0 vs 2.0), pest control (4.5 vs 3.5) and habitat (5.0 vs 4.0), and lower wildness value (2.0 vs 3.0) and livestock provision (zero vs 2.0).
- Meadow areas: loosely based on the average of amenity grassland and wild flora, but with higher scores for recreation (5.0) and livestock (2.5), as some meadow areas may be used for occasional grazing.
- OCC Highways: this is mainly roadside verges and central reservations. A new set of scores were derived that assumed a score of 1.0 for recreation (roadside verges may be used by runners and walkers); 2.0 for aesthetic value (green areas improve the view); 1.0 for other cultural services; 2.0 for pollination, pest control and habitat (verges may include wild flowers, so the score is higher than for amenity grass); and similar to grass for the other services (except that climate regulation is a little higher, at 2.0, as verges can include taller vegetation and even some shrubs).
- Perennial borders: we assumed maximum (5.0) scores for aesthetic value, pest control and pollination, high (4.0) scores for sense of place and habitat, and moderate (3.0) scores for spiritual and intellectual value. Perennial borders are likely to contain taller vegetation than grass, so we allowed scores of 2.0 for the bundle of services dependent on amount of vegetation (air quality, climate regulation, flood protection, soil erosion and water quality).
- Play areas: these generally include a mix of short grass with hard areas, so regulating services will be low. We assigned scores of 5.0 for recreation, 4.0 for sense of place, 1.0 for most other services and 0.0 for food provision.
- Seasonal bedding: for cultural services, we applied the same scores as for perennial borders, except that wildness scored 1.0 instead of 2.0, as seasonal bedding displays typically involve formal displays of non-native plants. For regulating services, scores were generally one point lower than perennial borders, as seasonal bedding tends to comprise shorter plants (thus less vegetation) with less structural diversity, and the display may be empty (bare soil) over the winter months. Water supply was half a point higher (1.0 compared to 0.5) for the same reason, as shorter plants will absorb less water from the soil.
- Shrub border: scores were similar to hedge (see above) except that the score for wildlife habitat was lower (4.0) as shrub borders may be more open in structure and thus may not offer the same degree of shelter and protection (e.g. nesting sites) as a hedge. Scores for air quality and climate regulation were a little higher to account for the taller vegetation in a shrub border.

- Water: similar to “standing water”, except that pollination was reduced from 2.5 to 2.0 (to be consistent with the score for pest control) and carbon storage was reduced from 2.5 to 1.0 (as it was thought to be unlikely that water in urban areas would have thick deposits of carbon-rich sediment).
- Wild flora area: loosely based on unimproved calcareous grassland (because that is also expected to be rich in natural flora), with a slightly lower score for recreation (4.5) to reflect possible restricted access for activities; higher scores for aesthetic value (5.0) and spiritual value (4.0) to reflect the greater abundance of flowering plants; and a lower score for soil erosion (2.0) as initial cultivation and ongoing maintenance (e.g. mowing) may disturb the soil. Livestock was scored at 2.5 as there may be occasional grazing to maintain the area.
- Woodland area: same as broad-leaved semi-natural woodland except that the score for livestock was zero (compared to 0.5) as it is unlikely that livestock would forage in urban woodlands.
- Tree: as for woodland, except for lower scores for recreation (3.0) and wildness (3.0) because this is a single tree, not a whole woodland.
- Tree group: as for woodland, except for lower scores for recreation (4.0) and wildness (4.0) as this is a small group of urban trees, not a whole woodland.

Extra categories from the open space layer

- Grass sports facilities (playing fields, tennis courts, golf courses, bowling greens, etc.), derived as the intersection of the ‘outdoor sports facilities’ layer from the open space study with amenity grassland from the habitat and land use study: these were assigned a score of 5.0 for recreation, and the other scores were set to be the same as amenity grassland.
- Allotments: these were assigned the same scores as allotments from the habitat and land use layer.
- Amenity green space: this included some small areas that were not included in the grounds layer or the habitat and land use survey. The score was set to the same as grass in the grounds layer.
- Cemeteries and churchyards: these were not included in any of the other datasets. Scores were based on amenity grassland but with higher values for wildlife habitat and aesthetic value, to reflect the presence of trees and shrubs, and lower recreational value but higher spiritual value.

Gardens

Gardens were extracted from OS MasterMap. They were assigned a maximum score of 5 for recreation, although this is debatable as the service is only accessible to the garden owners.

The scores for the additional land cover classes for urban green infrastructure are shown in Table 4.

Table 4. Matrix of scores for ecosystem service supply from different types of green infrastructure in the "grounds" and "open space" datasets in Bicester

Grounds layer	Recreation	Aesthetic	Spiritual	Intellectual	Sense of Place	Wildness	Pollination	Pest control	Habitat	Climate regulation	Air quality	Flood protection	Water purification	Erosion control	Microclimate	Noise	Intensive crops	Urban food	Livestock	Water supply		Food provision	Regulating (av)	Cultural (av)
Charter Housing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Grass	3.0	1.0	1.0	0.5	3.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.5	1.0	0.0	0.0	0.0	0.0	2.0		0.0	1.3	1.6
Hard surface	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Hedge	2.0	4.0	3.0	3.0	3.0	2.0	4.5	4.5	5.0	3.5	3.0	3.0	3.0	3.0	2.0	3.0	0.0	1.0	0.0	1.0		1.0	3.5	2.8
Meadow area	5.0	3.0	2.5	2.3	4.0	3.0	3.0	3.0	4.0	2.0	1.0	2.0	2.0	2.0	1.0	0.0	0.0	0.0	2.5	2.5		2.5	2.0	3.3
OCC Highways (verges etc)	1.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	0.0	0.0	0.0	0.0	1.5		0.0	1.6	1.2
Perennial border	2.0	5.0	3.0	3.0	4.0	2.0	5.0	5.0	4.0	2.0	2.0	2.0	2.0	2.0	1.0	0.0	0.0	0.0	0.0	1.5		0.0	2.5	3.2
Play area	5.0	1.0	1.0	1.0	4.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.5		0.0	0.9	2.2
Seasonal bedding	2.0	5.0	3.0	3.0	4.0	1.0	4.0	4.0	3.0	1.0	2.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0		0.0	1.8	3.0
Shrub border	2.0	4.0	3.0	3.0	3.0	2.0	4.5	4.5	4.0	4.0	4.0	3.0	3.0	3.0	2.0	3.0	0.0	1.0	0.0	1.0		1.0	3.5	2.8
Water	4.0	5.0	5.0	4.0	5.0	5.0	2.0	2.0	5.0	1.0	1.0	1.5	3.5	0.5	2.0	0.0	0.0	1.0	1.0	5.0		1.0	1.9	4.7
Wild flora area	3.0	5.0	4.0	4.0	5.0	4.0	5.0	4.0	5.0	2.0	1.5	1.5	2.5	2.0	1.0	0.0	0.0	0.0	2.5	2.5		2.5	2.5	4.2
Woodland area	5.0	5.0	5.0	4.5	5.0	5.0	5.0	4.0	5.0	5.0	5.0	4.5	4.0	5.0	5.0	5.0	0.0	2.0	0.0	2.0		2.0	4.8	4.9
Tree	3.0	5.0	5.0	4.0	5.0	3.0	5.0	4.0	4.0	5.0	5.0	4.5	4.0	5.0	5.0	5.0	0.0	2.0	0.0	2.0		2.0	4.7	4.2
Tree group	4.0	5.0	5.0	4.0	5.0	4.0	5.0	4.0	5.0	5.0	5.0	4.5	4.0	5.0	5.0	5.0	0.0	2.0	0.0	2.0		2.0	4.8	4.5
Open space layer																								
Grass sports facilities	5.0	1.0	1.0	0.5	3.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.0	1.0	0.0	0.0	0.0	0.0	2.0		0.0	1.2	1.9
Allotments	5.0	2.0	3.0	3.0	5.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.5	2.0	1.0	0.0	5.0	0.0	1.0		5.0	1.8	3.2
Cemeteries and churchyards	1.0	2.0	5.0	1.0	3.0	1.0	1.0	1.0	2.0	1.0	1.0	2.0	2.0	2.5	1.0	0.0	0.0	0.0	0.0	2.0		0.0	1.3	1.6
Amenity green space	3.0	1.0	1.0	0.5	3.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	2.0	2.5	1.0	0.0	0.0	0.0	0.0	2.0		0.0	1.3	1.6
Gardens	5.0	4.0	4.0	3.0	4.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	0.0	2.0	0.0	2.0		2.0	2.1	3.7

Combining different layers

There was a degree of overlap between features in these different datasets, but not in a consistent manner. For example, the inset below shows amenity grassland from three different datasets: the habitat and land use survey (pale green), the Grounds layer (purple hatching) and the open space survey (red hatching), showing that sometimes two or more of these overlap and sometimes they do not. There are also a few areas of grass visible on aerial photos and in OS MasterMap that do not appear in any of these datasets (presumably on private land).

Amenity grassland:

Habitat and land use survey

Grounds database

Open space survey

We tried not to lose important detail when combining layers. For example, the areas categorised as 'outdoor sports facilities' in the Open Space survey included mainly grassed areas but also trees around the edge of playing fields. We did not want to lose this level of detail, which is why we created a "grass sport facilities" layer from the intersection of amenity grassland and "outdoor sports facilities", which included the grass portions of playing fields but not the wooded parts (which were generally included separately within the habitat and land use layer).

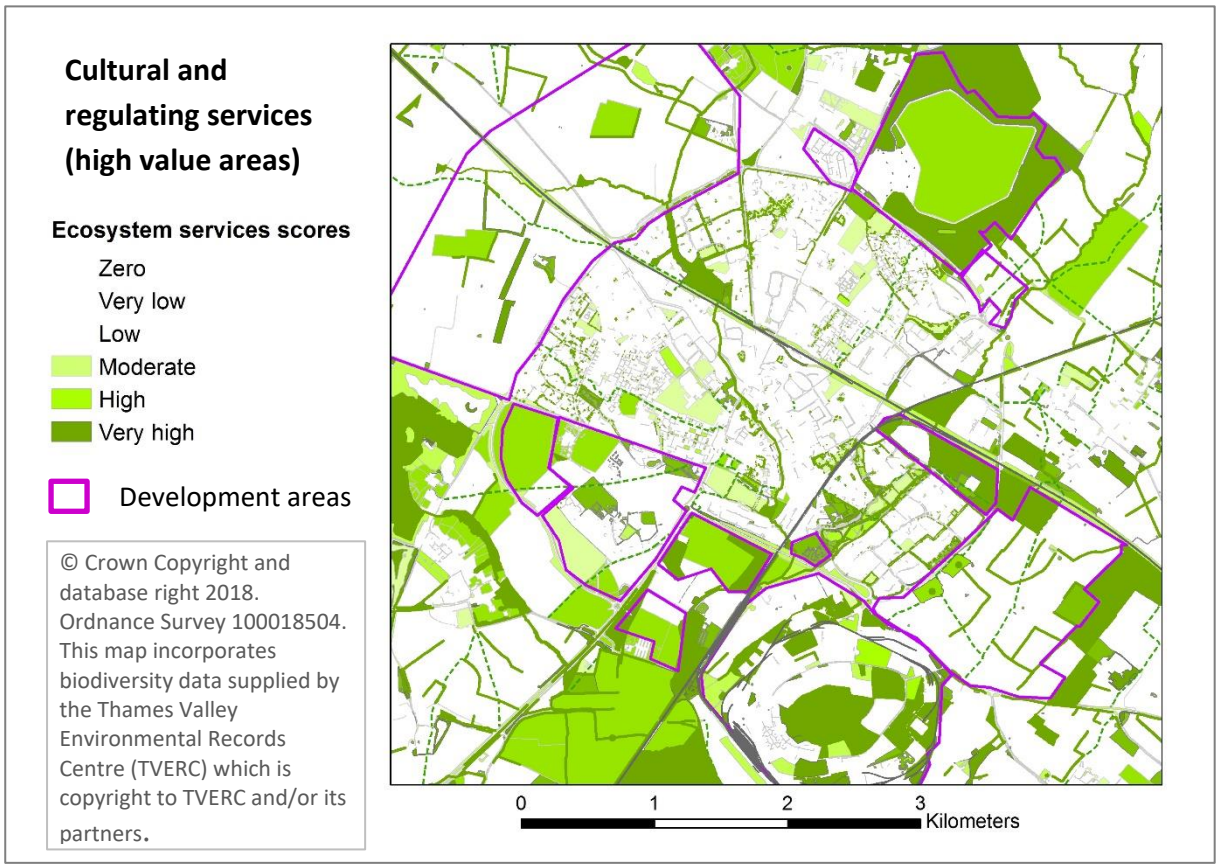
The quickest way of generating the output maps is simply by ordering the individual layers so that the most relevant layer is on top of the others. The order we adopted (with the top layer first) is:

1. Trees and tree groups (dissolved into a single layer) (CDC dataset for Bicester)
2. Water (extracted from OS Mastermap)
3. Linear woodland features (TVERC dataset)
4. Open space layer (grass sports areas, allotments, cemeteries and churchyards)
5. Grounds layer
6. Open space layer (amenity grassland: less detailed than the Grounds layer so underneath)
7. Habitat and land use survey
8. OS MasterMap layers: gardens ('mixed-use'), 'man-made surfaces' (e.g. car parks), 'buildings', 'natural land' and 'trees'. The last two categories cover small patches of natural land not included in the other datasets.

Alternatively, all the datasets can be stitched together into a single layer. However, this is complex and time-consuming. It requires determining the appropriate order of priority for different layers (as above) where land appears in multiple datasets, e.g. playing fields that are also classified as grassland. Creating a single layer is necessary for applying other tools such as ecological network mapping or assessing land-use change, but it is not necessary for generating land-cover score maps. We created a single layer for Cherwell District using the approach described a separate document (starting from OSMasterMap and then combining in the other layers one at a time).

Appendix 2: Ecosystem service maps for Bicester

Figure 1: High value areas for providing cultural and regulating services



This map shows the highest value areas for cultural and regulating services combined, including areas of historic interest and high nature value. The purple outlines show that many of these high value areas lie within development sites (some have already been lost to development). It is important to protect the remaining high value areas during future development.

A selection of maps for specific services are presented on the following pages (plus averages for all regulating and all cultural services). Further maps for services not shown here can be generated on request.

Figure 2: Cultural services (average score for all six) (private gardens omitted for clarity)

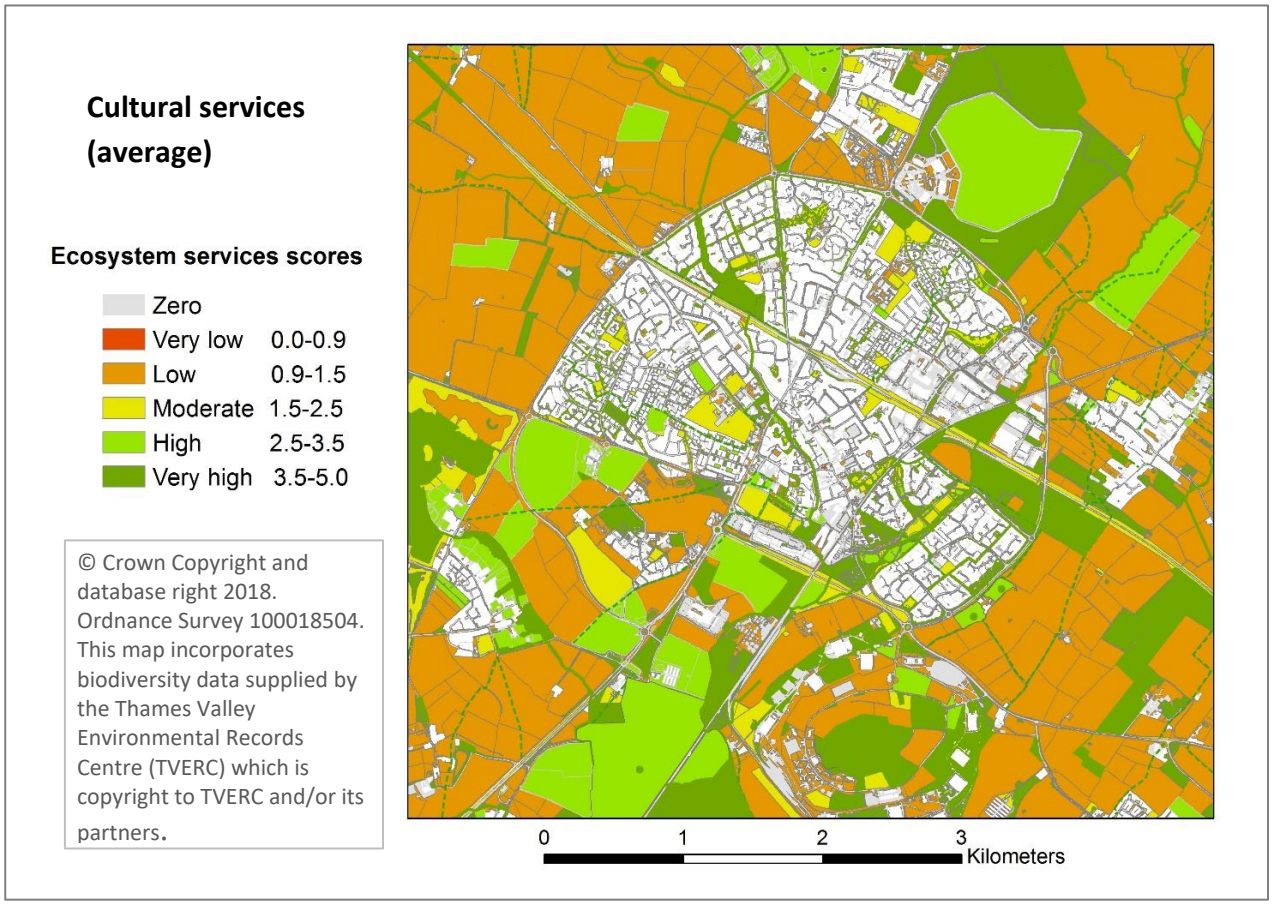


Figure 3: Regulating services (average scores)

Figure 4: Food provisioning services (max score)

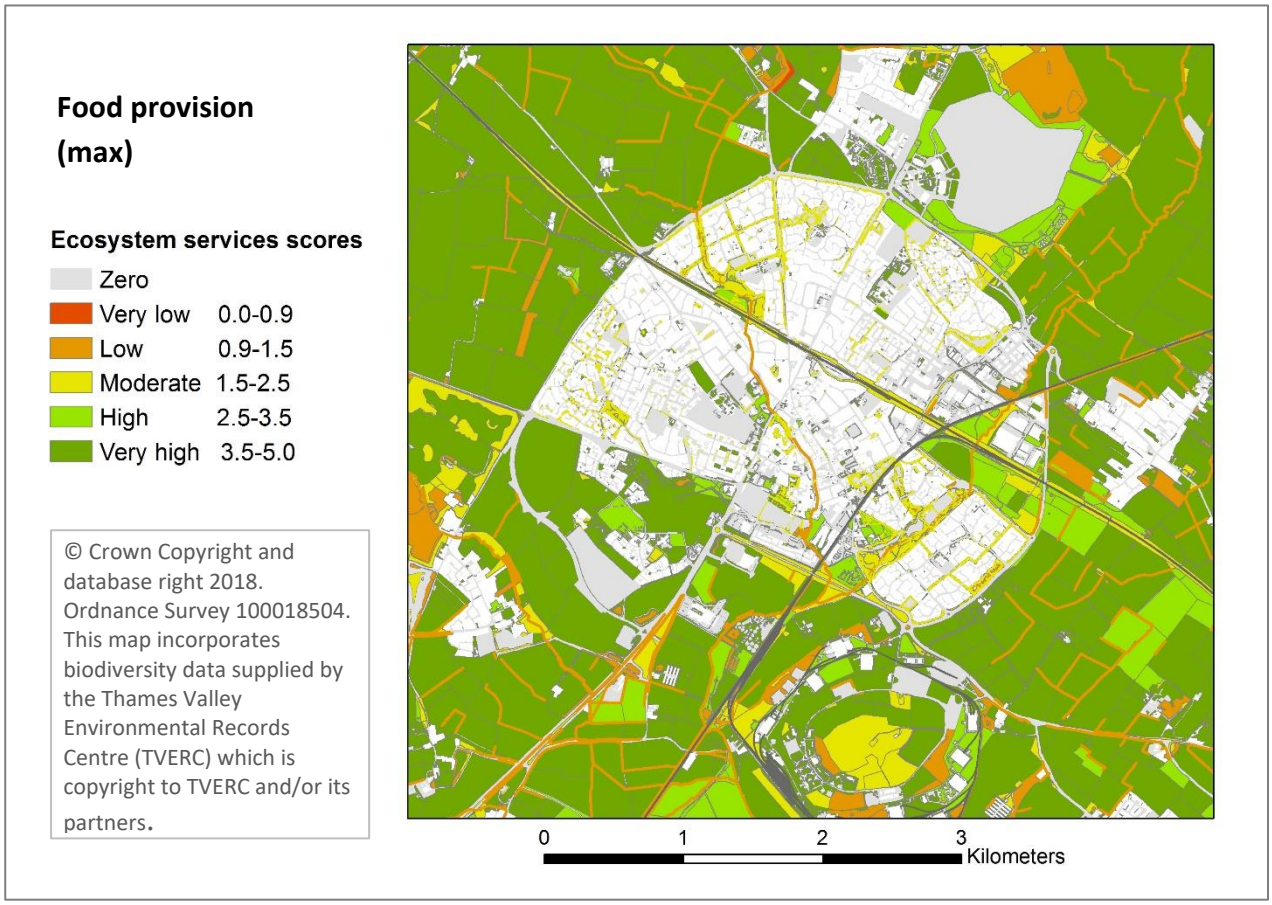


Figure 5: Water provision (gardens omitted for clarity)

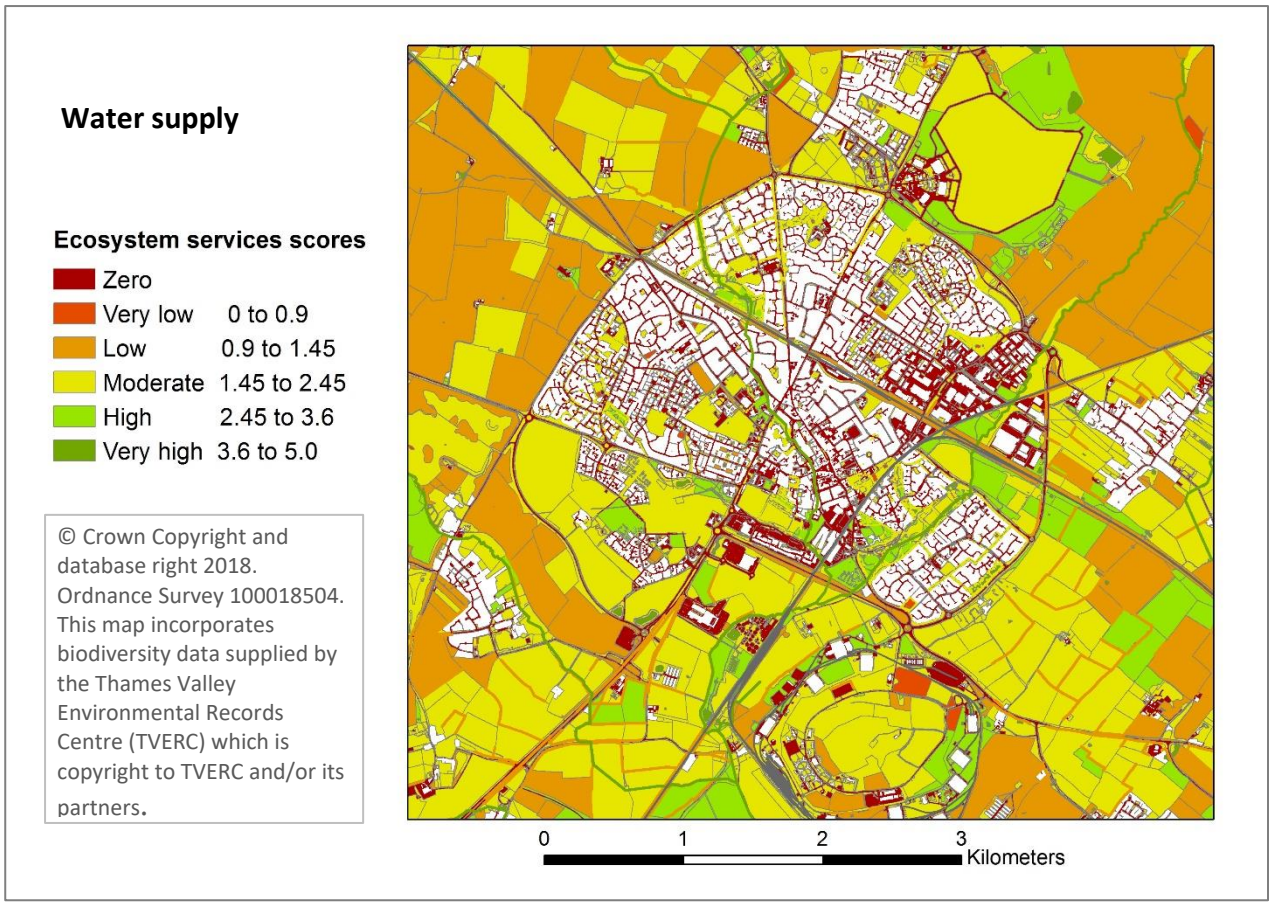


Figure 6: Flood protection

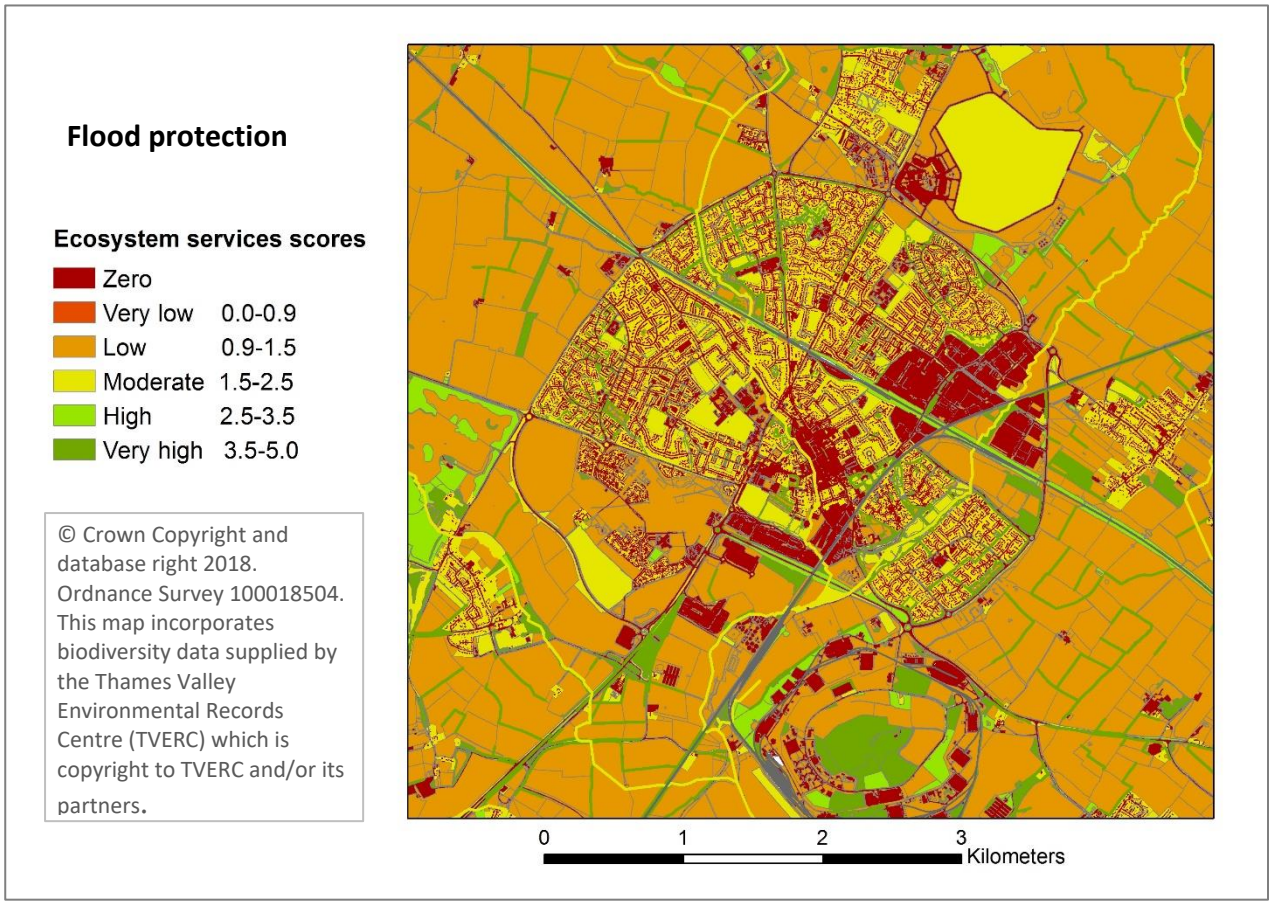


Figure 7: Habitat for wildlife

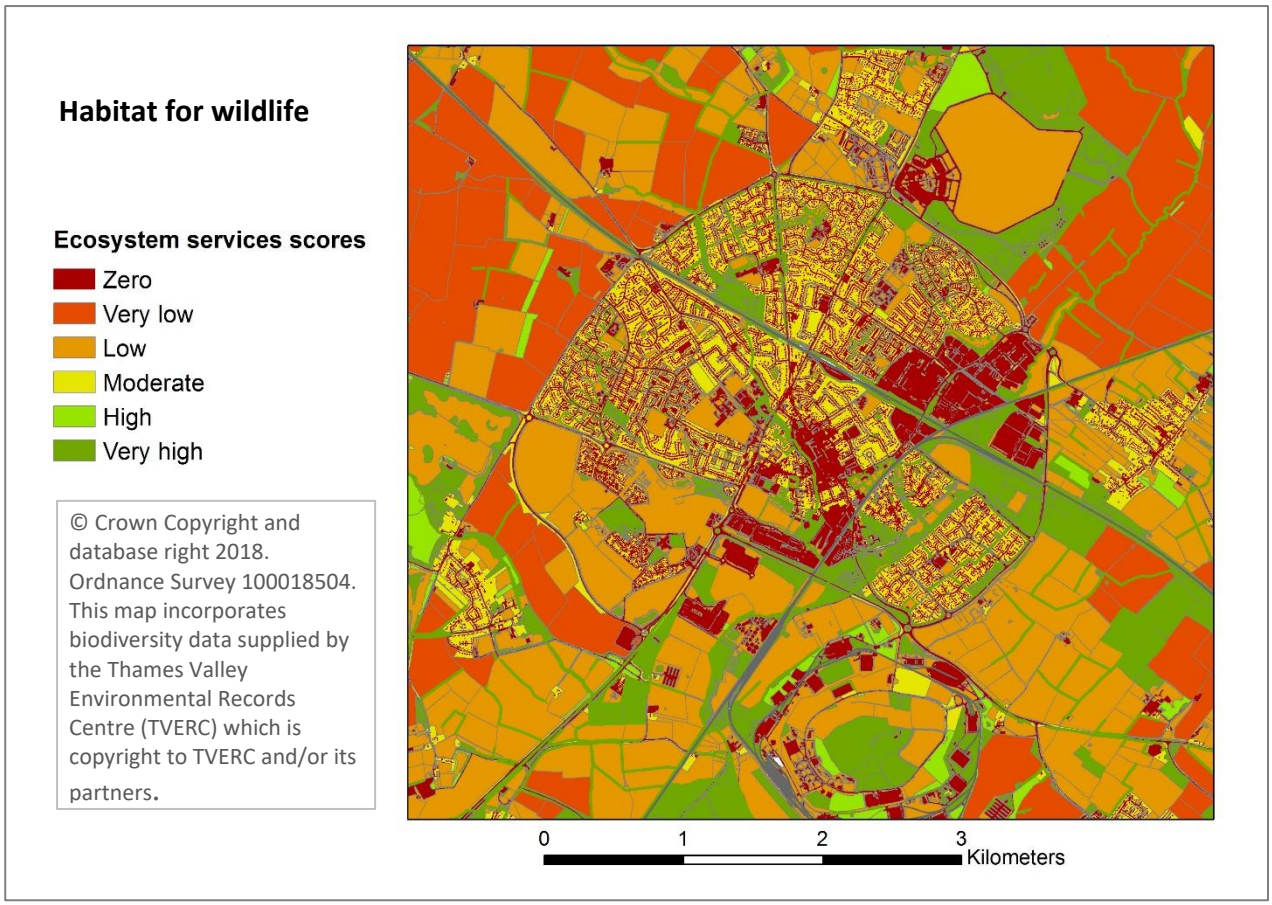


Figure 8: Recreation