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Further development of a spatial framework for mapping ecosystem services

Briefing paper 1 - Bayesian Belief Networks

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Contents

1 Bayesian Belief Networks

Bayesian Belief Networks (BBNs) are multivariate statistical tools with a graphical output, designed to represent and analyse the uncertainty that often surrounds our understanding of complex systems. A Bayesian Network is a complete model for variables (the boxes in Figure 1) and their relationships can be used both to illustrate the relationships and model scenario outcomes.

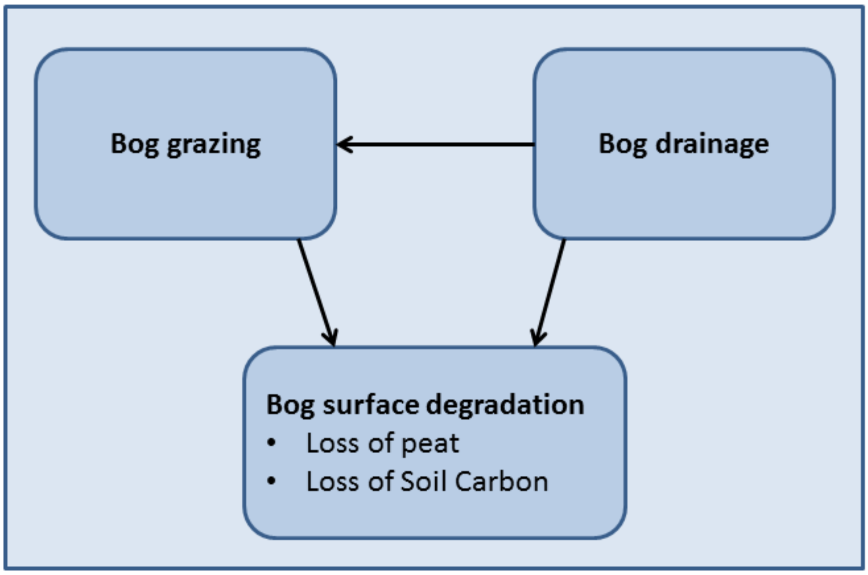

Figure 1. A simplified example of a Bayesian Network. The drainage of a bog leads to an increase in grass species and therefore an increase in its value for grazing. Both drainage and grazing of the bog lead to degradation of the bog surface and subsequent loss of peat and soil.

As well as being used in the fields of medicine, engineering and law, they have been used widely in the environmental arena to create diagnostic tools for environmental managers and for undertaking classification tasks (see Haines-Young, 2011).

In the context of the UK National Ecosystem Assessment (UK NEA) they have been used to model land cover change under a range of different future scenarios (Haines-Young *et al*, 2011), and in the pilot studies which were part of the Valuing Nature Network (VNN) they were used as a framework for understanding valuation issues[1].

There are a range of software tools for working with BBNs. Netica[2] software has been used in this study.

[1] http://www.valuing-nature.net/vnn-projects
[2] http://www.norsys.com/netica.html

2 Using BBNs to develop a spatial framework for mapping ecosystem services

There are three ways in which BBNs have been used to assist with developing a spatial framework for Ecosystem Service mapping:

- As a means of representing known relationships within component parts of hierarchical classification systems – these can be habitat classification systems (e.g. EUNIS levels 1 and 2 or Phase 1 levels 1, 2 and 3) or ecosystem services classifications systems (e.g. the four parts of the Common International Classification of Ecosystem Services - CICES).

- As a means of determining and representing how differing classification systems of the same type relate to each other. i.e. the relationship between:

    - Different habitat classification systems, where expert knowledge is applied as part of the project to decide how one system “fits” with another (e.g. how EUNIS fits with Phase 1).
    - Different ecosystem services classification systems, where expert knowledge is applied as part of the project to decide how one system “fits” with another (e.g. how NEA Services fits with CICES).

- To describe the relationship between habitat classification systems and ecosystem services classifications, where expert knowledge is applied to decide how the service systems and habitat systems relate to one another (e.g. how CICES fits with EUNIS or NEA services relate to Broad Habitats).

This document describes the way BBN principles have been applied to produce outputs that have informed the development of the Spatial Framework.

3 Structure of the BBNs

The structure of a BBN can be further illustrated by representing the relationships between differing classifications that are relevant to ecosystem services. In Figure 2, a BBN shows the different elements of three classifications used in ecosystem services work:

- The tiered CICES classification of ecosystem services (showing each of the four levels of the hierarchy that it comprises) – coloured brown;
- UK NEA classification of ecosystem services – coloured green; and
- UK NEA Broad Habitat classification – coloured yellow.

The ‘network’ consists of what is known as a ‘directed acyclic graph’ (DAG) which represents the system of interest as a set of variables, known as ‘nodes’ in the network (each node is depicted as a box) and the relationships between them (shown as arrows between the nodes).

In Figure 2, the nodes include the four levels in the CICES hierarchy (Nodes C to F); these are represented by the different service categories at the different levels in the CICES classification. The other nodes in the system included in the network are the UK NEA ecosystem service categories (Node B) and the Broad Habitats that the NEA identified as important for the delivery of ecosystem services (Node A).

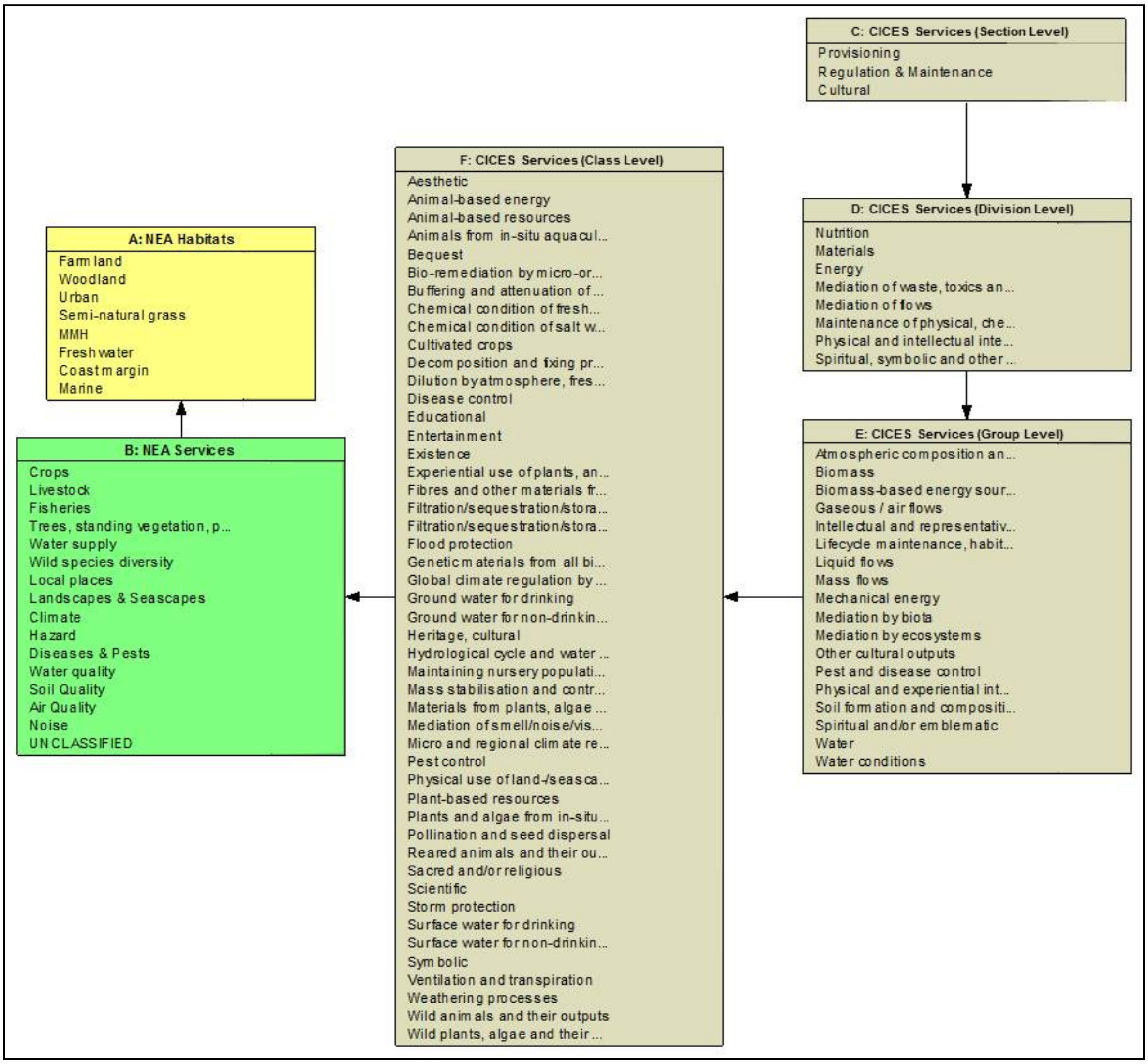

Figure 2. Using nodes in a BBN to illustrate the relationships between different elements of three classifications commonly used in ecosystem services work.

4 Conditional Probability Tables

The BBN is made 'operational' by means of a set of Conditional Probability Tables (CPTs) that underlie each element of the classification (the nodes). These CPTs express the way we believe the elements of the classifications are related to each other and the degree of certainty we have about this, represented as a score.

4.1 Known relationships between component parts of hierarchical classification systems

For a hierarchical classification scheme such as CICES, sub-classes lie wholly within the broader classes of the system. There is therefore a very high level of certainty about how the different hierarchical categories of the service relate to each other, as the relationships are known and are part of the definition of the typology. The certainty at this level is equally split between sub-classes.

4.2 Using scoring and expert opinion to construct the CPTs

The inter-relationships between classifications and sometimes within classifications are not always so certain. In these cases the CPT is constructed using degrees of certainty estimated using expert opinion. Table 1 illustrates an example of this and defines the relationship between the UK NEA habitats and UK NEA ecosystem services. The scores express the relative importance assigned to each NEA habitat for each NEA ecosystem service. For the purposes of generating the BBN the assessment scores have been summed across each ecosystem service and normalised so that they sum to 100. Thus the scores in Table 1 express the probability (according to the strength of belief from the UK NEA experts) that a given habitat is important to a given service.

Table 1. Conditional Probability Table (CPT) of the relationship between NEA Broad Habitats and UK NEA services.

NEA Services	Farmland	Woodland	Urban	Semi-natural grass	MMH	Freshwater	Coast margin	Marine
Crops	59.224	0	0	21.998	0	0	18.778	0
Livestock	30.166	10.055	0	22.409	18.24	0	19.13	0
Fisheries	6.27	0	0	0	0	23.29	23.858	46.581
Trees, standing vegetation, peat	14.378	19.171	16.021	10.681	17.388	17.802	4.559	0
Water supply	15.016	10.01	16.732	16.732	18.158	18.591	4.761	0
Wild species diversity	7.884	14.015	3.904	15.617	12.712	13.014	13.332	19.522
Local places	8.761	15.575	17.355	13.016	10.594	14.462	14.815	5.423
Landscapes & Seascapes	5.599	11.198	8.319	12.478	13.542	13.864	14.203	20.797
Climate	11.25	15	16.714	8.357	13.604	3.482	10.701	20.892
Hazard	10.3	10.3	15.303	11.477	12.456	12.753	13.064	14.347
Diseases & Pests	17.29	11.527	19.266	6.422	5.227	10.703	5.482	24.083
Water quality	7.852	10.47	7.777	15.555	12.661	12.962	13.279	19.444
Soil Quality	11.991	15.988	17.815	13.362	14.501	11.135	15.208	0
Air Quality	11.991	15.988	17.815	13.362	14.501	11.135	15.208	0
Noise	26.463	8.821	9.829	9.829	8	16.382	8.391	12.286
UNCLASSIFIED	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

For example, Table 1 suggests that just under a fifth (17.3%) of the overall provision made by NEA Broad Habitats to the regulating of Diseases and Pests UK NEA Service is considered to come from Farmland. The way these values are depicted in the BBN can be seen in Figure 3, Node A (UK NEA Habitats).

5 Representing and interpreting information in BBNs

Figure 3 shows the BBN representation of the inter-relationships for 'disease control' between the CICES hierarchical classifications (Nodes C, D, E and F), and the UK NEA services (Node B) and NEA habitats (Node A).

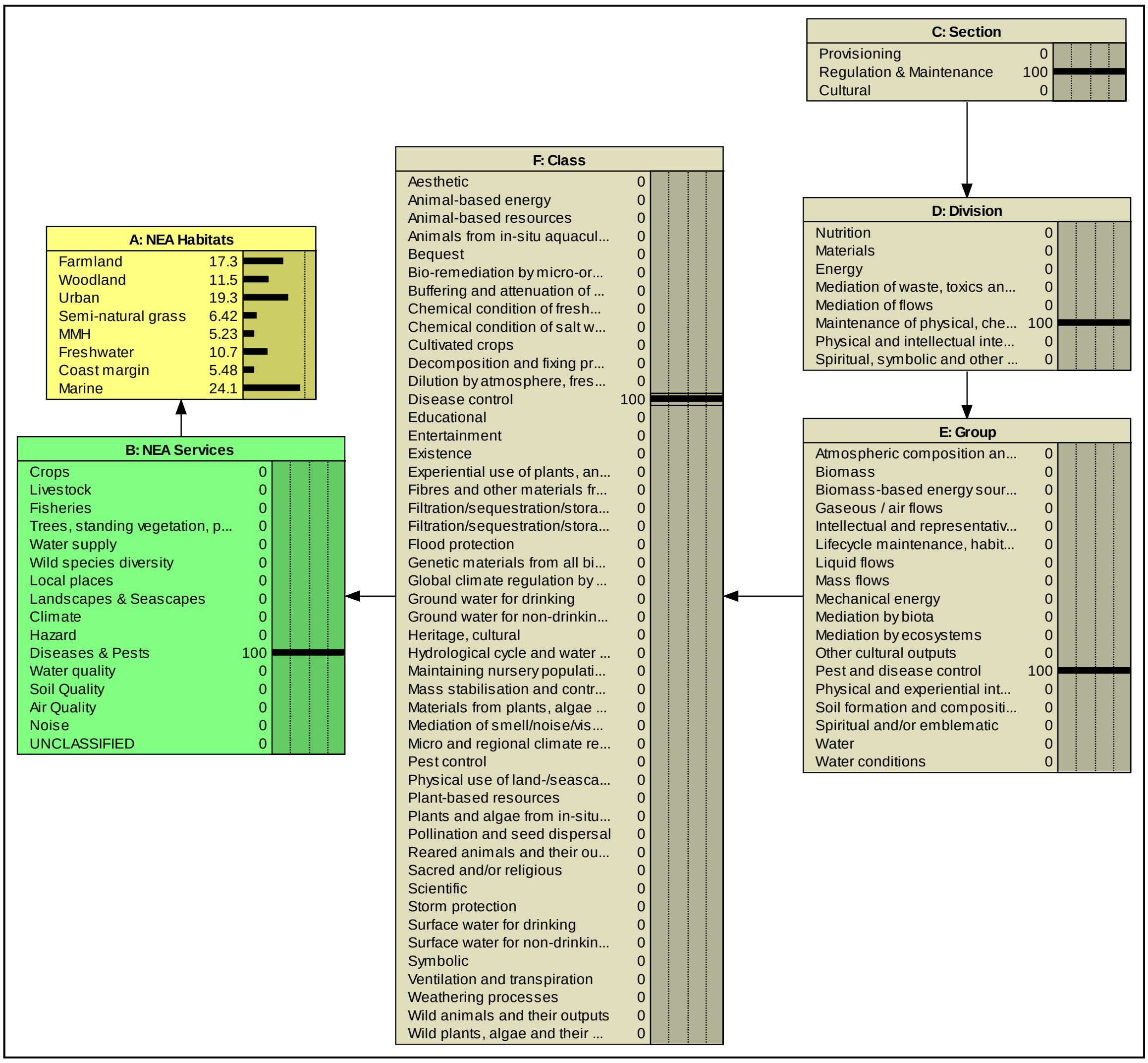

Figure 3. BBN representation of the inter-relationships between classifications, with "disease control" selected to illustrate the relationships.

The considered degree of correspondence is indicated by the black bars within the nodes. Within a classification (e.g. within CICES), the length of the bar is related to the number of relevant sub classes within the main class shown; that is the number of links between the main CICES class and the sub-classes.

It is completely certain (as illustrated by the black bars showing 100% frequency in Nodes B, C, D, E and F) that:

- CICES service 'disease control' (Class level, Node F) is wholly within and related to the CICES service (Group level) 'Pest and disease control' (Node E); and,
- both are wholly within the CICES service (Division level) 'Maintenance of physical, chemical and biological conditions' (Node D); and,

- all three are wholly within the CICES service (Section level) dealing with 'Regulation and Maintenance' (Node C).

Whilst it is completely certain that 'Disease control' (Class level in Node F) is covered by the NEA Service 'Diseases and Pests' (Node B), the way this translates to UK NEA habitats (Node A) is less certain. Expert opinion suggests that all eight habitats are providing disease and pest regulation to a greater or lesser extent with marine habitats considered to have a greater importance and certainty than other habitats (Figure 3).

The relationships between the three classifications are not always so certain and this is illustrated in Figure 4 and Figure 5.

In Figure 4 'Mediation of flows' has been selected at the Division level of CICES classification (Node D). At the more detailed CICES service levels in the classification (i.e. at Group and Class levels, Nodes E and F) more than one type of service is represented, and the certainty at this level is equally split between these. In the context of using CICES we would interpret this BBN as describing that if someone was reporting data on 'Mediation of flows' we believe they are telling us something about some or all of the services at the more detailed levels.

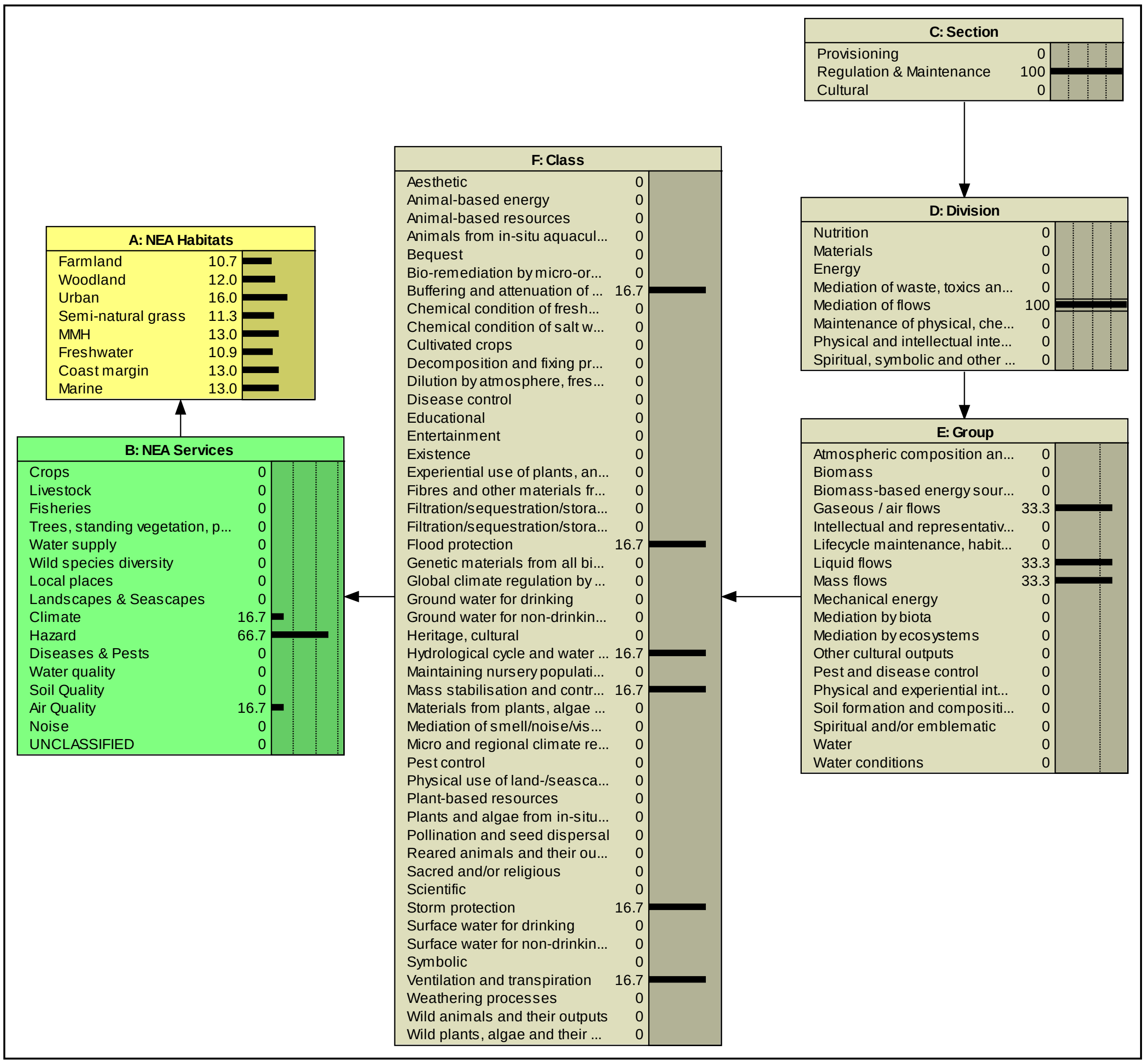

Figure 4. BBN showing how the CICES service (Division level Node D) 'Mediation of flows' relates to other classifications.

The strength of the BBN approach comes when there is less certainty about how classifications relate to each other. In Figure 6 this is illustrated by the relationships between CICES and the service categories used by the UK NEA, and the associate Broad Habitat classification used as the basis of the assessment. Given the rather broad categorisation of services used in the UK NEA there is some aggregation (in comparison with other service classification systems such as CICES) and hence a degree of interpretation about how the services relate to those shown in CICES. More significantly, there is also uncertainty about how important the different UK NEA habitats are to the output of ecosystem services.

The BBNs in Figures 3, 4 and 5 capture the relationships between the UK NEA components and CICES in the links between Nodes F, B and A. Expert judgement has been used to cross tabulate the UK NEA service groups into CICES. For the links between UK NEA services and habitats the results for the national assessment were used, that expressed the importance of each habitat to the output of each service at the UK scale.

On the basis of this link we can then select (Figure 5) a habitat of interest, say woodland, and the network represents the strength of association of the different UK NEA services associated with it and the equivalents in CICES. The BBN shows that for woodland, wild species diversity, local places and landscapes are the most important services according to the UK NEA; the broad equivalents in CICES are also expressed, with the size of the bars on the nodes indicating the strength of association between what we believe the UK NEA categories and CICES to be.

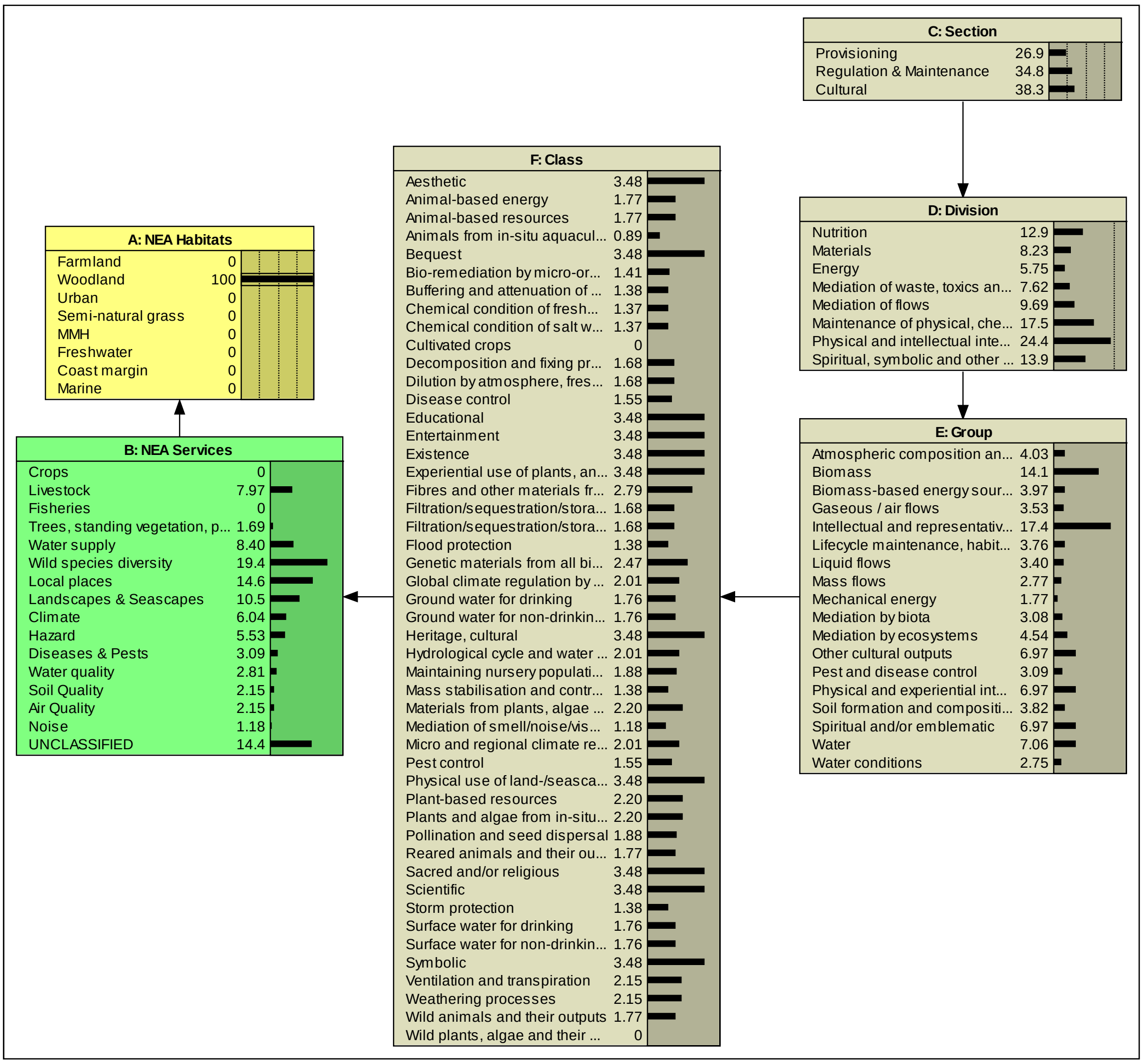

Figure 5. Identification of services associated with the woodland Broad Habitat as defined by the UK NEA.

There are alternative ways that BBNs can be used to represent the relationships between habitat and ecosystem services classifications. Burkhard *et al* (2009) have published a matrix linking the CORINE Level 3 classes to a service typology based on the MA. Unlike other classification systems they included a number of ‘supporting services’ which they took to represent the ‘ecological integrity’ of the system. Figure 6 illustrates the results from preliminary work based on the latter which is based on scoring the strength of the relationship between the different CORINE land cover classes and service output on a six point (0-5) scale. For the purposes of the BBN shown in Figure 6, these service scores were summed across the rows for each land cover type, and the relative strengths that each land cover type made to their output represented by a normalised score calculated from the row total. The habitat category ‘Dry Grasslands’ has been selected from the EUNIS Level 2 categories, and, alongside the equivalents for the other habitat classification systems, the predicted service output outputs according the UK NEA and the Burkhard *et al* (2009) typologies are shown.

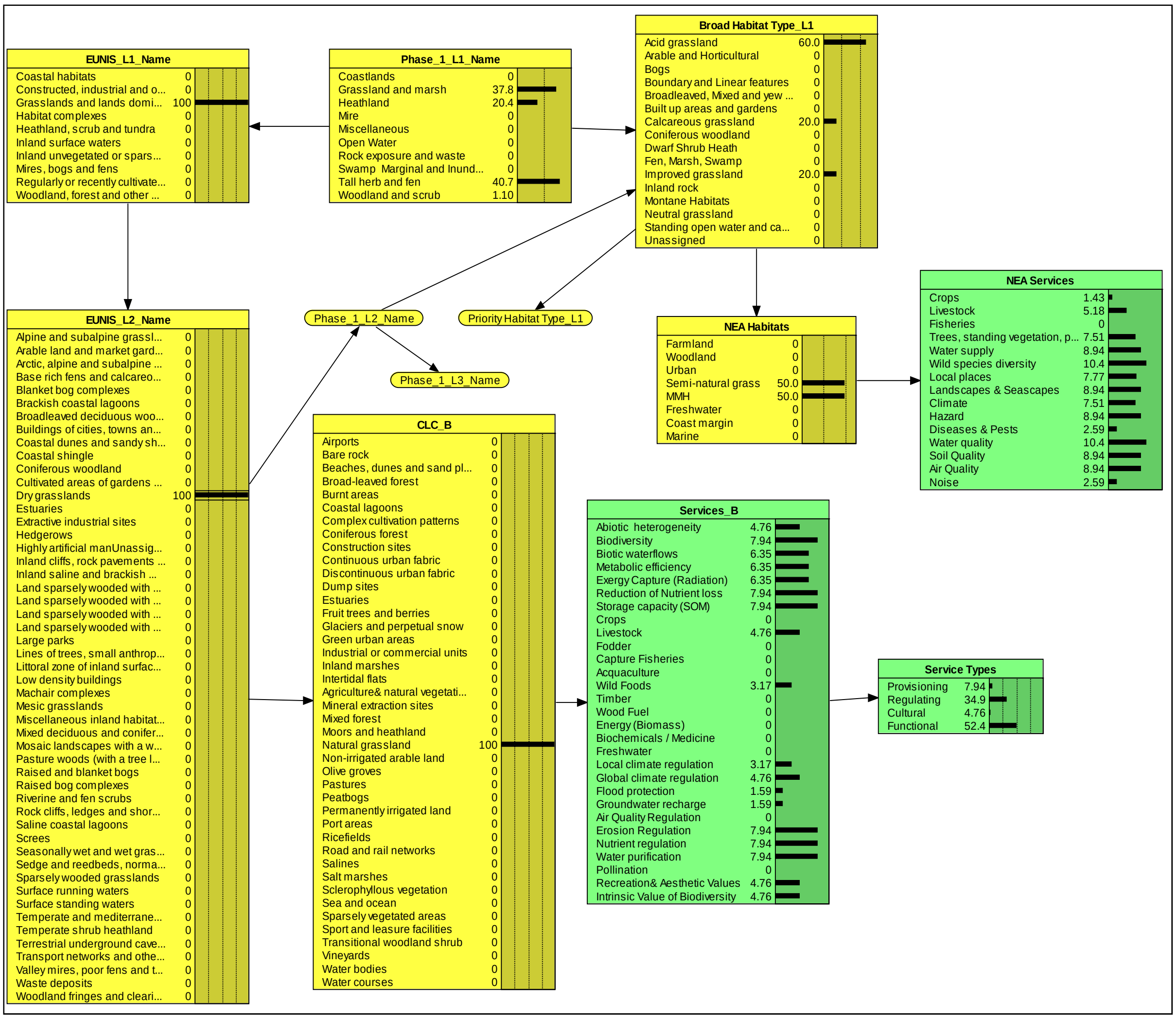

Figure 6. Linking habitat classifications to ecosystem services.

During the preliminary work, the extent to which this kind of output (Figure 6) can be interpreted by the user has been discussed and it has been suggested that a more simple presence or absence approach might be preferable. The team have therefore experimented with the way the BBN software (Netica) represents data, and the facility to display the 'most probable outcome' comes closest to this requirement.

Figure 7 illustrates how the network shown in Figure 6 would look using the approach based on maximum probability. While the dominance of certain classes is more evident, since the associated probabilities no longer sum to 100% the numbers displayed on the Netica interface are perhaps just as difficult for the user to interpret as simple frequency data. Therefore, we suggest that the maximum probability approach does not address the need for simplicity. Further work is required in order to recommend a suitable way forward, given the current limitations of the software.

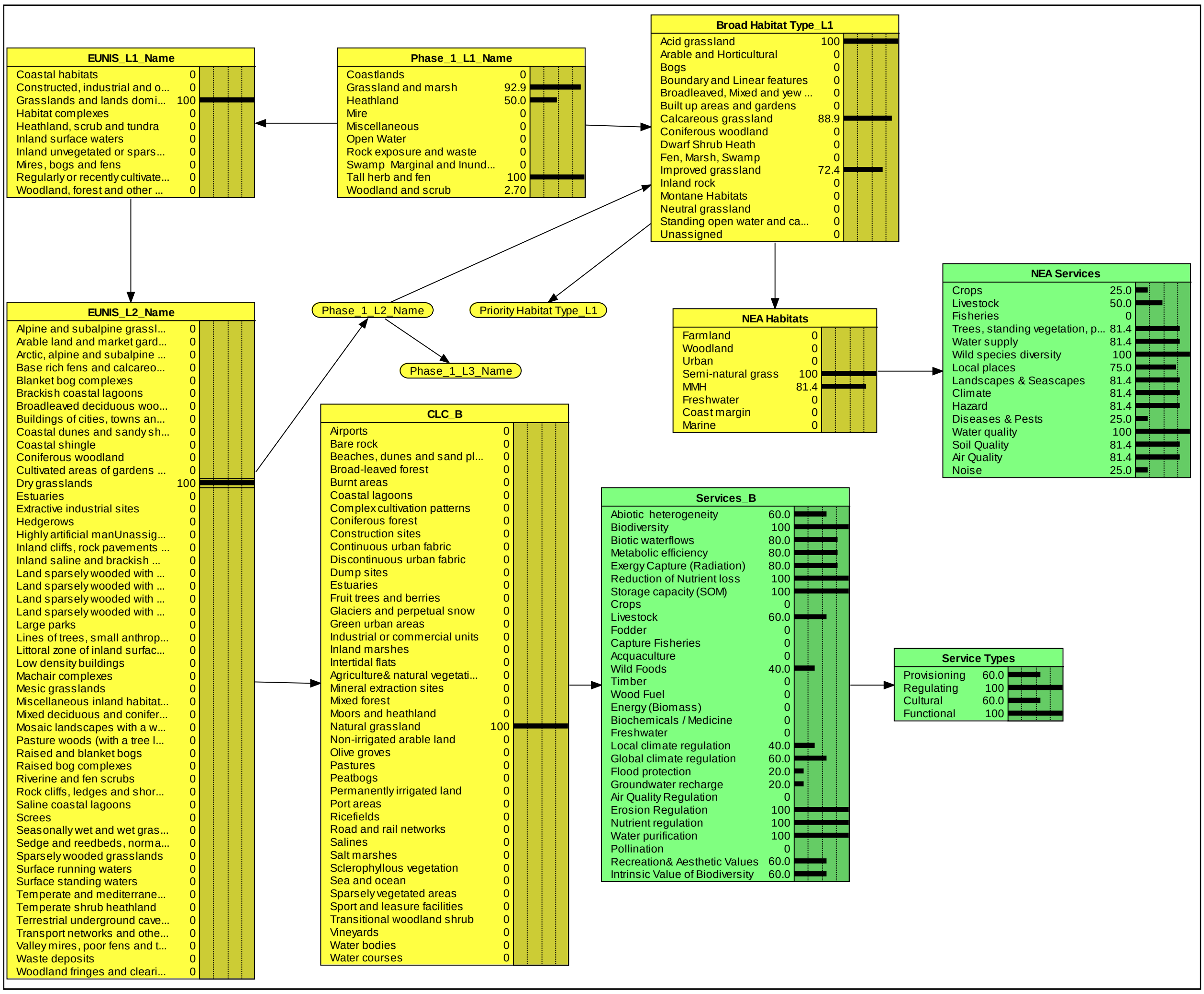

Figure 7. Displaying relationships in BBN using maximum probability approach.

The association of habitats and service outputs is one of the most challenging aspects for this project, and further work is required to make this as robust as possible. While published sources can be a helpful guide, those based on expert judgement are difficult to use because of the lack of transparency often associated with them. Alternative work is currently underway to examine whether a set of generalised biophysical characteristics can be used to predict service output for different types of habitat.

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