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A decision framework to attribute atmospheric nitrogen deposition as a threat to or cause of unfavourable habitat condition on protected sites

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This report describes the development of a decision framework to provide a means of attributing nitrogen deposition as a threat to, or cause of, unfavourable habitat condition on protected sites. It does not commit the country conservation bodies to implement the framework. Responsibility for the policy as regards to whether, or how, to implement the framework rests with the country conservation bodies.

Summary

The UK's semi-natural habitats exceed their atmospheric nitrogen (N) deposition critical load ranges across much of their area, and survey data suggests there are adverse impacts of this excess N deposition. However, information from Common Standards Monitoring (CSM) of protected sites does not appear to identify N deposition as a potential cause of unfavourable condition at many sites.

A decision framework was developed to provide a means of attributing N deposition as a threat to, or cause of, unfavourable habitat condition on protected sites. The framework provides a practical methodology for assessing the impacts of N deposition on protected sites in an objective way, which was previously lacking. It is based on a sound conceptual approach, and is both robust and flexible enough to cope with additional information. The framework is described in this main report, whilst the detailed methodology is included in supporting Annexes.

The framework incorporates both national/theoretical information (Factor 1 score) and site-based information (Factor 2 score). Factor 1 produces an Exceedance Score for a given site and habitat type. This summarises national/theoretical evidence that N deposition is likely to be resulting in unfavourable habitat condition. It takes into account the amount of N deposition at the site, together with a measure of certainty around that deposition, and how this relates to the habitat critical load range and certainty around this range. Factor 2 summarises information from CSM assessments and other site-based information on N deposition impacts. A final assessment matrix combines the outcomes of Factor 1 and Factor 2 scores to produce an overall assessment of whether N deposition is likely to be a threat to or cause of unfavourable habitat condition, either currently and/or in the future.

The framework has a number of strengths:

- it provides a clear and logical basis to attribute atmospheric N deposition as a threat to or cause of unfavourable habitat condition;
- it can be systematically updated when new evidence becomes available for specific habitats, without altering the conceptual approach; it incorporates uncertainty in N deposition, in the empirical N critical loads, and in the cross-matching process required to allocate proxy critical loads for relevant habitat types;
- during its development, the potential for CSM targets to be used as indicators of N deposition impact was thoroughly evaluated using a standardised and quality controlled methodology; and
- a cross-matched set of proxy critical loads was created for each CSM habitat, together with a measure of the uncertainty in that cross-matching process.

There are also a number of limitations or deficiencies to the framework:

- the uncertainty in national N deposition models is poorly quantified;
- there is a basic requirement for greater knowledge about N impacts in additional habitats which can only be achieved by new experimental work and/or well-designed gradient studies;
- the CSM assessment process was not designed for detecting N deposition impacts, so the vast majority of CSM targets either do not describe ecosystem components sensitive to N deposition, or are worded such that any impacts cannot be reliably attributed to N;
- as a result, there are very few useable strong N indicators, only a small number of habitats with one or more strong N indicators, and many habitats have no useable N indicators at all – the framework is therefore more useful for some habitats than others;

- many CSM targets have been re-worded at a country- or site-level – whilst this may not affect the CSM process for monitoring habitat condition, it reduced their utility in detecting N deposition impacts in a consistent way;
- evaluation of sites with known N deposition issues clearly showed some limitations of the CSM process in detecting N impacts – the main problem seemed to be the lack of sensitivity of CSM targets, because they were not designed for that purpose.

Based on these findings a number of **key recommendations** were made:

- there is a need to improve quantitative estimates of the uncertainty in wet and dry oxidised and reduced deposition;
- critical loads are not available for some CSM habitats and for others there is a low certainty in the assignment of the critical load because of poor correspondence between CSM and the EUNIS class for which a critical load is established. Experimental and/or survey work is recommended to establish critical loads for habitats which carry the greatest uncertainty;
- the ability of CSM to detect N deposition impacts at sites would be improved if new N-focused targets were designed, that could be applied across the UK without modification at the site-level;
- further analysis of existing survey and experimental data would better relate observed damage to conservation objectives to N deposition, and would guide development of new N-focused targets;
- incorporation of more information about confounding factors should improve the ability to confirm or rule them out as the cause of unfavourable condition, rather than N deposition;
- further consideration is needed on how to apply the framework given the different assessment approaches taken in England, Wales, Scotland and Northern Ireland, and how to automate the process.

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1 Introduction

The UK's semi-natural habitats exceed their nitrogen (N) deposition critical load ranges across much of their area, and survey data across a variety of habitats suggests there are adverse impacts of this excess N deposition. This evidence includes targeted surveys which specifically test whether there is an impact of N deposition (e.g. Field *et al* 2014), and data from non-targeted national monitoring schemes such as the UK Countryside Survey (Carey *et al* 2008) which also shows impacts of N deposition on species richness (Maskell *et al* 2010). However, information from Common Standards Monitoring (CSM) of protected areas under-reports the impacts of nitrogen deposition and rarely identifies N deposition as a contributory cause of unfavourable condition (e.g. Williams 2006). One reason for this is that CSM guidance was not designed to attribute potential N impacts, and there is no guidance on how to distinguish between possible N impacts and effects caused by other drivers which may produce similar symptoms. There may also be a lack of awareness among site managers and those carrying out and interpreting CSM monitoring data of the widespread nature of N impacts, and a lack of awareness of the type of observations that would indicate impacts due to N deposition.

To help address this issue, a decision framework was developed to assess whether N deposition is likely to be a cause of unfavourable condition or a future threat. This incorporated both national/theoretical information and site-based information.

1.1 The process for developing the decision framework

The decision framework was principally developed through a research contract, commissioned by JNCC. This built on a draft decision framework developed by an inter-agency group led by JNCC.

The research contract had six main objectives:

i. to develop a practical and straight-forward decision framework based on a matrix that combines the strength of (a) national and theoretical evidence, with (b) site-based evidence;
ii. to provide specific data to be used in the decision framework, for example where this can be pre-populated in a spreadsheet;
iii. to establish criteria for setting potential indicators of N deposition impacts within terrestrial habitats CSM guidance and, subsequently, identifying CSM targets which are potential indicators of N deposition;
iv. to trial the decision framework to test and demonstrate it;
v. to respond to comments from an internal and external peer review and revise the decision framework and/or supporting documents to address these comments;
vi. to finalise the decision framework, provide guidance on its application and provide the pre-populated data.

The final matrix recommended by the contractors, which defined the outcomes of the decision framework, was subsequently modified by JNCC following a review process by the Statutory Nature Conservation Bodies (SNCBs) (see section 1.3).

1.2 Overview of the decision framework

The decision framework consists of two components which are combined to produce an overall outcome as to whether N deposition is considered to be a threat to, or cause of, unfavourable habitat condition on a protected site (see Figure 1). These two components are: the **national/theoretical evidence** that a Habitat Feature is being affected by N deposition which results in an Exceedance Score (Factor 1 score), and the **site-based evidence** that there are discernible impacts of N deposition on the Habitat Feature which results in a Factor 2 score. These components are brought together in a matrix to provide an overall assessment (see Figure 1).

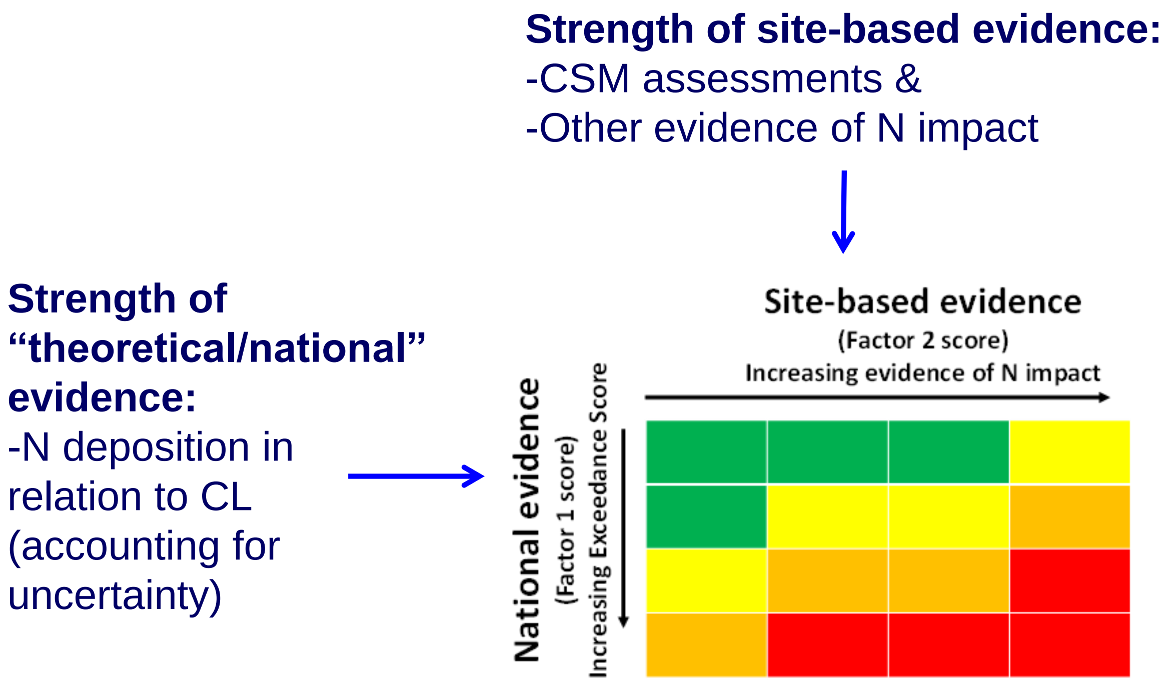

Figure 1. Simple schematic of the decision framework.

1.3 Overview of Report Structure

The following sections of this report provide a description of the decision framework and a brief overview of Factor 1 and Factor 2 scoring. Annexes 1 and 2 provide a detailed technical rationale for the scoring system for Factors 1 and 2 respectively, based on the relevant work packages (WP) of the research contract.

Section 4.1 provides a description of the matrix of the decision framework and describes the outcomes. A detailed rationale is given for these outcomes in section 4.2. Since the final matrix was modified from the version recommended by the contractors, an explanation is provided to support these changes (section 4.2.5). Furthermore, for transparency, the matrix recommended by the contractors and their supporting rationale are presented in Annex 3.

Box 1 explains the report sections and inter-linkages in more detail and serves to sign-post the reader to the relevant Annexes and associated spreadsheets where more information is required. It also serves to distinguish which parts of the report are based entirely on contractors' report and which parts have been subject to amendment by JNCC.

Box 1

- **Main Report:** this provides a description of the final version of the decision framework as agreed by the SNCBs together with conclusions and recommendations; it is based largely on the final contract report submitted by the contractors; an additional section (written by JNCC) has been added to provide a rationale for the outcomes in the final version of the decision framework matrix and to explain the reasons why this was changed from that recommended by the contractors.
- **Annex 1:** this describes in detail the scoring of national/theoretical evidence to derive an Exceedance Score (Factor 1); this Annex is the WP1 report submitted by the contractors.
- **Annex 2:** this describes in detail the site-based evidence used to derive a score for strength of site-based evidence (Factor 2); this Annex is the WP2 report submitted by the contractors.
- **Annex 3:** this describes the version of the matrix as recommended by the contractors, provides recommendations for future work (the key recommendations from this are summarised in this main report), and briefly describes the testing undertaken as part of WP3 (results are not presented in full from the testing because it was based on an earlier prototype of the matrix).
- **Factor 1 Spreadsheet (Exceedance Score):** this is a spreadsheet incorporating the elements of WP1 which generates the exceedance score for each CSM habitat (and sub-habitat) based on a user defined deposition; guidance for utilising the spreadsheet is given in Annex 1.
- **Factor 2 Spreadsheets (N indicators):** these spreadsheets display the results of a review of all targets for each CSM habitat and the identification of strong and weak N indicators; guidance for the spreadsheets is given in Annex 2.

1.4 Evidence Quality Assurance

This project was subject to the JNCC Evidence Quality Assurance (EQA) Policy (JNCC 2014). A Project Audit Document (PAD) was used to record the EQA measures applied to the project. The project was overseen by a Steering Group comprising representatives of the contractors, JNCC and the Country Conservation Bodies. Draft versions of the contract report were subject to independent external peer review and review by the Steering Group. Amendments were made to address the reviewers' comments.

There was a further review of the matrix and supporting justification by the SNCBs following the submission of the final report by the contractors. As explained in section 1.3, this resulted in some further refinements.

2 Strength of "theoretical/national" evidence, producing an Exceedance Score (Factor 1 score)

2.1 Overview

This component provides an Exceedance Score which summarises the national/theoretical evidence that N deposition will lead to unfavourable condition of a habitat at a site. This score summarises the amount of N deposition in relation to the matched critical load for a CSM habitat/feature, and takes into account uncertainty in both the N deposition and the process of deriving a critical load for each CSM habitat/feature.

The three main sources of uncertainty in this process are illustrated in Figure 2, and described in full in Annex 1:

- *the first source of uncertainty* is around the amount of N deposition which a CSM feature is exposed to, discussed in WP1.1.
- *the second source of uncertainty* has two components:
    i. the reliability of the defined critical load ranges (from Bobbink & Hettelingh 2011), described in WP1.2B;
    ii. UK evidence in the context of the wider international evidence, which together indicate that a CSM habitat may be more- or less- sensitive to N than the cross-matched critical load suggests – this is covered in WP1.2C.
- *the third source of uncertainty* lies in whether the critical load being used for a CSM habitat accurately reflects its N sensitivity – this also comprises two elements, which are described in WP1.2A:
    i. the cross-matching process to align CSM habitats with EUNIS categories;
    ii. the cross-matching process which allocated proxy critical loads at the EUNIS level to the CSM-EUNIS matched habitats.

The components and their uncertainty are combined as illustrated schematically in Figure 3. The N deposition and its uncertainty are used to calculate the likely N deposition range, while other components capture the uncertainty around the critical loads. This is described in full in Annex 1, see sections for WP1.

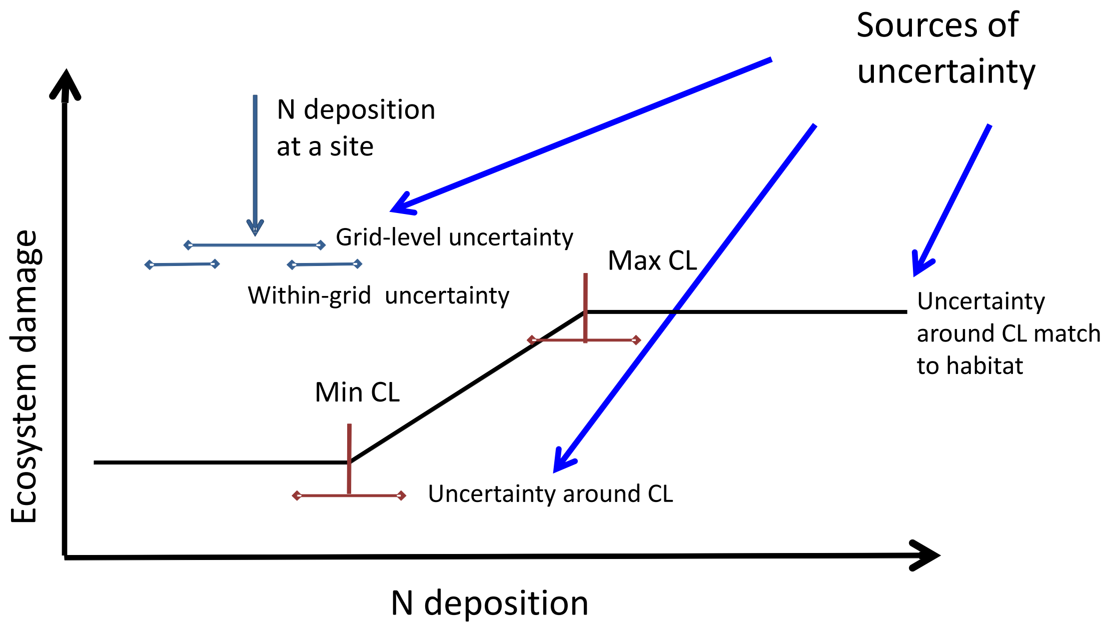

Figure 2. Schematic illustrating the three main sources of uncertainty in deriving an overall Exceedance Score by comparing N deposition with a critical load range. Black line symbolises ecosystem damage as N deposition exceeds the critical load (CL). Grey-blue lines represent N deposition and its associated uncertainty. Brown lines indicate CL bounds: Min CL = minimum of the critical load range, Max CL = maximum of the critical load range. Bright blue lines point out sources of uncertainty. The *y* axis “ecosystem damage” refers to an increasing chance of significant adverse impacts from N on any individual site throughout critical load range.

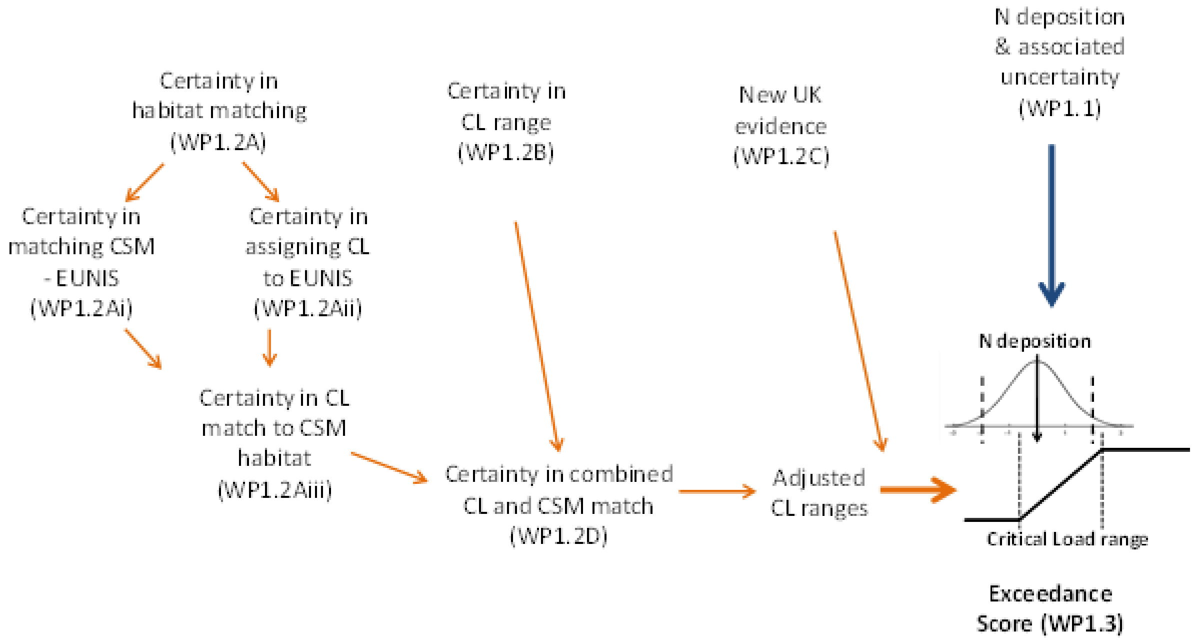

Figure 3. Schematic illustrating how the components of WP1 (Annex I) are combined to produce an Exceedance Score that summarises the degree to which a CSM habitat exceeds the critical load (CL) for N at a particular site, given the sources of uncertainty.

2.2 Calculation of the Exceedance Score

The N deposition, including its 95% Confidence Interval, is assessed against the adjusted critical load range to calculate different classes of Exceedance Score, as explained in Table 1 and Figures 4 and 5.

Table 1. Description of Exceedance Score classes based on N deposition relative to the critical load range. These are illustrated in Figure 5.

Exceedance Score	Description
Very Low	The full deposition range, including 95% confidence intervals falls entirely below the minimum critical load.
Low	The specified deposition value falls below the minimum critical load, but the upper confidence interval lies somewhere between the minimum and the maximum critical load.
Medium-Low	Both the specified deposition value and the upper confidence interval lie between the minimum and the maximum critical load, but the lower confidence interval is lower than the minimum critical load.
Medium	The deposition range, including the upper and lower 95% confidence intervals lies between the minimum and maximum critical load.
Medium-High	The specified deposition value lies below the maximum critical load, while the upper confidence interval lies above the maximum critical load. The position of the lower confidence interval is not important in this outcome.
High	Both the specified deposition value and the upper confidence interval lie above the maximum critical load.
Very High	The full deposition range, including 95% confidence intervals lies entirely above the maximum critical load.

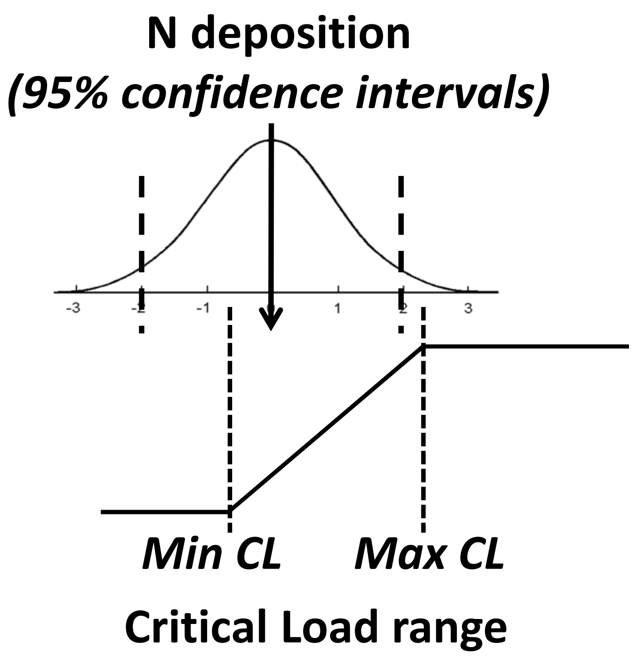

Figure 4. Illustration of how the Exceedance Score uses information on the quantity of N deposition, including associated uncertainty quantified as 95% confidence intervals (upper part of diagram), relative to the critical load range (lower part of diagram). The positions shown represent those for the Medium-Low Exceedance Score class in Table 1 and Figure 5.

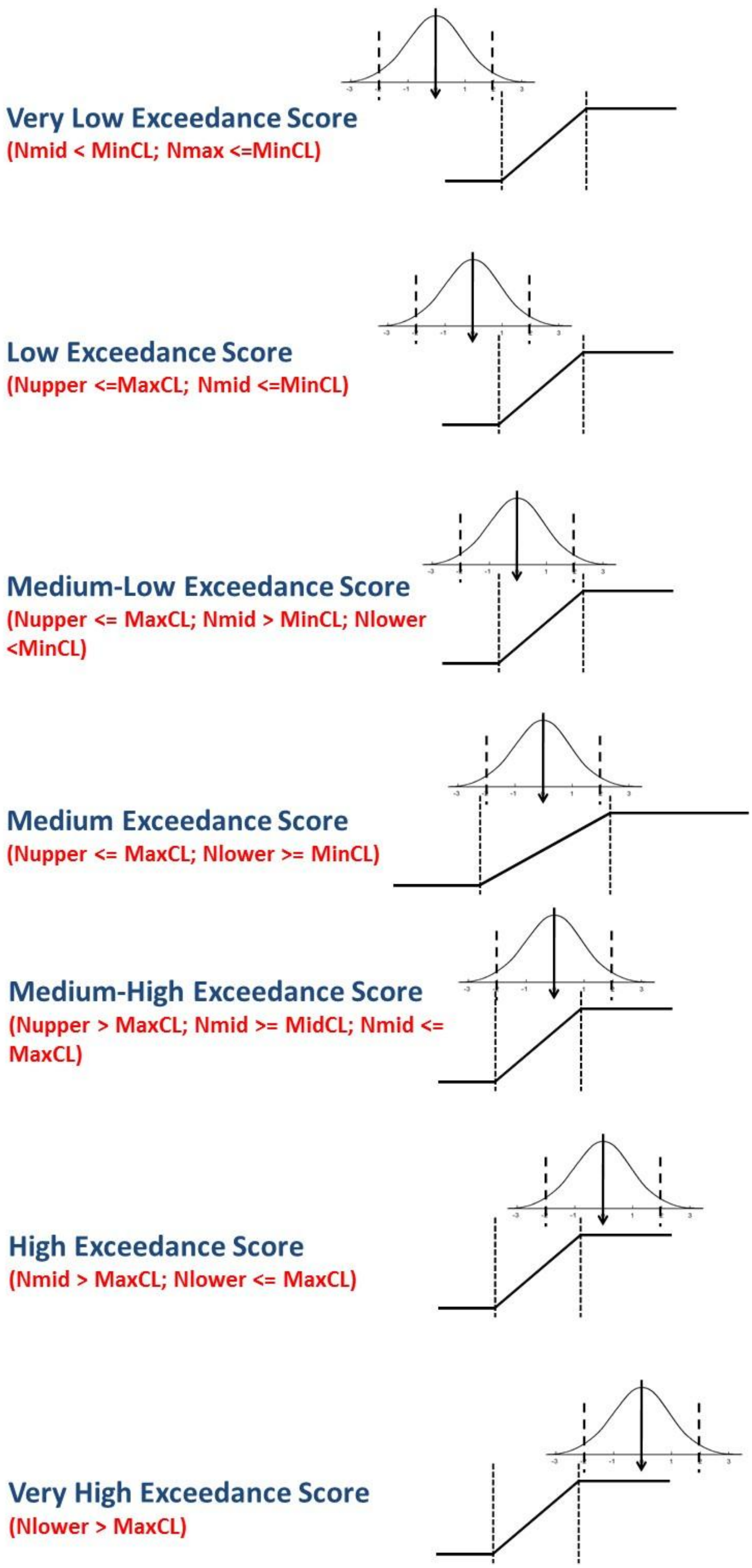

Figure 5. Illustration of the Exceedance Score classes. These reflect differences in the N deposition range relative to the N critical load range and are described in Table 1 (see Figure 4 for a description of the graphic).

3 Strength of site-based evidence (Factor 2 score)

The Factor 2 score summarises the strength of site-based evidence to determine whether the condition of a habitat feature is, or is not, being adversely impacted by N deposition. The approach is based mainly around using attributes and targets within CSM guidance to identify features or sites showing impacts consistent with those of excess nutrients, and to consider the confidence in whether this is driven by N deposition (rather than, or in addition to, other factors e.g. other sources of nutrients or management factors). The site-based evidence can also incorporate other sources of information such as reports, monitoring and scientific studies.

3.1 Overview of approach

Evidence from CSM and/or other sources can be combined to form eight outcomes in terms of interpreting N impacts in the context of other potentially confounding factors (Table 2).

Table 2. Framework to summarise the strength of site-based evidence that N deposition is the cause of adverse impacts on the condition of a habitat. The categories reflect: (i) the quality and how widely the interpretation of evidence is agreed upon (evidence strength); (ii) the likelihood that habitat condition is unfavourable due to N deposition impacts, rather than due to confounding factors.

Category	Description
Strong	Site-based evidence of adverse N deposition impacts is strong – impacts clearly due to N deposition rather than confounding factors – very likely that habitat condition is unfavourable due to N deposition impacts
Moderately strong	Site-based evidence of adverse N deposition impacts is moderately strong – some strong indicators of possible N deposition impacts which are weakly confounded – likely that habitat condition is unfavourable due to N deposition impacts
Moderate	Site-based evidence of adverse N deposition impacts is moderate – some strong indicators of possible N deposition impacts which are strongly confounded – moderately likely that habitat condition is unfavourable due to N deposition impacts
Weak	Site-based evidence of adverse N deposition impacts is weak – some weak indicators of possible N deposition impacts which are weakly confounded – it is possible that habitat condition is unfavourable due to N deposition impacts but evidence is weak
Very weak	Site-based evidence of adverse N deposition impacts is very weak – some weak indicators of possible N deposition impacts that are strongly confounded – unlikely that habitat condition is unfavourable due to N deposition impacts
No evidence	No site-based evidence of N deposition impacts – no possible influence on the assessment of site condition
Weak evidence for no N impact	Site-based evidence for NO adverse N deposition impacts is weak – some weak indicators of possible N deposition impacts, but these show no adverse impacts– quite unlikely that habitat condition is being impacted by N deposition impacts
Moderate evidence for no N impact	Site-based evidence for NO adverse N deposition impacts is moderately strong – some strong indicators of possible N deposition impacts, but these show no adverse impacts– unlikely that habitat condition is being impacted by N deposition impacts

3.2 Evidence from CSM assessments

For the CSM assessments, potential indicators were identified among the existing targets described in the CSM guidance. These are scored '2' for a strong indicator of N deposition impact, '1' for a weak indicator of N deposition impact or, '0' if the target cannot be used to indicate potential N deposition impact. For each of the targets which is a strong or a weak N indicator, the target is also scored for the likelihood that target failure could be due to confounding factors which produce a similar ecological response to N deposition. This methodology is described in full in Annex 2 and the scoring of CSM targets is presented in N indicators spreadsheets.

The assessment of the strength of evidence that could be derived from CSM Habitat Feature assessments is based on whether the strong or weak Indicators pass or fail and the extent to which they are confounded (i.e. confounding factors weaken the confidence that it is N deposition which is driving target failure). Greater weight of evidence was given to targets which had strong N indicators, so if any strong N indicator failed, that was considered a greater weight of evidence than failure of multiple weak N indicators. Further details are provided in Annex 2.

3.3 Use of other site-based evidence

This assessment feeds into the Factor 2 score to increase the confidence that N deposition is, or is not, impacting on the condition of a Habitat Feature, according to the outcomes described in Table 1 above. Such evidence could be used in the absence of information about N deposition impacts from a CSM site condition assessment, or it could be combined with this to increase the evidence-base. It could include additional evidence from more technical, targeted N-focused surveys or site-based studies on aspects potentially relevant to N deposition impacts, such as the lichen monitoring guide[1]. It is envisaged that this component of the evidence-base will only be available occasionally, and will not be routinely applied to all sites. This is described in detail in WP2.2 of the Annex 2 report.

It is not possible to provide a prescriptive method on how to combine evidence from other sources with that from CSM assessments, because the forms of evidence and strength of evidence can vary considerably. However, some general guidance is provided.

The combined evidence should be assessed within the framework outlined in Table 2. In most cases, site-based evidence should either confirm an outcome from the CSM assessments or, if the evidence is deemed strong enough, could be used to over-ride an outcome from CSM, by adding to the weight of evidence that N-deposition, or alternatively confounding factors, are responsible for poor site condition. The simplest approach is to take the score resulting from the stronger evidence. However, in many cases it will be necessary to compare across all the forms of evidence available and come to a value judgement within the framework outlined in Table 2 what the resulting outcome should be.

[1] http://www.apis.ac.uk/nitrogen-lichen-field-manual

4 Final assessment matrix

4.1 Description of the matrix

A final assessment matrix (see Table 3) was created so that a series of final outcomes could be generated based on the combined strength of evidence from:

(i) national-theoretical evidence – as represented by the Exceedance Scores (see Annex 1, Figure 10), which summarises the degree to which the critical load for a habitat is likely to be exceeded; and
(ii) site-based evidence (where available) of N deposition impacts on habitat condition – as provided by a CSM assessment (see Annex 2 section 4) or additional evidence sources (see Annex 2 section 5).

The matrix contains a set of cells representing different combinations of Exceedance Scores and strengths of site-based evidence. An additional row was created to cater for those habitats that had no critical load assigned to them (and therefore no Exceedance Score) but which are likely to be sensitive to nitrogen deposition. Five final outcome categories were identified. These were colour-coded from blue, green, through yellow and orange, to red, to reflect increasing strength of evidence that N deposition is likely to be adversely impacting and/or posing a threat to current and future habitat condition. A description of the outcomes can be found in the Table 4 and a rationale for these outcomes presented in Section 4.2.

Table 3. The final assessment matrix. This combines the strength of evidence from: (i) national-theoretical evidence as represented by a series of Exceedance Scores (left-hand column), which summarise the degree to which the N critical load for a habitat is likely to be exceeded (see Figure 5); and (ii) site-based evidence (where available) that N deposition is impacting on the condition of a habitat (top row), as provided by a CSM assessment (see Table 2) or additional sources. The bottom row is for habitats with no assigned N critical load but which are potentially sensitive to N deposition impacts and which have no Exceedance Score. The meaning of the coloured cells is explained in Table 4.

Exceedance Score	**←Strength of site-based evidence that N deposition *is not* causing adverse impacts**		**No site-based evidence**	**Strength of site-based evidence that N deposition *is* causing adverse impacts →**				
	Moderate	Weak		Very weak	Weak	Moderate	Moderately strong	Strong
Very low								
Low								
Medium-low								
Medium								
Medium-high								
High								
Very high								
No critical load								
No Exceedance score		**Not possible to assess**	**Not possible to assess**	**Not possible to assess**	**Not possible to assess**			

Table 4. Explanation of the outcome categories as described by the coloured cells in Table 3

Blue outcome category (no threat)	**Description**
Most likely impacts on habitat condition	• Habitat condition and recovery are <u>not being adversely impacted</u> by N deposition, <u>nor are they currently under threat</u>
Site condition categorisation	• Condition and trend as assessed by CSM or other means remains unaltered
Action	• Does not require action to reduce N deposition impacts
Future prospects	• If current levels of N deposition continue, habitat expected to remain unaffected by N deposition.

Green outcome category (threat)	**Description**
Most likely impacts on habitat condition	• Habitat condition and recovery are not currently being adversely impacted N deposition, but this does represent a low-medium level of threat
Site condition categorisation	• Condition and trend as assessed by CSM or other means remains unaltered; N deposition recorded as a threat
Action	• May require additional action to reduce N deposition impacts (remedies); would benefit from deposition reduction at national or site-level
Future prospects	• If current levels of N deposition continue, habitat condition will remain under threat unless effective remedies to reduce N deposition impacts are put in place • If such remedies are put in place, this will reduce current impact and potentially reduce or eliminate the level of threat

Yellow outcome category (high threat)	**Description**
Most likely impacts on habitat condition	• Habitat condition and recovery are being impacted by N deposition - although this is not sufficient to cause unfavourable condition or prevent recovery, it does represent a high-level of threat
Site condition categorisation	• Condition and trend as assessed by CSM or other means remains unaltered; N deposition recorded as a high threat
Action	• Requires additional action to reduce N deposition impacts (remedies); would benefit from deposition reduction at national or site-level • Country Conservation Bodies may choose to investigate some sites further, for example where Exceedance Score is medium-high and where national and site-based evidence appears in conflict.
Future prospects	• If current levels of N deposition continue, habitat condition will remain under high threat unless effective remedies to reduce N deposition impacts are put in place • If such remedies are put in place, this will reduce current impact and potentially reduce or eliminate the level of threat

Orange outcome category (not recovering)	**Description**
Most likely impacts on habitat condition	• Habitat condition <u>is either: (i) already being adversely impacted</u> by N deposition, such that it is <u>unable to recover/improve</u> (i.e. not recovering/improving); or (ii) if currently favourable, set to become <u>unfavourable in the</u>

	foreseeable future
Site condition categorisation	• Condition as assessed by CSM or other means may be favourable or unfavourable, but the trend in condition should be set as not recovering/improving (i.e. no change or declining).
Action	• Requires action to reduce N deposition impacts at national or site-level (remedies); would benefit from deposition reduction at national or site-level • Country Conservation Bodies may choose to investigate some sites further
Future prospects	• If current levels of N deposition continue, habitat condition will not be able to recover or improve and will become unfavourable in the foreseeable future (unless effective remedies to reduce N deposition impacts are put in place)

Red outcome category (unfavourable no change)	**Description**
Most likely impacts on habitat condition	• Habitat condition has already been and will continue to be adversely impacted by N deposition
Site condition categorisation	• Condition should be set as unfavourable and condition trend should be set as no change (or declining if there is evidence from CSM that it is declining)
Action	• Requires action to reduce N deposition impacts at national or site-level (remedies); would benefit from deposition reduction at national or site-level • Country Conservation Bodies may choose to investigate some sites further
Future prospects	• If current levels of N deposition continue, habitat condition will remain unfavourable and not able to recover (unless effective remedies to reduce N deposition impacts are put in place)

4.2 Rationale and approach to the categorisation of cells within matrix

4.2.1 General outline of approach

To decide where the different coloured outcomes should be positioned in the matrix (Table 3), it was necessary to consider the links between critical load exceedance, habitat condition, and the conservation objectives for a habitat. It was also necessary to consider the uncertainties and burden of proof required that N deposition is, or is not, causing unfavourable condition or is a future threat to condition. This was a complex area that required careful consideration. It is considered in full in section 4.2.2.

To start the process, the column labelled “no site-based evidence” (Table 3) was used as an initial benchmark, given that the strength of evidence in this column was based solely on the Exceedance Score. The four key transitions, between the blue-green, green-yellow, yellow-orange and orange-red outcomes, were positioned with reference to: (i) the description of impacts of N deposition on habitat condition and the overall nature conservation objectives (see section 4.2.2); and (ii) the visual representation of Exceedance Scores (see Figure 5). Section 4.2.3 explains how the different coloured outcomes were positioned. Having decided on the final outcomes for the “no site-based evidence” column, the next step was to decide what effect site-based evidence should have. This is explained in section 4.2.4.

As explained in previous sections, the matrix presented here has been modified from that recommended in the research contract (see Annex 3). Section 4.2.5 summaries the differences and the reason for the changes.

4.2.2 Interpreting the Exceedance Scores

The key points taken into account in interpreting the Exceedance Scores in the context of condition assessment and conservation objectives are set out below (see also Annex 1 section 5.2).

- Critical loads are defined as “*A quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (Nilsson & Grennfelt 1988)*. They can therefore be seen as a measure based on the lowest level of detectable impact. In the case of empirical critical loads for nutrient N, damage to one or more receptors representing ecological structure or function is likely to occur (over time) at any point above the critical load.

- N critical loads are expressed as a range, e.g. 10-20 kg N ha^{-1} $year^{-1}$. This is to reflect (i) variation in the level at which damaging impacts occur from one site to another because of, for example, differences in rainfall, soil pH, management, nutrient limitation); and (ii) uncertainty in the empirical data on which the critical load is set.

- The lower bound of the critical load range represents the point at which adverse ecological impacts on at least one sensitive ecosystem component have been observed in the habitat. The upper bound of the critical load range represents the point above which adverse ecological impacts are likely to occur in the majority of examples of a particular habitat.

- For a collection of habitats that have been well studied in the UK with respect to N (grasslands, bogs, heath, dunes), evidence from national gradient studies shows that impacts (for example on species richness) frequently begin to occur at the lower end of the critical load range and sometimes below it (e.g. Field *et al* 2014; Payne *et al* 2014; Emmett *et al* 2011).

- As N deposition and therefore critical load exceedance increases, the impacts become more severe, and affect a wider range of species and functions.

- Critical loads incorporate an element of response over time, since not all impacts of N deposition occur immediately, and some may be latent or dependent on interactions with other factors. This means that interpreting damage to conservation objectives should not only take into account current visible impacts, but should also consider the latent impacts of excess N deposition above the critical load which has accumulated in the system.

- N-sensitive species are likely to have already been lost, or at least greatly reduced, in high deposition areas. This raises questions about the reference-point used for setting conservation objectives and CSM targets, used in assessing site-based evidence. At some sites, features such as the lichen flora of lowland woods or dwarf-shrub cover of lowland heathland may not be considered important in a context of nitrogen impacts because: (i) the CSM targets do not consider such features; or (ii) the generic CSM targets already accommodate previous N deposition impacts or any locally set CSM targets or thresholds do the same. It is unclear to what extent such N deposition impacts should be accepted, noting that CSM targets are not meant to be set at levels which seek to achieve substantial improvements to features beyond that needed to maintain their biological interest at the time of site selection, apart from in certain circumstances where features were selected with the specific view of improving them to a better state (e.g. degraded raised bogs) (JNCC 2004).

- In at least some cases, there is likely to be a difference between the point at which N deposition starts to cause “ecological damage” (as quantified by the critical load), and the point at which a habitat feature is deemed to be in “unfavourable condition” (as prescribed by the thresholds set for CSM targets). Whilst the critical load is designed to detect the lowest-level of impact, CSM targets tend to accept some degree of impact before failing. In effect, a certain level of damage to the habitat due to N deposition is likely to occur before the thresholds defined in CSM targets fail, even for those targets which have been scored as strong N indicators. However, at this point, N is already accumulating within the vegetation and soil system.

- CSM guidance provides a minimum number of practical attributes and targets for each habitat which allows site condition to be assessed rapidly (JNCC 2004). So a key question is whether the current attributes/targets in CSM fully encompass and comprehensively define the conservation objectives and condition of a particular feature. This seems an unrealistic proposition given that around one third of habitats do not currently have any CSM targets that are considered to be indicators of N deposition impacts, and over two thirds of habitats do not have any strong N deposition indicators. Yet, for many of these habitat types, there is good evidence from the UK and Europe of N deposition impacts on habitat structure (e.g. species richness) and function (e.g. soil processes).

- CSM was developed 10-15 years ago, when there was less awareness and knowledge of N deposition impacts, and it was not designed to specifically consider N deposition as a driver of unfavourable condition in site condition assessment. Although there is scope for further developing CSM targets to incorporate more N indicators, attribution of N deposition as a driver will nearly always be limited by confounding factors. Therefore, Exceedance Scores can serve as a resource efficient proxy for N deposition impacts on habitat features. It recognises that some habitats do not have any strong N indicator targets within CSM, but nevertheless their overall condition and integrity can be impacted by N deposition (e.g. woodlands).

4.2.3 Linking Exceedance Score and site-based evidence to the matrix outcomes

Given the interpretation of Exceedance Scores and site-based evidence described in Section 4.2.2, the challenge when designing the matrix and defining the outcomes was to decide whether, at a particular Exceedance Score, the condition of a feature should be considered unfavourable, future-unfavourable, or only under threat. This was done first for the "no site-based evidence" column based solely on the Exceedance Scores, starting with the unfavourable condition (red) category.

Unfavourable condition (red) category
It was decided that, in the absence of any site-based evidence, this category should apply only where the Exceedance Score was very high, i.e. where predicted deposition was more than double the upper bound of critical load range (see Figure 5). At this level of deposition, available evidence indicated that it was very likely that habitat condition would, and would continue to be, adversely impacted by N deposition such. This would result in the habitat feature classed as in unfavourable condition.

Not recovering, future-unfavourable (orange) category
In this case, rather than N deposition simply equating with unfavourable condition (*cf* red category), it was decided that, in the absence of any site-based evidence, the most likely outcome would be that deposition would: (i) prevent the full recovery of a habitat currently in unfavourable condition; or (ii) result in a habitat currently in favourable condition becoming unfavourable in the future (future-unfavourable).

Looking at the relationship between the N deposition and critical load ranges for the high Exceedance Score (see Figure 5), the deposition range spans the upper bound of the critical load and the specified deposition value exceeds this. Although at this point there is a moderately high likelihood that N deposition exceeds the upper end of the critical load range, uncertainty in the deposition (as shown by the range) means it is possible that only the lower bound of the critical load is being exceeded. It was therefore considered inappropriate to conclude that at a high Exceedance Score, habitat condition would always be unfavourable, only that deposition would very likely prevent full recovery and/or lead to habitat condition becoming unfavourable in the future (unless action is taken).

High threat (yellow) category
For habitats in this category, future condition and habitat recovery were identified as being under threat from N deposition, and the level of threat was assessed as high (unless action is taken in the short-medium term). Any condition assessment carried out under CSM would remain unchanged (*cf* red and orange categories), and this would also not affect how the habitat was classified in terms of future-favourability for EU Habitats Directive reporting purposes. In the absence of any site-based evidence, this category matched best with the medium-high and medium Exceedance Scores, where the deposition range lay above the minimum critical load, but not above the maximum (Figure 5).

Threat (green) category
For habitats in this category, N deposition was again taken to represent a threat to habitat condition, but less so, and over a longer timescale, than the high threat (yellow) category. In

the absence of any site-based evidence, the medium-low and low Exceedance Scores seemed to best match with this category, with deposition very likely being below the upper critical load bound, but above lower bound (Figure 5).

No change (blue) category
This category applied to habitats where condition was very likely not being affected or threatened by N deposition. In the absence of site-based evidence, this matched best with the very low Exceedance Score, where the whole deposition range is below the lower bound of the critical load.

4.2.4 Adjusting the matrix outcomes to take account of site-based evidence

Having decided on the final outcomes for the “no site-based evidence” column (section 4.2.3), the next step was to decide what effect site-based evidence should have (see Table 3). This included where such evidence demonstrated that N deposition is not causing adverse impacts, as well as where it is.

Where this evidence was weak or very weak, it was decided that this was insufficient to influence the outcomes from that assigned in the “no site-based evidence” column. Therefore, the same outcomes were given in these columns for each of the Exceedance Scores.

Only where the weight of site-based evidence was moderate, moderately strong or strong was it decided that this should affect the assigned outcomes. This was done relatively subjectively, with strong evidence having a substantially greater effect than moderately strong evidence, and, in turn, moderate evidence. So, whilst all the outcomes in the strong evidence column were changed to either the red or orange categories, only five changes of a single step each (e.g. blue to green) were made in the moderately strong evidence column, and only two or three changes made to the moderate evidence column.

4.2.5 Justification for modifications to the version of the matrix recommended by the contractors

The matrix agreed by the SNCBs for implementation differed from that recommended by the contractors. The matrix as proposed by the contractors is presented in Annex 3 and can be compared with the final version in Table 3 in Section 4.1. This section explains the differences and the rationale for the changes made. The focus of this explanation is on the matrix column where there is “no site evidence”; the outcomes in other columns follow on from this.

The main change made as a result of the review by the SNCBs was to introduce an additional, fifth outcome category. This involved division of the original yellow category (see Table 1, Annex 3) into a “threat” (green) category and “high threat” (yellow) category, thereby allowing actions to reduce N deposition to be prioritised for habitats that fall into the high threat category.

The positioning of these threat categories in the matrix did not map exactly onto the original yellow category in the contractors’ version of the matrix, i.e. it was not a simple sub-division. In the latter, the orange category (“future unfavourable”) also applied to the “medium high” Exceedance Score in the absence of site evidence. This was because in this situation both the specified deposition and a large part of the deposition range fall within the critical load range (Figure 5); and there is evidence for impacts below the upper (and sometimes the lower) end of the critical load range in some habitats in the UK. Nevertheless, the SNCBs considered this was insufficient to conclude with a high-level of confidence that habitat condition would, in all cases, be “very likely” to become unfavourable in future i.e. the evidence from national surveys of impacts below the critical loads does not mean we have a high confidence that the critical load at an individual site will be at the lower critical load bound.

If a more precautionary approach was taken (for example the Habitats Directive Article 6.3. test of “no adverse effect on integrity”), it would be appropriate to use the lower critical load bound. However, in the current application, the SNCBs have taken a more conservative approach and put more emphasis on exceedance of the upper critical load range when deciding on the position of the boundaries between the yellow-orange categories.

A further consideration is the probable “lag” between the point at which N deposition starts to cause an ecological impact and when this results in unfavourable condition or prevents maintenance (or recovery) of a habitat. To say, in the absence of any strong indicators of N deposition, that a habitat feature at a site is currently unfavourable or will become unfavourable in the foreseeable future (hence not “recovering”), the SNCBs wanted to have a high likelihood of that occurring. In the current context, the burden of proof was orientated towards showing impact, not towards showing no impact.

An additional modification was made to the red outcome category. The contractors recommended that the condition trend for this should always be set as “declining”. The SNCBs raised concerns that often other factors were a cause of unfavourable condition, and these were usually subject to on-site management or other remedial actions. The SNCBs wanted to be able to reflect where management (or other on- and off-site factors) were satisfactory, thus not appearing to penalise site managers or others for matters outside of their control, nor acting to disincentive such action. In response:

- the description of the “red” outcome was changed to “unfavourable-not recovering”, meaning that: (i) the overall condition of a habitat would still be assessed as “unfavourable”; but (ii) the trend in condition would be set as “no change” (rather than “declining), unless it was assessed by CSM as “declining” (in which case it would remain unchanged) (see Table 4);
- it was recommended that the SNCB recording systems should indicate whether the cause of unfavourable condition and/or trend was due to “site management or other non-N deposition factors” or “N deposition from off-site sources”.

5 Conclusions

The decision framework provides a practical methodology for assessing the impacts of N deposition on protected sites in an objective way, which was previously lacking. It is based on a sound conceptual approach, and is both robust and flexible enough to cope with additional information.

5.1 Strengths of the decision framework

The decision framework has a number of strengths:

- it can be systematically updated when new evidence becomes available for specific habitats, without altering the conceptual approach; it incorporates uncertainty in N deposition, in the empirical N critical loads, and in the cross-matching process required to allocate proxy critical loads for relevant habitat types;
- during its development, the potential for CSM targets to be used as indicators of N deposition impact was thoroughly evaluated using a standardised and quality controlled methodology; and

- a cross-matched set of proxy critical loads was created for each CSM habitat, together with a measure of the uncertainty in that cross-matching process.

5.2 Limitations of the decision framework

The decision framework is limited by the availability of national/theoretical information behind the Factor 1 score, in particular:

- the uncertainty in national N deposition models is poorly quantified, both in terms of how that uncertainty varies on a spatial basis across the UK and how it varies at sub-grid scales (i.e. within 5x5km grid cells).
- the process of allocating proxy critical loads for the vast majority of CSM habitats is based on expert judgement and involves varying degrees of uncertainty.

There are further limitations that relate to the site-based evidence, Factor 2 score:

- the CSM assessment process was not designed for detecting N deposition impacts, so the vast majority of CSM targets either do not describe ecosystem components sensitive to N deposition, or are worded such that any impacts cannot be reliably attributed to N should the target fail – as a result, there are very few useable strong N indicators (i.e. targets which can reliably be used to infer an impact of N), and only a small number of habitats have one or more strong N indicators;
- even where there are strong N indicators, these could fail due to some other confounding factor that produces similar ecological responses to N – this means that, at best, CSM will only provide moderately strong evidence that N deposition is or is not impacting on a habitat;
- where there are no N indicators, the Factor 2 score relies on other site-based evidence, which is likely to be lacking for the majority of sites. In the absence of any site-based evidence, the assessment is based solely on the Factor 1 score, carrying greater uncertainty in the outcome.

The testing exercise revealed some additional challenges to implementing the decision framework:

- many CSM targets had been re-worded at a country- or site-level, and, in some cases, not all of the standard CSM targets were used in a site assessment – whilst this may not affect the CSM process for monitoring habitat condition, it did reduce the utility of these assessments in detecting N deposition impacts in a consistent way;
- evaluation of sites with known N deposition issues clearly showed some limitations of the CSM process in detecting N impacts – the main problem seemed to be the lack of sensitivity of CSM targets to detect N impacts, because they were not designed for that purpose.

5.3 Key recommendations

Based on these findings a number of key recommendations were made:

- there is a need to improve quantitative estimates of the uncertainty in wet and dry oxidised and reduced deposition at the national scale, including spatial variation in that uncertainty, and to quantify uncertainty in N deposition at sub 5x5km level;
- critical loads are not available for some CSM habitats and for others there is a low certainty in the assignment of the critical load because of the poor correspondence between CSM and the EUNIS class for which a critical load is established.

Experimental and/or survey work is recommended to establish critical loads for habitats which carry the greatest uncertainty;

- the ability of CSM to detect N deposition impacts at sites would be improved if new N-focused targets were designed that could be applied across the UK without modification at the site-level;.
- further analysis of existing survey and experimental data would better relate observed damage to conservation objectives to quantified loads of N deposition, and would guide development of new N-focused targets;
- further consideration is needed on how to apply the decision framework, given the different assessment approaches taken in England, Wales, Scotland and Northern Ireland, and the potential to automate the process with electronically stored data.

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