Bioindicator methods for monitoring of nitrogen impacts on statutory nature conservation sites

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JNCC, EN, SNH, CCW, EHS, SEPA
Assessing air pollution impacts: Critical loads & Bioindicators

- Critical loads & critical levels approaches
  - Mostly national, but can be site-based.
  - Essentially only a risk assessment.
  “Likelihood of change”

- Bioindicators & biomonitoring:
  - Actual measurement of ecosystem parameters
  - Relates directly to site “condition”
  - Can consider temporal changes at a site level
Uncertainties and needs

- Wide range of different views regarding the usefulness of bioindicators & biomonitoring for N.
- Potentially attractive for Agencies to help monitor site condition in relation to air pollution impacts and for local assessments
- Uncertainty regarding the specific benefits and limitations of the different methods.
- Need research…
JNCC & Agencies Research Project

- **Stage 1:**
  - Review existing methods
  - Test novel techniques at one site
  - Identify methods with high potential for further application by Agencies

- **Stage 2:**
  - Further test the practical application of methods recommended for application
  - Use 4 key sites for detailed methods (NH$_3$, NO$_x$, wet deposition and controlled dose comparison)
  - Simplest methods to be then applied at UK scale.
Definitions

- Can get easily hung up on definitions – keep it simple here

- **Bioindicators:**
  - General group of approaches where biological measurement used to indicate something (e.g. might be applied at one time for spatial comparison).

- **Biomonitoring:**
  - Repeated application of bioindicator methods over time (e.g. weeks to decades)
N bioindicators: What is being indicated?

• Several purposes for N bioindicators to estimate:
  – N deposition fluxes from the atmosphere
  – Air concentrations of N species (NO$_x$, NH$_3$ etc)
  – Environmental effects of N, including physiological and environmental changes

• Should consider biomonitoring in conjunction with physical monitoring

• Can use biomonitoring results as input for local application of the critical loads approach.
Types of N bioindicator methods

Biochemical methods
– Measure the accumulation of N or a chemical/physiological response in a plant/soil component

Species composition methods
– Record the presence of certain species previously categorized according to their N preferences and generate an overall site index

Transplant methods
– Locally occurring or standardized plants are exposed to a range of N conditions and their responses assessed.
Biochemical bio-indicator methods for nitrogen
Foliar tissue N

- Most extensively studied parameter
- Response to N deposition rather than concentrations
- Uncertainties in the past particularly related to need to standardize protocols and have robust reference estimates of N deposition.
Total foliar tissue N

Results near a farm at Earlston in Scotland
Spatial variability of foliar N

Results from Leende Heide, the Netherlands
Foliar amino acids

- Large rates of accumulation
- But amino acids accumulated different between species
“Substrate N” and foliar ammonium

Substrate Nitrogen
  – Total available N for growth expected to vary more than total N.
  – Approximate substrate N by measuring total soluble N in leaves.
  – More general than amino acids

Foliar ammonium
  – Foliar ammonium represents primary pool for N compound synthesis and recycling
  – Smaller pool expected to have larger response
Foliar ammonium

- Best results so far for bryophytes
- Species differences consistent with N habitat preferences
- Massive response of factor 20 over range tested.
Response of different foliar N pools

- Larger response from the smaller pool size
- Smaller pools may also respond more quickly to change in N deposition
- Foliar ammonium potentially easier to measure
Combining Bioindicators with the Critical loads approach

- Currently feasible for foliar N and foliar ammonium
- Measured biomonitor data indicates whether a site is significantly above or below the critical load
Estimating N deposition based on foliar ammonium

- Bryophytes in woodland ground flora
- Needed for more data in clean conditions to improve confidence limits

\[ N_{dep} = 1.5106 (\text{TissueNH}_4^+)^{0.7398} \]

\[ R^2 = 0.9221 \]
Biochemical bioindicators of plant N responses

- Response parameters include enzyme activities, soil emissions and bioassays of damage e.g. tests of frost hardiness or photosynthetic activity.
- Methods relevant to assess ecological impacts and for monitoring of general ‘condition’
- But less direct than accumulation methods and more affected by other factors, so generally less well suited to assess N deposition.
Species composition bio-indicator methods for nitrogen
Ellenberg Approach for Higher Plants and Bryophytes

- Demonstrated close relationship to N deposition
- But species composition affected by many other factors, especially soil, management & light effects.
- Suited to local scale assessments and long term biomonitoring
Lichens for assessing impact of atmospheric nitrogen

• Tested:
  – several overall biodiversity measures
  – Several N indicator methods inc.
    • Ellenberg (Wirth) values
    • French (Lallmont) scale
    • Van Herk (Acidophyte / Nitrophyte classification)
    • Compared Twigs and Trunks
    • Also assessed bark pH

• Some suggestion: Lichens are particularly responding to NH$_3$. Effects of NH$_4^+$ and NO$_y$ are much less certain.

• Effect of NH$_3$ to *increase* bark pH is critical
**Total Lichen biodiversity and bark pH**

![Graph of Lichen Diversity](image)

- **VDI** - German, **LDV** - European

![Graph of Bark and Twig pH](image)

- Bark pH
- twig pH
Sensitivity of lichens to NH$_3$

Acidophytes (AIW) hate NH$_3$

“Troll’s Beard” (Bryoria): disappearing from many sites

Nitrophytes (NIW) love NH$_3$

Cladonia

Xanthoria

thrives by farms
Combination of Acidophytes and Nitrophytes
Ellenberg (Wirth): detailed and potential simpler system

![Graph showing Lichen Mean Ellenberg Score vs. NH3 concentration (ug m⁻³)]

- Parameter: Twigs (chk)
- Parameter: Trunks

![Graph showing Ellenberg: Easy Spp Only! vs. NH3 concentration (ug m⁻³)]

- Parameter: Twigs
- Parameter: Trunks
Twig acidophytes are completely excluded above a trunk pH of 4-4.2. This equates to an NH$_3$ conc of around 2 ug m$^{-3}$.

Note outlier for Thetford trunks: rich Parmelion community (not in AIW)
Potential for two-tier Lichen approach for Nitrogen

- **Detailed method:** further develop van Herk approach, including application to twigs. Good for full site assessment by experts.
- **Simpler method:** refine simple Ellenberg approach, including application to twigs. Good for application by trained non experts to get indications at sites and for raising public awareness.
Transplant bio-indicator methods for nitrogen
Native reciprocal transplants

- Works best for bryophytes – no soil attached and more robust than lichens
- Need two or more locations with similar climate
- Measure growth rates, and N content
- Observe reduced performance in polluted conditions or recovery in clean conditions
- Good for demonstration to stakeholders to show the benefits of emission abatement at a site level.
Grass biomonitors

- Lolium perenne using EUROBIONET wicking system

\[ y = -0.0036x + 2.0921 \]

\[ R^2 = 0.7777 \]
Grass biomonitors

L. perenne Biomass

\[ y = -0.004x + 2.1829 \]

\[ R^2 = 0.8674 \]

NH\(_3\) Concentration (µg m\(^{-3}\))
Biomass (g)

L. perenne above ground %N concentration

\[ y = 0.1768 \ln(x) + 3.03 \]

\[ R^2 = 0.5403 \]

Log NH\(_3\) concentration (µg m\(^{-3}\))
Grass biomonitors

L. perenne: Mean mg N per pot

$y = -0.1677x + 77.129$

$R^2 = 0.984$

Mean mg N per pot

Distance from poultry farm (m)

L. perenne: Mean mg N per pot

$y = 11.94\ln(x) + 39.662$

$R^2 = 0.9352$

Mean mg N per pot

Log Ambient NH$_3$ concentration $\mu$g m$^{-3}$
Overview of methods tested and recommendations

- Foliar N conc.
- Enzyme Activity
- Foliar N:P ratio
- Lichen diversity
- Lichens (Lallemont)
- Lichen (Simplified Ellenberg)
- Native transplant
- Frost hardness
- Soil gas fluxes (N2O, NO)
- N isotope analysis
- Chlor fluorescence
- Soil invertebrates

How good/robust? (score)

How easy? (score)
Classification of method types and recommendation for further development

• Chemical Methods
  – Total foliar N
  – Soluble foliar N/NH$_4^+$
  – Bark pH

• Diversity Methods
  – Ellenberg scale (Higher plants and bryophytes)
  – Van Kerk scale for lichens (inc for twigs)
  – Ellenberg (Wirth) scale for lichens (inc for twigs)

• Transplant Methods
  – Standardized grass transplants
  – (Native reciprocal transplants)
Conclusions

- Methods refer to different timescales – This affects the translation from bioindicating to biomonitoring.
- The methods by definition refer to an ecosystem or biological impact – therefore they give a direct implication of critical load / level exceedance.
- The accumulation methods most quantitatively related to atmospheric deposition, but different different deposition components may have different effects.
- For application to statutory nature conservation sites the bioindicators can be best used for local sources with small scale transects into reserves (NO\textsubscript{x} and NH\textsubscript{3} as sources).
**Conclusions and next steps**

- The assessment for elevated wet deposition is much less certain (due to linked altitude effects).
- The most robust assessments would use more than one method in parallel and complement physical monitoring efforts.
- Ongoing work is focusing at 4 sites for detailed methods, plus UK wide survey of simple methods.
- Contributors are invited across the Agencies to try out the simple methods next year.