3 Mapping critical levels for vegetation

3.2.3 Ammonia (NH_3)

The fertilisation effect of NH_3 can in the longer-term lead to a variety of adverse effects, including growth stimulation (which can alter species balance with some species being potentially out-competed) and increased susceptibility to abiotic (drought, frost) and biotic stresses. As for NO_x, for application for mapping critical levels and their exceedance, it is strongly recommended that only the annual mean values of NH_3 are used. This is because mapped and modelled values of the longer-term critical levels are more robust, and the long-term effects of NH_3 are thought to be more significant than the short-term effects.

The critical levels in Table 3.3 refer to ecosystems with the most sensitive lichens and bryophytes and vascular plants. The aim of these critical levels is to protect the functioning of plant and lichen individuals and communities. Lichens and bryophyte species were found to be more sensitive than vascular plants (Table 3.3). Critical levels are currently not set for intensively managed agricultural grasslands (pastures) and arable crops, which are often sources rather than sinks of ammonia and are less likely to contain sensitive species.

Table 3.3: Critical levels for NH_3 (µg m^{-3}).

Plant and lichen individuals and communities	Critical level NH_3 [µg m^{-3}]	Time period
Lichens and bryophytes (including ecosystems where lichens and bryophytes are a key part of ecosystem integrity)	1	Annual mean
Vascular plants (including ecosystems where lichens and bryophytes are not a key part of ecosystem integrity)	3*	Annual mean
Provisional critical levels		
Lichens and bryophytes	12##	Monthly mean
Vascular plants	23	Monthly mean

*An explicit uncertainty range of 2-4 µg m^{-3} was set for vascular plants. The uncertainty range is intended to be useful when applying the critical level in different assessment contexts (e.g. precautionary approach or balance of evidence).
##This value is not derived from experiments or observations, unlike other critical levels. It is highlighted here to be mathematically consistent with the annual level for lichens and bryophytes.

The critical levels presented in Table 3.3, except that for the monthly mean for lichens and bryophytes, were recommended for inclusion in this manual at a workshop, held in Edinburgh from 4-6 December, 2006: *Atmospheric ammonia: Detecting emission changes and environmental impacts* (UNECE, 2007). Their inclusion was subsequently approved at the 20th Task Force meeting of the ICP Vegetation (Dubna, Russian Federation, 5-8 March, 2007) and adopted at the 23rd meeting of the Task Force on Modelling and Mapping (Sofia, Bulgaria, 26-27 April, 2007).

15 years later, the critical levels in Table 3.3 were reviewed and confirmed at an Ammonia Expert Workshop, prepared by the Coordination Center for Effects (CCE) and held in Dessau, Germany and online 28-29 March 2022. The monthly mean critical level for lichens and

bryophytes was added. Amendments to this chapter, based on the Dessau-Workshop conclusions, were presented and approved at the 36th Task Force Meeting of the ICP Vegetation (13-15 February 2023) and the 39th ICP Modelling & Mapping Task Force meeting in Prague (28-30 March 2023).

The following recommendations were given by the Edinburgh meeting (December 2006) and confirmed by the Dessau Workshop (March 2022):

1. The definition of a long-term critical level for lichens and bryophytes, including ecosystems where lichens and bryophytes are a key part of the ecosystem integrity, of 1 μg m^{-3} (annual mean);
2. The definition of a long-term critical level for vascular plants, of 3 μg m^{-3}, with an uncertainty range of 2-4 μg m^{-3} (annual mean);
3. Long-term critical level values are based on observation of actual species changes from both field surveys and long-term exposure experiments, where effects were related to measured ammonia concentrations and could not be assumed to provide a protection for longer than 20-30 years;
4. To retain the monthly critical level (23 μg NH_3 m^{-3}) for vascular plants only as a provisional value. This value is based on the assessment of adverse effects of short-term exposures as discussed at the UNECE workshop on Critical Levels held in 1992 in Egham, United Kingdom (Van der Eerden et al., 1993). The monthly critical level was estimated with the "envelope" method using exposure-response data from mainly short-term fumigation experiments. Thus, it does not have the same relevance as the long-term critical levels (annual averages of 1 and 3 μg NH_3 m^{-3}) derived from long-term field studies. The provisionally retained monthly value has to be considered as expert judgement to allow the assessment of effects of short-term peak concentrations which can occur, for example, during periods of manure application (e.g. in spring).

The following recommendations were added after the Dessau Workshop (March, 2022):

5. The monthly critical level of 23 μg m^{-3} had been derived for vascular plants, and does not apply to lichens, bryophytes and ecosystems where these are important to ecosystem integrity, e.g. peatlands. It can easily be seen that one month of 23 μg m^{-3}, would give a minimum annual average of 1.9 μg m^{-3}, which already exceeds the long-term critical level for lichens and bryophytes. Therefore, to be mathematically consistent with the long-term critical level for those very sensitive elements, a maximum monthly value of 12 μg m^{-3} would apply, though further evidence would be needed to assess whether this value is sufficiently precautionary for sensitive lichen and bryophyte species.
6. To remove ambiguity (e.g. where lichens and bryophytes are considered to be a key part of heathlands and other habitats), references to "*heathland, grassland and forest ground flora*" in the table 3.3 were removed in comparison to the previous version of this chapter. Additionally, references to the term "*vegetation*" as a standalone term as well as to "*lower and higher plants*" were removed, referring instead to 'lichens and bryophytes' and 'vascular plants' respectively and acknowledging that lichens are not part of the vegetation in the strict sense.
7. In the background information as well as in the presentations of the Dessau workshop, both published within the workshop proceedings, the latest supporting scientific literature of the past 15 years has been compiled (Franzaring et al., 2022, Chapters 2 and 4). This literature review focused on studies in which the effects of ammonia on plants and lichens were investigated. While many investigations were done in the field using e.g. lichens and gradient studies in the lee of farms, there were only a few controlled fumigation experiments published, in which reference concentrations of ammonia were set to derive dose-response

relationships. The compiled research results since the 2009 revision to the ammonia critical levels, corroborates the changes made previously. As such, the key evidence (Table 3.4) remains unchanged.

8. It must be noted that the effects of ammonia will be modified by concurrent elevated NO_x concentrations and depend on the wider ecological status of the ecosystem (e.g. combined impacts of management and drought). Since most research was based on Northwestern European peat bogs and heathlands, it is recommended that future revisions of critical levels should include other important European habitat types.

The proceedings of the UNECE Workshop on Ammonia (Edinburgh, December 2006) were published in Sutton et al. (2009) by Springer: Sutton M.A., Baker S., Reis S. (eds.), Atmospheric Ammonia: Detecting emission changes and environmental impacts. This book includes details of the evidence used to justify the change in critical levels, as summarised in Table 3.4.

The proceedings of the Dessau-Workshop in March 2022 were published by the German Environment Agency. The report was collated by Franzaring et al. (2022). Review of internationally proposed critical levels for ammonia - proceedings of an Expert Workshop held in Dessau and online on 28/29 March 2022 can be downloaded from the website of the German Environment Agency[1].

Table 3.4: Key evidence based on observations of changes in species composition (a true ecological endpoint) in response to measured air concentrations of ammonia and for justifying separate critical levels for ecosystems where lichens and bryophytes are a key part of ecosystem integrity.

Location	Receptor type	Lowest measured NH_3 concentration [µg m^{-3}]	Estimated NOEC * [µg m^{-3}]	Reference
SE Scotland, poultry farm	Epiphytic lichens	0.6	0.7 (on twigs) 1.8 (on trunks)	(Pitcairn et al., 2004, Sutton et al., 2009)
Devon, SW England	Epiphytic lichens diversity (twig)	0.8 (modelled)	1.6	(Wolseley et al., 2006)
United Kingdom, national NH_3 network	Epiphytic lichens	0.1	1.0	(Leith et al., 2005, Sutton et al., 2009)
Switzerland	Lichen population index	1.9 (modelled)	2.4	(Rihm et al., 2009)
SE Scotland, field NH_3 experiment, Whim bog	Lichens and bryophytes – damage and death	0.5	< 4	(Sheppard et al., 2009)
Corroborative evidence **				
SW England	Epiphytic lichens	1.5	ca. 2	(Leith et al., 2005)
South Portugal	Epiphytic lichens	0.5	1	(Pinho et al., 2009)

[1] https://www.umweltbundesamt.de/publikationen/review-of-internationally-proposed-critical-levels

Location	Receptor type	Lowest measured NH_3 concentration [µg m^{-3}]	Estimated NOEC * [µg m^{-3}]	Reference
Italy, pig farm	Epiphytic lichens	0.7	2.5	(Frati et al., 2007)

*NOECs were directly estimated from exposure/response curves or calculated with regression analysis. The data are from recent experimental studies, both field surveys and controlled field experiments on the impact of NH_3 on vegetation.
**In these cases, NH_3 concentration data were available for less than one year, which is why these results are categorised as “corroborative evidence”.