

Selecting Biomonitors of Atmospheric Nitrogen Deposition: Guidelines for Practitioners and Decision Makers

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Abstract: Environmental pollution is a major threat to public health and is the cause of important economic losses worldwide. Atmospheric nitrogen deposition is one of the most significant components of environmental pollution, which, in addition to being a health risk, is one of the leading drivers of global biodiversity loss. However, monitoring pollution is not possible in many regions of the world because the instrumentation, deployment, operation, and maintenance of automated systems is onerous. An affordable alternative is the use of biomonitors, naturally occurring or transplanted organisms that respond to environmental pollution with a consistent and measurable ecophysiological response. This policy brief advocates for the use of biomonitors of atmospheric nitrogen deposition. Descriptions of the biological and monitoring particularities of commonly utilized biomonitor lichens, bryophytes, vascular epiphytes, herbs, and woody plants, are followed by a discussion of the principal ecophysiological parameters that have been shown to respond to the different nitrogen emissions and their rate of deposition.

Keywords: atmospheric pollution; environmental management; epiphytes; grasses; mosses; planetary boundaries; policy; public health.

1. A systematic literature review of biomonitors of nitrogen deposition

The biomonitoring synthesis from the main text was conducted from a systematic literature review based on searches in the Scopus database (Elsevier, Amsterdam) complemented with relevant articles identified as relevant from the authors' collective experience (Figure S1). We searched for papers containing the phrases "biomonitor(s)", "nitrogen deposition", and "nitrogen/NO_x/ammonium/ammonia emissions". We focused on works that evaluated physiological traits of autotrophic organisms in response to Nitrogen emissions and deposition. Papers dealing primarily with population biology were excluded, as well as those focusing on types of pollution including aquatic pollution and heavy metals.

We identified 63 articles that utilized the physiological responses of autotrophic organisms with potential for biomonitoring nitrogen deposition (Figure S2; Table S1). While bryophytes were the most utilized lifeform for biomonitoring (26 studies), biomonitoring has also been conducted with lichens (mostly utilized as bioindicators), ferns, vascular epiphytes (especially two species in the neotropical genus *Tillandsia*), herbs, and woody plants (Figure S2a). The studies considered a combined total of 247 biomonitoring species, the most numerous being woody plants (Figure S2b).

Most of the articles reported were field studies, while only 10% were conducted under controlled environmental conditions, usually to calibrate plant responses to (simulated) nitrogen pollution. The parameters that were most sensitive to nitrogen deposition included the nitrogen elemental and isotopic status of biomonitors, photosynthesis indicators (chlorophyll and accessory pigment concentration and chlorophyll fluorescence), the activity of enzymes related to the nitrogen metabolism and with oxidative stress protection (Table S1).

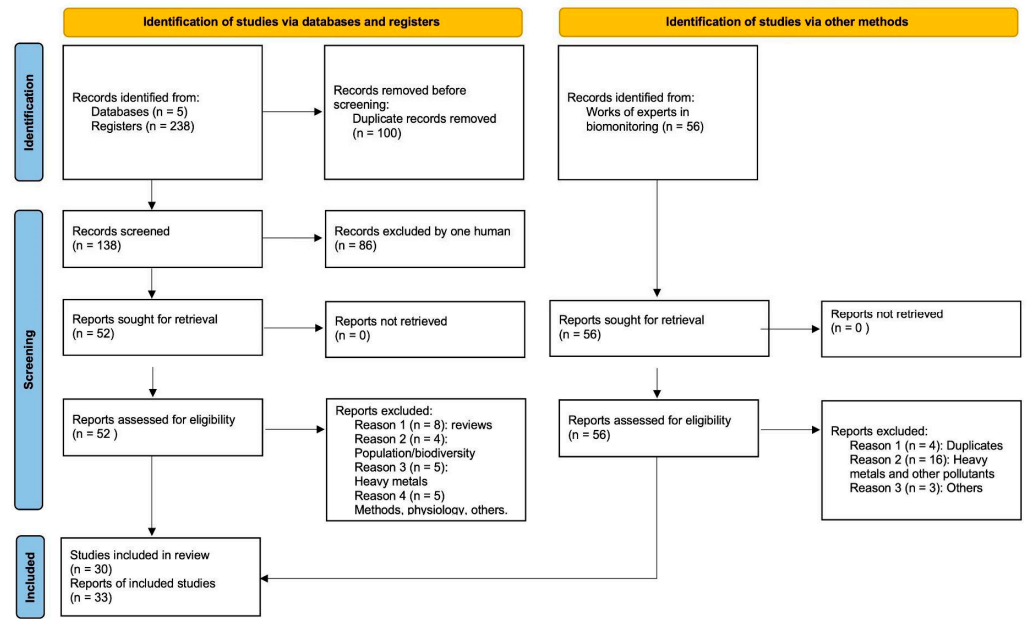


Figure S1. PRISMA [90] flow diagram for the systematic literature review conducted for biomoni-tors of nitrogen deposition.

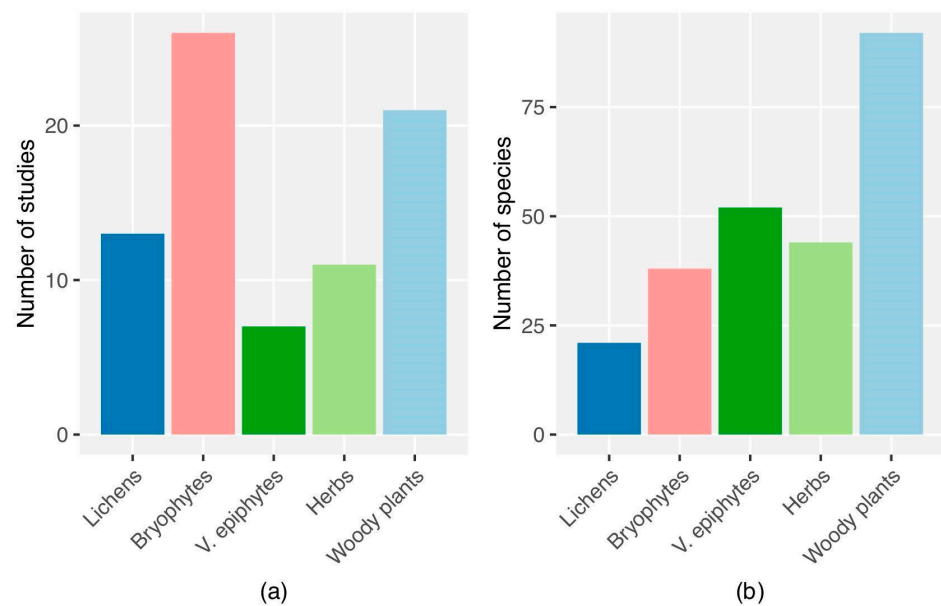


Figure S2. Number of studies identified in the literature review that utilized different biomonitor lifeforms **(a)** and total number of species per lifeform reported in the literature **(b)**.

Table S1. Biomonitoring of nitrogen deposition identified in the systematic literature review. Species and physiological traits analyzed under pollution gradients (field) or under with controlled environmental conditions of N pollution (Ctrl. cond.). N%, N elemental content; N/P and C/N, ratios of nitrogen with phosphorus and carbon; Protein, protein content; a.a, amino acids; Chl *T*, total chlorophylls; Chl *a/b*, ratio chlorophyll *a/b*; Neo+Lut/ β -Car, neoxanthin + lutein/ β -carotene; F_v/F_m , Fluorescence of chlorophyll *a*; Φ_{PSII} , quantum efficiency of photosystem II; NQP_{max} , non-photochemical quenching; K, content of potassium; MDA, malondialdehyde; NR, nitrate reductase activity; NiR, nitrite reductase activity; GS, glutamine synthetase activity; PME, phosphomonoesterase activity; SOD, superoxide dismutase activity; POD, peroxidase activity; PPO, polyphenol oxidase activity; DHA, dehydrogenase activity. Reference numbers correspond to those in the main text.

Liveform	Species	Biomass	Chlorophylls	Enzymes	Isotopes	Study	Site of study	Reference
Lichens	<i>Alectoria sarmentosa</i>	N%, N/P				Ctrl. Cond.	Sweden	[91]
	<i>Anaptychia</i> sp	N%, C/N			$\delta^{15}N$	Field	Valley of Mexico	[92]
	<i>Cladonia mitis</i>	N%, C/N				Field	Fort McMurray, Canada	[69]
	<i>Evernia mesomorpha</i>	N%, C/N				Field	Fort McMurray, Canada	[69]
	<i>Evernia prunastri</i>		F_v/F_m , Membrane integrity	DHA		Field	Italy	[93]
	<i>Flavopunctelia praesignis</i>		Chl <i>T</i> , Membrane integrity			Field	Morelia, México	[38]

<i>Hypogymnia physodes</i>	N%			Field	British Columbia, Canada	[94]
<i>Letharia vulpina</i>	N%, C/N		$\delta^{15}\text{N}$	Field	Sierra Nevada, USA	[95]
<i>Melanohalea exasperatula</i>	N%			Field	Utah and New Mexico, USA	[40]
<i>Melanohalea subolivacea</i>	N%			Field	Utah and New Mexico, USA	[40]
<i>Parmelia sulcata</i>	N%		$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Parmelia sulcata</i>	N%			Field	British Columbia, Canada	[94]
<i>Parmotrema hypoleucinum</i>	N%			Field	Portugal	[96]
<i>Phycia adscendens</i>	N%			Field	Genoble, France	[97]
<i>Phycia aipolia/stellaris</i>	N%			Field	Utah and New Mexico, USA	[40]
<i>Phycia sp</i>	N%		$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Platismatia glauca</i>	N%, N/P	Chl <i>a</i>	$\delta^{15}\text{N}$	Ctrl. Cond.	Vindeln, Sweden	[91]

	<i>Platismatia glauca</i>	N%		Field	British Columbia, Canada	[94]
	<i>Ramalina ecklonii</i>	Protein	Chl <i>T</i> , Chl <i>a/b</i> , Pheophytine <i>a</i> , Pheop. <i>a</i> / Chl <i>a</i>	Field	Cordoba, Argentina	[98]
	<i>Usnea ceratina</i>		Chl <i>T</i> , Bleaching, Necrosis	Field	Morelia, México	[38]
	<i>Usnea lapponica/hirta</i>	N%		Field	Utah and New Mexico, USA	[40]
	<i>Xanthomendoza montana</i>	N%		Field	Utah and New Mexico, USA	[40]
	<i>Xanthoria parietina</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[99]
	<i>Xanthoria parietina</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
	<i>Xanthoria parietina</i>	N%		Field	Portugal	[96]
Bryophytes	<i>Abietinella abietina</i>	N%	$\delta^{15}\text{N}$	Field	Austria	[43]
	<i>Abietinella abietina</i>	N%		Field	Sites of Europe	[100]
	<i>Abietinella abietina</i>	N%		Field	Sites of Europe	[101]

<i>Brachythecium</i>	N%		Field	Sites of Europe	[101]	
<i>Brachythecium rutabulum</i>	N%		Field	Sites of Europe	[101]	
<i>Braunia secunda</i>		NR, PME	Ctrl. Cond.	Valley of Mexico	[87]	
<i>Braunia secunda</i>	N%, N/P, Sclerophyll index	NR, PME	Ctrl. Cond.	Morelia, México	[48]	
<i>Bryum argenteum</i>	N%		Field	Sicily, Italy.	[102]	
<i>Bryum argenteum</i>	N%		Field	London, UK	[103]	
<i>Bryum capillare</i>	N%		Field	London, UK	[103]	
<i>Ceratodon purpureus</i>	N%		Field	London, UK	[103]	
<i>Dicranum</i>	N%		Field	Sites of Europe	[101]	
<i>Dicranum scoparium</i>	N%	NR	Ctrl. Cond.	Ny-Ålesund, Svalbard	[104]	
<i>Diplophyllum albicans</i>	N%		$\delta^{15}\text{N}$	Field	Navarra, Spain	[105]
<i>Fabronia sp</i>	N%, C/N		$\delta^{15}\text{N}$	Field	Valley of Mexico	[92]

<i>Grimmia pulvinata</i>	N%	$\delta^{15}\text{N}$	Field	London, UK	[103]
<i>Grimmia sp</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Valley of Mexico	[92]
<i>Haplocladium microphyllum</i>	N%	$\delta^{15}\text{N}$	Field	Southern China	[42]
<i>Homalothecium</i>	N%		Field	Sites of Europe	[101]
<i>Homalothecium lutescens</i>	N%	$\delta^{15}\text{N}$	Field	Navarra, Spain	[105]
<i>Homalothecium sericeum</i>	N%	$\delta^{15}\text{N}$	Field	London, UK	[103]
<i>Hylocomium splendens</i>	N%		Field	Sites of Europe	[106]
<i>Hylocomium splendens</i>	N%		Field	Sites of Europe	[44]
<i>Hylocomium splendens</i>	N%		Field	Scotland and England	[107]
<i>Hylocomium splendens</i>	N%		Field	Sites of Europe	[100]
<i>Hylocomium splendens</i>	N%		Field	Sites of Europe	[101]

<i>Hylocomium splendens</i>	N%		$\delta^{15}\text{N}$	Field	Southern China	[42]
<i>Hylocomium splendens</i>	N%		$\delta^{15}\text{N}$	Field	Austria	[43]
<i>Hypnum cupressiforme</i>	N%		$\delta^{15}\text{N}$	Field	Austria	[43]
<i>Hypnum cupressiforme</i>	N%		$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Hypnum cupressiforme</i>	N%		$\delta^{15}\text{N}$	Field	Navarra, Spain	[105]
<i>Hypnum cupressiforme</i>	N%			Field	Navarra, Spain	[108]
<i>Hypnum cupressiforme</i>	N%			Field	Basque Country, Spain	[109]
<i>Hypnum cupressiforme</i>	N%			Field	Sites of Europe	[106]
<i>Hypnum cupressiforme</i>	N%			Field	Sites of Europe	[44]
<i>Hypnum cupressiforme</i>	N%		$\delta^{15}\text{N}$	Field	Navarra, Spain	[110]
<i>Hypnum cupressiforme</i>	N%, C/N, N/P, protein	Chl <i>T</i> , Chl <i>a/b</i> , Carotenes, MDA	SOD, NR, PME	$\delta^{15}\text{N}$	Field	Navarra, Spain [111]

<i>Hypnum cupressiforme</i>	N%		Field	Alpes	[112]	
<i>Hypnum cupressiforme</i>	N%		Field	Sites of Europe	[100]	
<i>Hypnum cupressiforme</i>	N%		Field	London, UK	[103]	
<i>Hypnum cupressiforme</i>	N%		Field	Sites of Europe	[101]	
<i>Isothecium myosuroides</i>	N%		Field	British Columbia, Canada	[94]	
<i>Leptodontium pungens</i>		NR, PME	Ctrl. Cond.	Valley of Mexico	[87]	
<i>Leucobryum junipe-roideum</i>	N%		$\delta^{15}\text{N}$	Field	Navarra, Spain	[105]
<i>Pleurochaete squarrosa</i>	N%		$\delta^{15}\text{N}$	Field	Navarra, Spain	[110]
<i>Pleurozium schreberi</i>	N%		$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Pleurozium schreberi</i>	N%		Field	Sites of Europe	[44]	
<i>Pleurozium schreberi</i>	N%		Field	Sites of Europe	[100]	

<i>Pleurozium schreberi</i>	N%				Field	Sites of Europe	[101]
<i>Pleurozium schreberi</i>	N%			$\delta^{15}\text{N}$	Field	Southern China	[42]
<i>Pleurozium schreberi</i>	N%				Field	Sites of Europe	[106]
<i>Pleurozium schreberi</i>	N%				Field	Alpes	[112]
<i>Pleuroziumschreberi</i>	N%			$\delta^{15}\text{N}$	Field	Austria	[43]
<i>Polytrichastrum formosum</i>	N%			$\delta^{15}\text{N}$	Field	Navarra, Spain	[105]
<i>Polytrichum juniperinum</i>	N%		NR		Ctrl. Cond.	Ny-Ålesund, Svalbard	[104]
<i>Pseudoscleropodium purum</i>	N%, N/P, Sclerophyll index	Chl <i>T</i> , Chl <i>a/b</i> , Neo+Lut/B-Car, F_v/F_m , ϕ_{PSII} , NQP_{max} , <i>K</i>	NR, PME		Ctrl. Cond.	Derbyshire Dales, UK	[79]
<i>Pseudoscleropodium purum</i>	N%			$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Pseudoscleropodium purum</i>	N%				Field	Sites of Europe	[106]
<i>Pseudoscleropodium purum</i>	N%				Field	Sites of Europe	[44]

<i>Pseudoscleropodium purum</i>	N%				Field	Sites of Europe	[100]
<i>Pseudoscleropodium purum</i>	N%				Field	Sites of Europe	[101]
<i>Pseudoscleropodium purum</i>	N%		NR, PME	$\delta^{15}\text{N}$	Field	Galicia and Cataluña, Spain	[113]
<i>Racomitrium lanuginosum</i>	N%				Field	London, UK	[103]
<i>Racomitrium lanuginosum</i>		K	NR		Ctrl. Cond.	Glas Maol, scocia	[86]
<i>Rhytidiadelphus loreus</i>	N%			$\delta^{15}\text{N}$	Field	Navarra, Spain	[105]
<i>Rhytidiadelphus squarrosus</i>	N%, N/P, Sclerophyll index	Chl <i>T</i> , Chl <i>a/b</i> , Neo+Lut/B-Car, F_v/F_m , Φ_{PSII} , NQP_{max} , K	NR, PME		Ctrl. Cond.	Derbyshire Dales, UK	[79]
<i>Rhytidiadelphus squarrosus</i>	N%				Field	Sites of Europe	[101]
<i>Scleropodium purum</i>	N%			$\delta^{15}\text{N}$	Field	Austria	[43]
<i>Scleropodium purum</i>	N%				Field	Sites of Europe	[101]

	<i>Sphagnum capillifolium</i>	N%, C/N		Field	Fort McMurray, Canada	[69]
	<i>Sphagnum fuscum</i>	N%, C/N		Field	Fort McMurray, Canada	[69]
	<i>Thuidium abietinum</i>	N%		Field	Sites of Europe	[101]
	<i>Thuidium delicatulum</i>	N%, N/P, Sclerophyll index	NR, PME	Ctrl. Cond.	Morelia, México	[48]
	<i>Thuidium tamariscinum</i>	N%		Field	Sites of Europe	[100]
	<i>Thuidium tamariscinum</i>	N%		Field	Sites of Europe	[101]
	<i>Tortula muralis</i>	N%	$\delta^{15}\text{N}$	Field	Italy	[114]
	<i>Tortula muralis</i>	N%	$\delta^{15}\text{N}$	Field	London, UK	[103]
Vascular epiphytes	<i>Acianthera casapensis</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
	<i>Aechmea pectinata</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
	<i>Aechmea sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]

<i>Anthurium hoehnei</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Anthurium longicusspidatum</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Anthurium mareense</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Begonia sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Billbergia cf. distachia</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Billbergia sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Cyrtochilum annulare</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum excisum</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum ferrugineum</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum karstenii</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum moritzii</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]

<i>Epidendrum sp. 1</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum sp. 2</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum sp. 4</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epiphyllum sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Fern sp 1</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Fern sp 2</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Fern sp 3</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Hofmeisterella eumicroscopica</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Lepanthes sp.</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Masdevallia strumifera</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Maxillaria spilotantha</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]

<i>Monstera sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Oncidium cultratum</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Oncidium ornithorhyncum</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Ornithidium aggregatum</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Ornithidium aureum</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Philodendron sonderianum</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Philodendron sp 1</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Philodendron sp 2</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Philodendron sp 3</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Pleurothallis microcardia</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Pleurothallis ramulosa</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]

<i>Pleurothallis talpinaria</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Restrepiopsis powersii</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Rhipsalis sp 1</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Rhipsalis sp 2</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Specklinia sp.</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Stelis galeata</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Stellis eublepharis</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Stellis sp. 2</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Stellis sp. 3</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Telipogon andicola</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Telipogon nervosus</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]

<i>Tillandsia recurvata</i>	N%, C/N		$\delta^{15}\text{N}$	Field	Valley of Mexico	[92]
<i>Tillandsia recurvata</i>	N%, N/P, Sclerophyll index	NR, PME		Ctrl. Cond.	Morelia, México	[48]
<i>Tillandsia recurvata</i>	Dry/fresh weight, Leaf area, Specific area foliar, Sclerophyll index, Thickness epidermis	Chl <i>T</i>		Field	Curitiba, Brazil,	[115]
<i>Tillandsia usneoides</i>		Anomalous scales %		Field	São Paulo State, Brazil	[116]
<i>Tillandsia usneoides</i>	N%, N/P, Sclerophyll index	NR, PME		Ctrl. Cond.	Morelia, México	[48]
<i>Tillandsia usneoides</i>	N%		$\delta^{15}\text{N}$	Field	Wilmington, USA	[78]
<i>Trichipteris corcovadensis</i>			$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Vriesia inflata</i>			$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Vriesia philippocobrugii</i>			$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]

Herbs	<i>Agrostis perennans</i>	C:N			$\delta^{15}\text{N}$	Field	Pennsylvania, USA	[56]
	<i>Avena fatua</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Los Angeles Basin, USA	[55]
	<i>Bidens pilosa</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , F_v/F_m	NR	$\delta^{15}\text{N}$	Ctrl. Cond.	Morelia, México	[58]
	<i>Bidens pilosa</i>				$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
	<i>Bromus diandrus</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Los Angeles Basin, USA	[55]
	<i>Bromus hordeaceus</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Los Angeles Basin, USA	[55]
	<i>Bromus madritensis</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Los Angeles Basin, USA	[55]
	<i>Cenchrus ciliaris</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Sonora, México	[60]
	<i>Cenchrus ciliaris</i>	N%				Field	Punjab province, Pakistan	[59]
	<i>Chloris gayana</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , F_v/F_m	NR	$\delta^{15}\text{N}$	Ctrl. Cond.	Morelia, México	[58]
	<i>Chloris pycnотryx</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , F_v/F_m	NR	$\delta^{15}\text{N}$	Ctrl. Cond.	Morelia, México	[58]

<i>Chloris virgata</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , <i>F_v</i> / <i>F_m</i>	NR	$\delta^{15}\text{N}$	Ctrl. Cond.	Morelia, México	[58]
<i>Costus arabicus</i>				$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Cyclopogon peruvianus</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Cyrtochilum revolutum</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Datura alba</i>	N%				Field	Punjab province, Pakistan	[59]
<i>Deschampsia flexuosa</i>	N%				Field	Scotland and England	[107]
<i>Elleanthus aurantiacus</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum macrostachyum</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum megalospathum</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum secundum</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Epidendrum sp. 3</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]

<i>Epidendrum zipaquiranum</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Hordeum vulgate</i>	N%				Field	The Netherlands	[73]
<i>Impatiens sp</i>				$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Lepidium virginicum</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , F_v/F_m	NR	$\delta^{15}\text{N}$	Ctrl. Cond.	Morelia, México	[58]
<i>Lolium multiflorum</i>				$\delta^{15}\text{N}$	Field	Denmark	[117]
<i>Maianthemum trifolium</i>	N%, C/N				Field	Fort McMurray, Canada	[69]
<i>Masdevallia amanda</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Masdevallia coriacea</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Maxillaria lawrenceana</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
<i>Nardus stricta</i>	N%				Field	Scotland and England	[107]
<i>Panicum virgatum</i>	C/N			$\delta^{15}\text{N}$	Field	Pennsylvania, USA	[56]

<i>Parthenium hysterophorus</i>	N%					Field	Punjab province, Pakistan	[59]
<i>Pennisetum setaceum</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , <i>F_v</i> / <i>F_m</i>	NR	$\delta^{15}\text{N}$	Ctrl. Cond.		Morelia, México	[58]
<i>Piper cernuum</i>				$\delta^{15}\text{N}$	Field		São Paulo State, Brazil	[49]
<i>Pleurothallis killipii</i>	N%, C/N			$\delta^{15}\text{N}$	Field		Facatativá, Colombia	[51]
<i>Pleurothallis phalangifera</i>	N%, C/N			$\delta^{15}\text{N}$	Field		Facatativá, Colombia	[51]
<i>Pleurothallis revoluta</i>	N%, C/N			$\delta^{15}\text{N}$	Field		Facatativá, Colombia	[51]
<i>Prescottia stachyodes</i>	N%, C/N			$\delta^{15}\text{N}$	Field		Facatativá, Colombia	[51]
<i>Rubus chamaemorus</i>	N%, C/N				Field		Fort McMurray, Canada	[69]
<i>Stelis argentata</i>	N%, C/N			$\delta^{15}\text{N}$	Field		Facatativá, Colombia	[51]
<i>Stellis sp. 1</i>	N%, C/N			$\delta^{15}\text{N}$	Field		Facatativá, Colombia	[51]

	<i>Stenorrhynchos speciosum</i>	N%, C/N			$\delta^{15}\text{N}$	Field	Facatativá, Colombia	[51]
	<i>Taraxacum officinale</i>	Dry weight, N%, C/N	Chl <i>T</i> , Chl <i>a/b</i> , F_v/F_m	NR	$\delta^{15}\text{N}$	Ctrl. Cond.	Morelia, México	[58]
	<i>Wedelia trilobata</i>				$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
Woody species	<i>Abies alba</i>	N%			$\delta^{15}\text{N}$	Field	Europe	[70]
	<i>Abies balsamea</i>	N%			$\delta^{15}\text{N}$	Field	North America	[70]
	<i>Acer pensylvanicum</i>	N%			$\delta^{15}\text{N}$	Field	North America	[70]
	<i>Acer platanoides</i>	N%			$\delta^{15}\text{N}$	Field	Germany	[63]
	<i>Acer platanoides</i>	N%			$\delta^{15}\text{N}$	Field	Salt Lake Valley, USA	[64]
	<i>Acer pseudoplatanus</i>	N%			$\delta^{15}\text{N}$	Field	Germany	[63]
	<i>Acer rubrum</i>	N%			$\delta^{15}\text{N}$	Field	North America	[70]
	<i>Acer saccharum</i>	N%			$\delta^{15}\text{N}$	Field	North America	[70]

<i>Acer spicatum</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Alnus glutinosa</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Alnus incana</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Amelanchier laevis</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Betula alleghaniensis</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Betula lenta</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Betula papyrifera</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Betula pendula</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Betula pendula</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Betula populifolia</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Calluna vulgaris</i>	N%		Field	Scotland and England	[107]

<i>Calluna vulgaris</i>	N%, C/N, a.a	$\delta^{15}\text{N}$	Field	London and rural Surrey, UK	[57]
<i>Calotropis procera</i>	N%		Field	Punjab province, Pakistan	[59]
<i>Cariniana ianeirensis</i>	N%	$\delta^{15}\text{N}$	Field	Bolivia, Thailand, Cameroon	[62]
<i>Carpinus betula</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Carpinus betulus</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Cecropia sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Cedrela odorata</i>	N%	$\delta^{15}\text{N}$	Field	Mato Grosso, Brazil	[107]
<i>Chusquea coleu</i>	N%	$\delta^{15}\text{N}$	Field	South America	[70]
<i>Chusquea quila</i>	N%	$\delta^{15}\text{N}$	Field	South America	[70]
<i>Cinnamomum camphora</i>	N%	$\delta^{15}\text{N}$	Field	Guiyang, China	[68]

<i>Corylus avellana</i>	N%			$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Corylus avellana</i>	N%			$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Dalbergia sissoo</i>		Chl <i>T</i>	POD, PPO		Field	Udaipur, India	[118]
<i>Daniellia ogea</i>	N%			$\delta^{15}\text{N}$	Field	Bolivia, Thailand, Cameroon	[62]
<i>Erica cinerea</i>	N%				Field	Scotland and England	[107]
<i>Eriotheca sp</i>				$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Fagus grandifolia</i>	N%			$\delta^{15}\text{N}$	Field	North America	[70]
<i>Fagus sylvatica</i>	N%			$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Ficus sp</i>				$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Fraxinus americana</i>	N%			$\delta^{15}\text{N}$	Field	North America	[70]

<i>Fraxinus excelsior</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Gleditsia triacanthos</i>	N%	$\delta^{15}\text{N}$	Field	Salt Lake Valley, USA	[64]
<i>Hura crepitans</i>	N%	$\delta^{15}\text{N}$	Field	Bolivia, Thailand, Cameroon	[62]
<i>Juniperus virginiana</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Koelreuteria paniculata</i>	N%	$\delta^{15}\text{N}$	Field	Salt Lake Valley, USA	[64]
<i>Liriodendron tulipifera</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Malus domestica</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Melia azedarach</i>	N%	$\delta^{15}\text{N}$	Field	Bolivia, Thailand, Cameroon	[62]
<i>Miconia sp</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Nothofagus betuloides</i>	N%	$\delta^{15}\text{N}$	Field	South America	[70]

<i>Nothofagus obliqua</i>	N%		$\delta^{15}\text{N}$	Field	South America	[70]
<i>Ostrya virginiana</i>	N%		$\delta^{15}\text{N}$	Field	North America	[70]
<i>Persea lingue</i>	N%		$\delta^{15}\text{N}$	Field	South America	[70]
<i>Picea abies</i>	N%		$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Picea abies</i>			$\delta^{15}\text{N}$	Field	Switzerland	[66]
<i>Picea abies</i>			$\delta^{15}\text{N}$	Field	Fichtelgebirge, Germany	[119]
<i>Picea abies</i>	N%		$\delta^{15}\text{N}$	Field	Fichtelgebirge, Germany	[120]
<i>Picea abies</i>			$\delta^{15}\text{N}$	Field	Switzerland	[61]
<i>Picea abies</i>		NR, NiR, GS	$\delta^{15}\text{N}$	Ctrl. Cond.	Garmisch- Partenkirchen	[121]
<i>Picea engelmannii</i>	N%		$\delta^{15}\text{N}$	Field	North America	[70]
<i>Picea glauca</i>	N%		$\delta^{15}\text{N}$	Field	North America	[70]

<i>Picea mariana</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Picea mariana</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Fort McMurray, Canada	[69]
<i>Picea rubens</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Picea sitchensis</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Pinus banksiana</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Pinus densiflora</i>	N%, C/N	$\delta^{15}\text{N}$	Field	Korean cities	[122]
<i>Pinus edulis</i>	N%	$\delta^{15}\text{N}$	Field	Grand Canyon, USA	[67]
<i>Pinus pinaster</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Pinus resinosa</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Pinus rigida</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Pinus strobus</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]

<i>Pinus sylvestris</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Pinus sylvestris</i>	N%	$\delta^{15}\text{N}$	Field	Leipzig-Halle, Germany	[123]
<i>Pinus sylvestris</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Populus canadensis</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Populus tremuloides</i>	N%	$\delta^{15}\text{N}$	Field	Salt Lake Valley, USA	[64]
<i>Populus tremuloides</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Prunus avium</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Prunus domestica</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Prunus serotina</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Pseudotsuga menziesii</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Pyrus calleryana</i> Maxim.	N%	$\delta^{15}\text{N}$	Field	Salt Lake Valley, USA	[64]

<i>Quercus petraea</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Quercus robur</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Quercus robur</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Quercus rubra</i>	N%	$\delta^{15}\text{N}$	Field	Europe	[70]
<i>Quercus velutina</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Rhododendron groenlandicum</i>	N%, C/N		Field	Fort McMurray, Canada	[69]
<i>Ricinus communis</i>	N%		Field	Punjab province, Pakistan	[59]
<i>Salix spp.</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Saxegothaea conspicua</i>	N%	$\delta^{15}\text{N}$	Field	South America	[70]
<i>Sorbus americana</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]

<i>Sorbus torminalis</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Swietenia macrophylla</i>	N%	$\delta^{15}\text{N}$	Field	Mato Grosso, Brazil	[124]
<i>Terminalia ivorensis</i>	N%	$\delta^{15}\text{N}$	Field	Bolivia, Thailand, Cameroon	[62]
<i>Thuja occidentalis</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Tibouchina pulcra</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Tilia americana</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Tilia cordata</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Tilia cordata</i>		$\delta^{15}\text{N}$	Field	Basque Country, Spain	[26]
<i>Tilia platyphyllos</i>	N%	$\delta^{15}\text{N}$	Field	Germany	[63]
<i>Toona ciliata</i>	N%	$\delta^{15}\text{N}$	Field	Bolivia, Thailand, Cameroon	[62]

<i>Trema micrantha</i>		$\delta^{15}\text{N}$	Field	São Paulo State, Brazil	[49]
<i>Tsuga canadensis</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
<i>Vaccinium oxycoccos</i>	N%, C/N		Field	Fort McMurray, Canada	[69]
<i>Vaccinium vitisidaea</i>	N%, C/N		Field	Fort McMurray, Canada	[69]
<i>Viburnum alnifolium</i>	N%	$\delta^{15}\text{N}$	Field	North America	[70]
