National Emissions Ceilings Directive Article 10 (4) - Complementary Report

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Background

This report provides a description of the new ecosystem monitoring network (EMN) setup under article 9 of the new NEC Directive (Directive 2016/2284). It provides a brief explanation of data and methods focused on terrestrial ecosystems prepared by FCUL on behalf of APA. Furthermore, analytical results are presented, focusing on Annex V parameters and the reporting template.

Monitoring Sites

The EMN was established in 2018 including 3 plots for terrestrial ecosystems and 3 plots for freshwater ecosystems. At field campaign, slight changes were made in the location of the terrestrial ecosystems monitoring plots due to physical constrains. These include exact monitoring site coordinates, elevation, slope, orientation/exposition and plot/sample size, which were corrected in the new template that accompanies this report and presented in section 0 (Reporting on sites) in this report.

Site selection

The selection of the monitoring sites was based on the following criteria:

For terrestrial ecosystems:

1. Public forests with state management
2. Proximity to air quality stations (CAFE Directive)
3. Air pollution gradients

For freshwater ecosystems:

1. Monitoring sites of the Water Framework Directive
2. Proximity to air quality stations
3. Pristine waters, not influenced by agriculture activity or industry

Biophysical characterization

Monitoring sites are located in three distinct regions of Portugal, covering a climate gradient with temperatures increasing and precipitation decreasing towards south (Table I and Figure 1). The regional wind regime in Portugal is mostly influenced by the Northern Atlantic, showing a strong northern component in wind direction along the western coastline (including the northernmost monitoring sites) (cf. Lorente-Plazas et al., 2015). In the southernmost monitoring site, the wind direction is also influenced by the Northern Atlantic but shows a stronger north-western component. In all regions, there are no significant seasonal changes in wind direction, only in velocity, which increases during the summer (cf. Lorente-Plazas et al., 2015).

All ecosystem monitoring sites are within Mediterranean Bio-geographical Region, which occupies approximately 95% of the whole national territory.

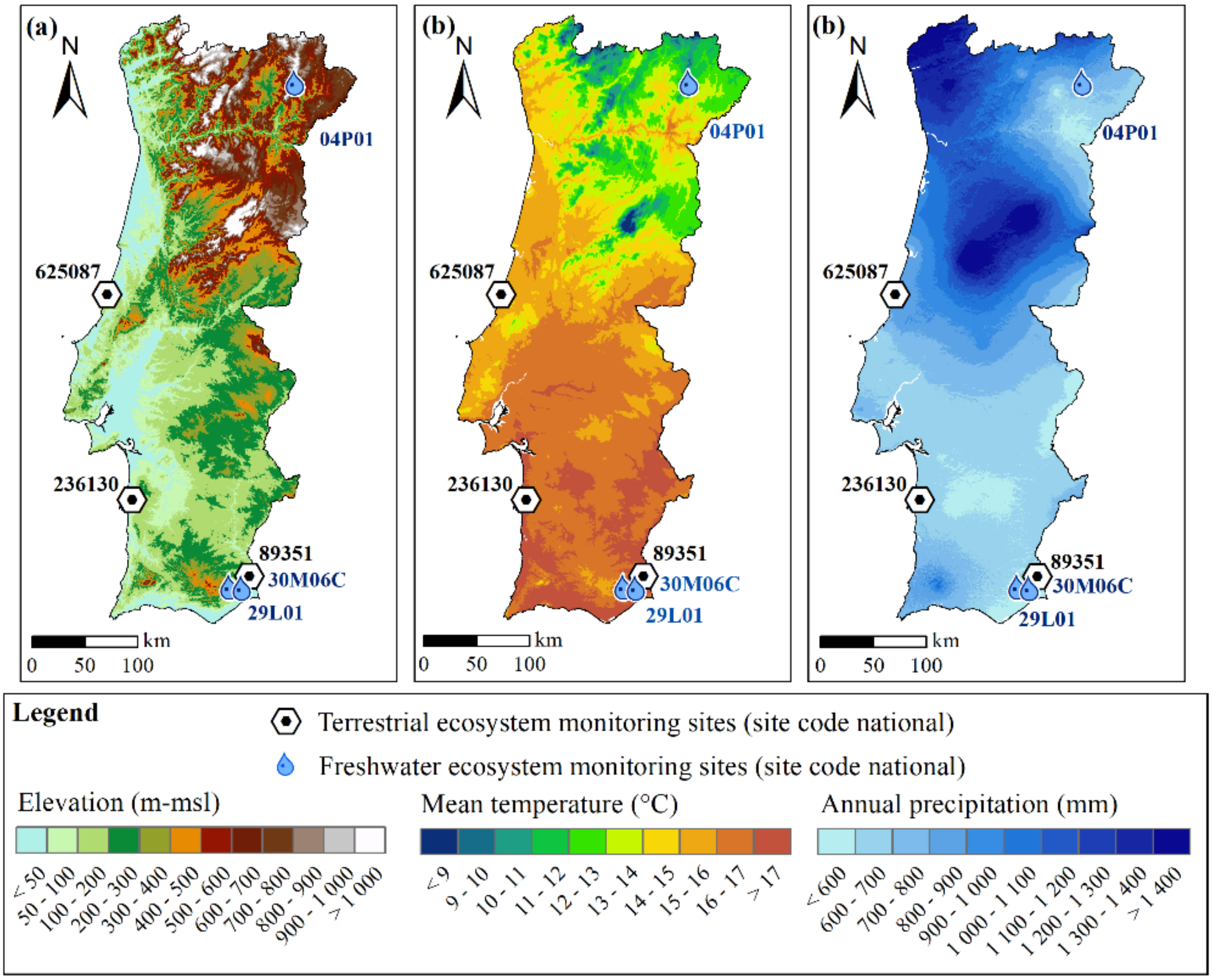

Figure 1: Location of monitoring sites over: (a) Elevation above mean sea level (msl); (b) average annual temperature; (c) Annual precipitation map. The ASTER Global Digital Elevation Model is a product of METI and NASA (NASA/METI/AIST/Japan Spacesystems, and U.S./Japan ASTER Science Team, 2009). Temperature and precipitation data from the Digital Climatic Atlas of the Iberian Peninsula (Ninyerola et al., 2005)

Table I: Climatic information of the monitoring sites based on data from the Digital Climatic Atlas of the Iberian Peninsula, collected from 1950 to 1999 (Ninyerola et al., 2005)

Site code national	Monitored Ecosystem	Site name	Average temperature (°C)			Precipitation (mm)
			Minimum	Mean	Maximum	
625087	Terrestrial	Mata Nacional de Leiria	11.0	15.3	22.8	841
236130		Área Florestal de Sines	11.8	17.1	23.5	651
89351		Mata Nacional Terras da Ordem	12.2	17.6	24.0	588
04P01	Freshwater	Albufeira do Azibo	6.7	12.6	18.6	717
29L01		Ponte Monte dos Fortes	12.3	17.6	23.9	575
30M06C		Albufeira Odeleite/Choça Queimada	12.3	17.7	24.1	533

Terrestrial ecosystem monitoring was mostly done in accordance to ICP Forest manuals, as indicated in the "Technical specification for NEC Article 10 (4b) requirements on monitoring data reporting under Article 9 of the NEC directive" document. Exceptions to the methods described in the ICP Forest manuals are identified in Relevant NOx and SOx emissions are found over 7km away from the Mata Nacional de Leiria (related with industrial activities related with the production of glass and paper) and Área Florestal de Sines (related with energy production) monitoring sites (Figure 8). Emissions closer to the Área Florestal de Sines monitoring site correspond to maximum national values for NOx and SOx. The terrestrial ecosystem Mata Nacional Terras da Ordem site and all freshwater ecosystem monitoring sites are in nitrogen and sulfur low emission regions (Figure 8). Summarizing, the site selection will offer the opportunity to monitor the effect of air pollution following an air pollution gradient.

Reporting section. Freshwater ecosystems monitoring was done in accordance with the methodologies defined under the Water Framework Directive.

Mata Nacional de Leiria

The monitoring site Mata Nacional de Leiria, located further North, develops on a littoral area. The area is occupied by mature dunes comprising silica-rich sand forming a generally flat to slightly undulated morphology (Gomes et al., 2010). The forest at the monitoring site is a 39-48 years old forest of mixed composition, mainly containing maritime pine (*Pinus pinaster*), oak (*Quercus lusitanica*), ferns (*Pteridium aquilinum*) in regions where light intensity is lowest and invasive species such as acacia (*Acacia* spp) (cf. Gomes et al., 2010) (Figure 2). Relevant plagues affecting the trees are moths, such as the pine processionary (*Thaumetopoea pityocampa Schiff*) and the European pine shoot moth (*Rhyacionia buoliana Schiff*), and beetles (*Tomicus piniperda L.*) (Gomes et al., 2010).

Figure 2: General aspect of the monitoring site Mata Nacional de Leiria

Área Florestal de Sines

The monitoring site at Área Florestal de Sines is located 7.5km inland, comprising one of the most extensive agroforestry properties hold by the Portuguese State, with irregular boundaries and crossed by easements and landlocked properties (Pinho et al., 2012). The monitoring site corresponds to an extensive hummocky mature dune field. In the monitoring site, the forest is mostly composed by oak trees (*Quercus suber* L.) and scattered climbers (*Rubus* sp.) (Figure 3). Relevant plagues affecting the trees are wood boring insect species (*Coroebus undatus*, *Coroebus, florentinus* and *Platypus cylindrus*) and fungi (*Phytophthora* spp and *Biscogniauxia mediterranea*) (Morais, 2012).

Figure 3: General aspect of the monitoring site Área Florestal de Sines

Mata Nacional Terras da Ordem

The Mata Nacional Terras da Ordem site, located further south, comprises an extensive area with discontinuous patches in an irregular hilly terrain. It is based on thin and poorly developed lithosols of shales and greywacke (Amaral et al., 2010). At the monitoring site, there is a predominance of stone pine (*Pinus pinea*) and shrubs (*Cistus ladanifer* and *Genista hirsuta*) (Figure 4). Plagues affecting stone pines in Mata Nacional Terras da Ordem mostly include bark beetles (Coleoptera: Scolytidae, *Tomicus piniperda* L. and *Tomicus destruens* Wollaston) (Amaral et al., 2010). Specifically, at plot level, the pine trees are over 49 years old and have yet to produce pinecones (cf. Amaral et al., 2010). Low productivity and damages by plagues most probably occur due to harsh conditions related with a poorly developed and degraded soil profile (Amaral et al., 2010).

Figure 4: General aspect of the monitoring site Mata Nacional Terras da Ordem

Albufeira do Azibo

Albufeira do Azibo is the northernmost freshwater ecosystem monitoring site (Figure 1, Table I and Figure 5). It comprises a dam with a 91km^2 river basin area and a 4100$\times$1000m^2 reservoir area reaching a maximum depth of 30m (mean depth of 13.2m) (Geraldes & Boavida, 2004; Comissão Nacional Portuguesa de Grandes Barragens, 2019). It was originally built in the 80s to provide water for water supply and for irrigation further downstream (Instituto de Conservação da Natureza e Florestas, 2019), generating only slight water level fluctuations ranging between 1.5 and 2m (Geraldes & Boavida, 2004). Nowadays it is also used for recreational activities, accentuated during the summer (Geraldes & Boavida, 2004). The Albufeira do Azibo is part of the Portuguese Natura 2000 site Morais (Natura 2000 SiteCode: PTCON0023) and it consists of a protected landscape area under national decree-law nº13/99 (3rd of August).

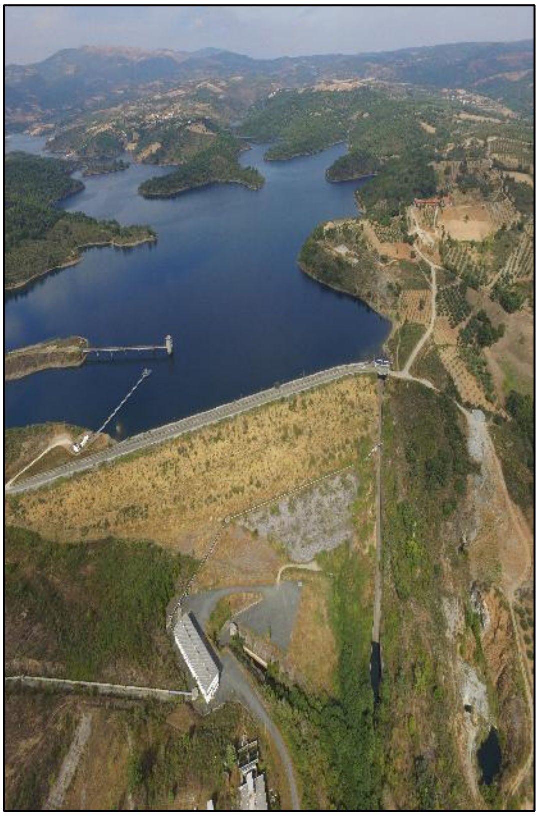

Figure 5: Aerial view of Albufeira de Azibo monitoring site. Photograph from Comissão Nacional Portuguesa de Grandes Barragens (2019)

Albufeira Odeleite/Choça Queimada

The freshwater monitoring site Albufeira Odeleite/Choça Queimada (Figure 6, Figure 1 and Table I) is located in the river basin of Albufeira Odeleite/Choça Queimada with an area of 352km^2, with 7200×1000m^2 area reservoir, with a maximum depth of 30m (Galvão et al., 2012; Comissão Nacional Portuguesa de Grandes Barragens, 2019). It was built in the 1997 mostly to provide water for household consumption, but also for irrigation (Galvão et al., 2012; Comissão Nacional Portuguesa de Grandes Barragens, 2019). Deforestation and farming mal practices in the beginning of the XX century has contributed to soil erosion and desertification (Galvão et al., 2012). With the objective of improving the soil profile, pine woods have been replanted in the watershed (Galvão et al., 2012), including the Mata Nacional Terras da Ordem terrestrial ecosystem monitoring site. Nowadays, with few exceptions, there are no human impacts in the watersehad (Galvão et al., 2012). The Albufeira Odeleite/Choça Queimada have repeatedly developed cyanobacteria blooms in the summer, in association with high hydraulic retention (Galvão et al., 2012).

Figure 6: Aerial view of Albufeira Odeleite/Choça Queimada monitoring site Photograph from Comissão Nacional Portuguesa de Grandes Barragens (2019)

Ponte Monte dos Fortes

The Ponte Monte dos Fortes freshwater monitoring site (

Figure **7**) is located approximately 12km upstream of the Albufeira Odeleite/Choça Queimada dam. It drains a river basin of approximately 290km^2. This monitoring site coincides with a hydrometric monitoring station functioning since the 60s. In this section the river is ephemeral, the average daily level averaging zero during summer months (August and September) (data from Sistema Nacional de Informação de Recursos Hídricos, 2019).

Figure 7: View of the Ponte Monte dos Fortes freshwater monitoring site. Photograph from Sistema Nacional de Informação de Recursos Hídricos (2019)

Air pollution at the monitoring sites

One of the site selection criteria of the monitoring sites was based on the characterization of air pollution gradients in Portugal, based on official reported values from the 2015 national inventory (INERPA - Inventário Nacional de Emissões Atmosféricas) of ammonia (NH_3), nitrogen oxide (NOx) and sulfur oxide (SOx) emissions in 2015 (version 2017-05-01).

Based on the emissions inventory, ammonia emissions mostly result from livestock and agricultural-related activities, and show higher values over 10km away from the Mata Nacional de Leiria and Área Florestal de Sines monitoring sites (Figure 8). However, the property being monitored in Área Florestal de Sines was, up to last year, used for beef cattle raise and is near fields used for agricultural proposes. The continued monitoring of the Área Florestal de Sines monitoring site will offer the opportunity to evaluate the effects of the decrease in local ammonia emissions at plot-level.

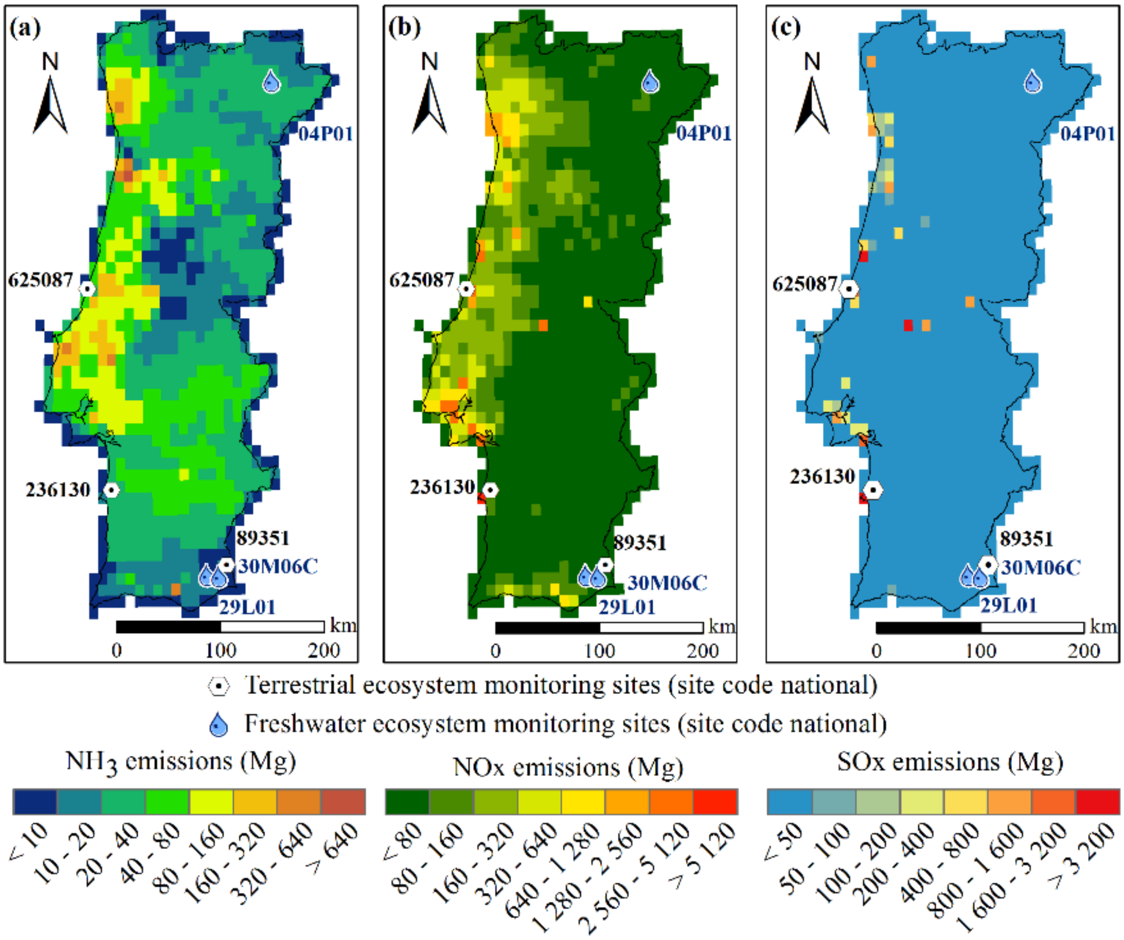

Figure 8: Emissions of ammonia (NH_3), nitrogen oxide (NOx) and sulfur oxide (SOx) emissions in 2015 obtained from INERPA (version 2017-05-01)

Relevant NOx and SOx emissions are found over 7km away from the Mata Nacional de Leiria (related with industrial activities related with the production of glass and paper) and Área Florestal de Sines (related with energy production) monitoring sites (Figure 8). Emissions closer to the Área Florestal de Sines monitoring site correspond to maximum national values for NOx and SOx. The terrestrial ecosystem Mata Nacional Terras da Ordem site and all freshwater ecosystem monitoring sites are in nitrogen and sulfur low emission regions (Figure 8). Summarizing, the site selection will offer the opportunity to monitor the effect of air pollution following an air pollution gradient.

Reporting

The ecosystem monitoring program was focused on obtaining indicators listed in the Annex V of the NEC Directive. However, whenever available, other indicators listed in the reporting template were measured/described.

Reporting on sites

Monitoring site coordinates are INSPIRE compliant (geographic coordinates in decimal degrees with 5 decimals) and to monitoring plot centroid coordinates, obtained with a GPS (Table II). MAES ecosystem type reported in 2018 remains unaltered. EUNIS habitat classification was selected from the 2017 revised classification (available at https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification). Moreover, the ecosystem type as defined by the MAES classification (Mapping and Assessment of Ecosystems and their Services), also for all monitoring sites, is Woodland, forest and other wooded land. Following the EUNIS classification, the habitats observed in the monitoring sites are: (1) mixed deciduous and coniferous woodland in Mata Nacional de Leiria; (2) Mediterranean evergreen oak woodland in Área Florestal de Sines; (3) Coniferous woodland in Mata Nacional Terras da Ordem; (4) and Inland surface water in all freshwater monitoring sites.

Table II: Monitoring site geographical coordinates. DD-decimal degrees

Site code national	Monitored Ecosystem	Site name	Longitude (DD)	Latitude (DD)
625087	Terrestrial	Mata Nacional de Leiria	-9.01627	39.76890
236130		Área Florestal de Sines	-8.74791	38.01891
89351		Mata Nacional Terras da Ordem	-7.49877	37.35787
04P01	Freshwater	Albufeira do Azibo	-6.8897	41.5604
29L01		Ponte Monte dos Fortes	-7.6253	37.3411
30M06C		Albufeira Odeleite/Choça Queimada	-7.4960	37.3293

Acidification exceedances in the region can only be obtained by integrating nitrogen and sulfur deposition using a modelling approach and are yet unknown. Determination of critical load exceedances for eutrophication in the monitoring sites was based on modelled nitrogen deposition gridded data for 2016, extracted from EMEP/MSC-W model (European Monitoring and Evaluation Programme/Meteorological Synthesizing Center-West) (Figure 9a) and considering critical loads for the ecosystems in the study sites, reported by Bobbink & Hettelingh (2010).

An indicative value of 5 kg N/ha.year was assumed for Mixed deciduous and coniferous woodland and of 3-10 kg N/ha.year for freshwater habitats, corresponding to lower critical values available for similar habitats (coniferous forest and oligotrophic lakes, respectively) (Table III)

Exceedances of critical levels of ozone are shown in Figure 9b and Table III, and were determined based on the Phytotoxic O_3 Dose (PODyIAM) extracted from the 2016 EMEP/MSC-W model results, and following the methodology in the most recent ICP vegetation manual (Mills et al., 2017). Critical levels defined for Mediterranean forest trees are of 13.7 mmol/m^2 (Mills et al., 2017).

Nitrogen deposition is below critical loads in all monitoring sites. In what concerns critical levels of ozone, exceedance was detected in Mata Nacional de Leiria and Área Florestal de Sines monitoring sites (Figure 9). In this case, a mapped PODy values of 22.07 and 16.97mmol/m^2 were obtained (Table III), which amounts to an exceedance of 8.37 and 3.27mmol/m^2, respectively.

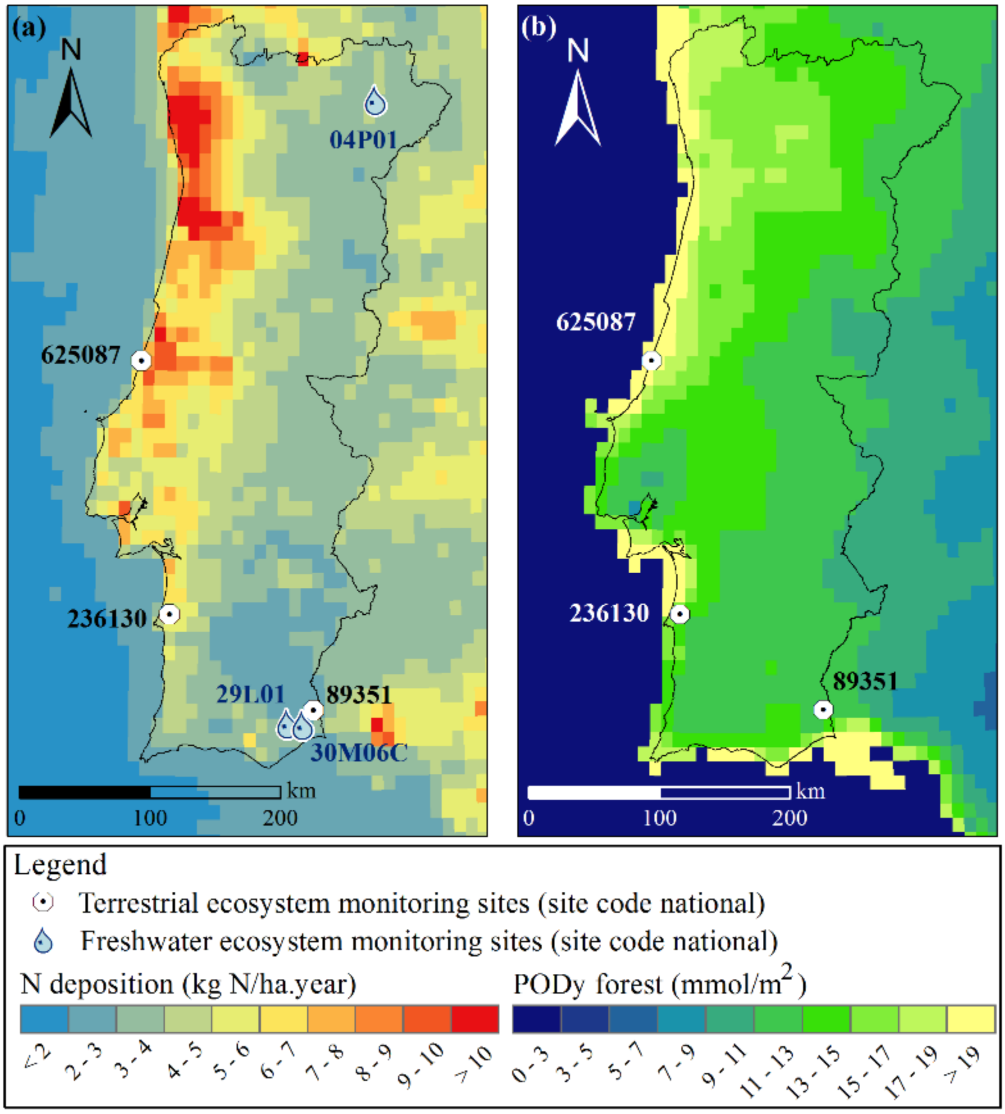

Figure 9: EMEP model results for 2016: (a) Nitrogen deposition and (b) PODy forest

Table III: Empirical critical loads of N deposition and Ozone concentration and EMEP N deposition and PODy for forest in 2016. *indicative value. N.A.-not applicable

Monitoring site	EUNIS Habitat	Empirical Critical loads of N deposition (kg N/ha.year)	EMEP model N deposition (kg N/ha.year)	PODy Critical level (mmol/m^2)	EMEP model forest PODy (mmol/m^2)
Mata Nacional de Leiria	Mixed deciduous and coniferous woodland	5*	4.36	13.7	22.07

<table>
<tr><th>Monitoring site</th><th>EUNIS Habitat</th><th>Empirical Critical loads of N deposition (kg N/ha.year)</th><th>EMEP model N deposition (kg N/ha.year)</th><th>PODy Critical level (mmol/m^2)</th><th>EMEP model forest PODy (mmol/m^2)</th></tr>
<tr><td>Área Florestal de Sines</td><td>Mediterranean evergreen oak woodland</td><td>10-20</td><td>5.88</td><td>13.7</td><td>16.97</td></tr>
<tr><td>Mata Nacional Terras da Ordem</td><td>Coniferous woodland</td><td>5-10</td><td>2.97</td><td>13.7</td><td>12.02</td></tr>
<tr><td>Albufeira do Azibo</td><td rowspan="3">Inland surface waters</td><td>3-10*</td><td>3.60</td><td colspan="2" rowspan="3">n.a.</td></tr>
<tr><td>Ponte Monte dos Fortes</td><td>3-10*</td><td>2.59</td></tr>
<tr><td>Albufeira Odeleite/Choça Queimada</td><td>3-10*</td><td>2.97</td></tr>
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Vegetation and Soil

Site parameters (elevation, slope and orientation/exposition) were determined with geographical information system (GIS) software. Elevation was obtained by overlapping the plot centroid to the ASTER Global Digital Elevation Model (NASA/METI/AIST/Japan Space systems, and U.S./Japan ASTER Science Team, 2009). Slope and orientation/exposition was determined in plot centroids over the digital terrain model using GIS software. Site parameters are presented in Table IV.

Table IV: Site parameters

Site code national	Site name	Elevation (m.a.s.l)*	Slope (°)	Orientation /exposition
625087	Mata Nacional de Leiria	62	11	West (290°N)
236130	Área Florestal de Sines	69	5	Southwest (233°N)
89351	Mata Nacional Terras da Ordem	127	8	South (183°N)

*Meters above sea level

Characterization of parameters for vegetation (all ecosystem types and forest and other woodland) followed indications of the ICP Forest manual, Part II (Ferreti et al., 2017). Codes provided type of species mixture, species number, forest type, age class, and number of layers (columns L, M, O, P, and Q in the reporting template) were based on the classification listed in Table V, as indicated by Ferreti et al. (2017). Área Florestal de Sines monitoring site was previously used for pasture, including silvo-pastural systems. However, it has only been used for cork oak extraction in the past year. For the management parameter, the "origin of current stand" described in Ferreti et al. (2017) was used (Table V). Given the lack of additional definitions and the limited choice between classes, classification of all parameters was decided based on the closest alternative to field observations. The monitoring sites Mata Nacional de Leiria and Manta Nacional Terras da Ordem correspond to "coniferous forests of the Mediterranean, Anatolian and Macaronesian regions" forest type (code 10 in the reporting template) (Table VI). The Área Florestal de Sines monitoring site corresponds to "Broadleaved evergreen forest" (code 9 in the reporting template).

Further characterization of the vegetation in the monitoring sites is presented in

Table VI and

Table VII.

Table V: URL with the classification table used in characterizing parameters for vegetation

Parameter	URL of classification tables
Management	https://www.icp-forests.org/documentation/Dictionaries/d_stand_actual.html
Type of species mixture	https://www.icp-forests.org/documentation/Dictionaries/d_tree_species_mix.html
Species number	https://www.icp-forests.org/documentation/Dictionaries/d_tree_spec.html
Forest type	https://www.icp-forests.org/documentation/Dictionaries/d_forest_type.html
Age class	https://www.icp-forests.org/documentation/Dictionaries/d_mean_age.html
Number of layers	https://www.icp-forests.org/documentation/Dictionaries/d_tree_layers.html

Table VI: Characterization of vegetation (all ecosystem types)

Site code national	Site name	Plot size (m^2)	Date of sampling	Manage-ment	Forest type
625087	Mata Nacional de Leiria	41510	08-05-2019	Planted	Coniferous forests of the Medi-terranean, Anatolian and Maca-ronesian regions (code 10)
236130	Área Florestal de Sines	3375	07-05-2019	Mixed	Broadleaved evergreen forest (code 9)
89351	Mata Nacional Ter-ras da Ordem	5606	01-06-2019	Planted	Coniferous forests of the Medi-terranean, Anatolian and Maca-ronesian regions (code 10)

Table VII: Characterization of vegetation structure (forest and other woodlands)

Site code na-tional	Site name	Species mixture	Main species	Age (years)	Number of tree layers	Coverage of tree layers (%)	Can-opy closure (%)
625087	Mata Nacional de Leiria	Irregular	Pinus pinaster	43	2	90	70
236130	Área Florestal de Sines	Monocul-ture	Quercus suber	Unknown	1	30	30
89351	Mata Nacional Terras da Ordem	Monocul-ture	Pinus pinea	49	1	30	30

Soil profile characterization was undertaken together with soil chemical monitoring and followed the ICP Forest manual, Part X, for sampling and analysis of soil (Cools & De Vos, 2016). Soil profile description was undertaken in the field, based on 5 boreholes using an Edelman auger (Ø=8cm) and head. Effective soil depth was described as >100cm when continuous rock was at higher depths (Cools & De Vos, 2016). Soil profile and horizon characterization was based on the information available in the ICP Forest manuals (Table VIII). Soil profile and horizon classification was based solely on field observations and does not include analytical data.

Table VIII: Sources of classifications used in the characterization of soil profile and horizons

Parameter	Classification source
Soil Type	Table in ICP Forest manual, Part X, Annex II, page 132
Soil Profile	Table 2 in IUSS Working Group WRB (2015) page 10
Soil horizon depths	Top of horizons identified in the field. Vales are separated by a semicolon when there is more than one horizon in the soil profile.
Parent material	Table in ICP Forest manual, Part X, Annex II, page 111
Humus type/Peat Type	Soil horizon designation as described in the ICP Forest manual, part X, Annex VI, section 2, from page 154 onwards
Mean highest and mean lowest groundwater table depth	Table in ICP Forest manual, Part X, Annex II, section 2.13.1, page 115.
Groundwater table	Table in ICP Forest manual, Part X, Annex II, section 2.13.2, page 115
Horizon name	Soil horizon designation as described in the ICP Forest manual, part X, Annex VI, section 2, from page 154 onwards.

Parameter	Classification source
Upper and lower limit horizon	As observed in the field, starting in the mineral layer. Different horizons in one plot/soil profile are separated by a semicolon.
Horizon distinctness and topography	Tables in ICP Forest manual, Part X, Annex II, sections 3.1.3 and 3.1.4, page 122. First code is associated with distinctness, second code with topography, separated by semicolons.
Code coarse fragments	Described as Abundance in ICP Forest manual, Part X, Annex II, sections 3.7.1, page 129.
Coarse fragments	Based on weight difference after removal of > 2mm fraction by dry sieving. Method described in ICP Forest manual, Part X, Annex I, Soil analysis method 1 (SA01), page 32.
Code porosity	Tables in ICP Forest manual, Part X, Annex II, sections 3.12, page 136.

Soils of Mata Nacional de Leiria correspond to Arenosols. An organic top horizon is sometimes found and classified has litter (OL), followed by a C horizon which include unlithified material little affected by pedogenetic processes (Table IX to

Table XI). Soils of Área Florestal de Sines correspond to Arenosols also, including only a mineral layer comprising unlithified material only slightly affected by pedogenetic processes, described as a C horizon.

Soils of Mata Nacional Terras da Ordem are poorly developed and classified as Regosols. They comprise a thin top mineral layer only slightly affected by pedogenetic processes and described as a C horizon, sitting on top of a hard bedrock of shale, classified as an R layer. The depth of the R horizon or bedrock (32cm) corresponds to an average from all 5 sampling locations.

Additional soil profile and horizon properties are described in Table IX and

Table XI.

Table IX: Soil profile characteristics in the monitoring sites based on field observations

Site code national	Site name	Date of profile description	Soil type	Parent material	Humus type/ Peat Type	Groundwater table	Groundwater table	Effective soil depth (cm)
625087	Mata Nacional de Leiria	08-05-2019	Single grain	Aeolian deposits	Litter (OL)	No water table observed or unknown	No water table	>100
236130	Área Florestal de Sines	07-05-2019	Single grain	Aeolian deposits	Absent	No water table observed or unknown	No water table	>100
89351	Mata Nacional	01-06-2019	Single grain	Metamorphic rocks	Absent	No water table observed or unknown	No water table	32

Site code national	Site name	Date of profile description	Soil type	Parent material	Humus type/ Peat Type	Groundwater table	Groundwater table	Effective soil depth (cm)
	Terras da Ordem							

Table X: Soil horizon characteristics in the monitoring sites based on field observations

Site code national	Site name	Sampling date	Sampling depth (cm)	Horizon name	Upper and lower limit horizon	Distinctness	Topography
625087	Mata Nacional de Leiria	08-05-2019	0-100	Litter (OL)	-	Very sharp	Smooth
				C horizon	0-100		
236130	Área Florestal de Sines	07-05-2019	0-100	C horizon	0-100	-	-
89351	Mata Nacional Terras da Ordem	01-06-2019	0-32	C horizon	0-32	Abrupt	Irregular
				R layer	>32		

Table XI: Soil horizon characteristics in the monitoring sites based on observations of collected samples

Site code national	Site name	Code coarse fragments	Coarse fragments (% weight)	Code porosity
625087	Mata Nacional de Leiria	Very few to few	0.257	High
236130	Área Florestal de Sines	Common	8.404	Medium
89351	Mata Nacional Terras da Ordem	Common	6.663	Low

Terrestrial ecosystem-vegetation

Sampling and analysis of needles and leaves mostly followed indications in the ICP Forest manual, Part XII (Rautio et al., 2016). A minimum of 5 trees per monitoring site, belonging to the main species, were randomly selected and sampled (Figure 10). Leaves and needles were collected using an extendable lopper. A composite sample per monitoring site was made by mixing equal quantities of each sample. Only composite samples were analysed, therefore the variance of the elements reported cannot be presented.

For all these monitoring sites, dominant trees correspond to evergreen species. According to Rautio et al., (2016), sampling of needles and leaves must occur during the dormancy period. In Portugal, the dormancy period of maritime pines (*Pinus pinaster*), the dominant species in Mata Nacional de Leira monitoring site, is during summer months, from July to September (cf. Vieira et al., 2013).

The dormancy period of cork oak (*Quercur suber* L.), the dominant species in Área Florestal de Sines monitoring site, occurs from July to February, with maximum growth detected during spring, associated with spring precipitation (Oliveira et al., 1994; Costa et al., 2016).

The dormancy period of stone pine (*Pinus pinea*), the dominant species in Mata Nacional Terras da Ordem monitoring site, is from October to April (cf. Mutke et al., 2003). The sampling in Mata Nacional de Leiria occurred between May and June, and therefore deviates from the indications of Rautio et al., (2016). In addition, due to the height of the pine trees, it wasn't possible to sample the upper third of the crown.

Taking into consideration the regular wood exploitation in Mata Nacional de Leiria, a second set of sample trees will be included in the upcoming sampling to guarantee that future monitoring is not compromised in case some of the sampled trees are knocked down.

Pre-treatment of samples and analytical methods followed procedures describe in Rautio et al., (2016). The key indicators for nutrient balance in foliage listed in Annex V of the NEC directive (N/P, N/K and N/Mg) were determined. Potassium (K), magnesium (Mg) and phosphorous (P) were analysed at the Portuguese Environment Agency Laboratory, using ICP-AES. Carbon (C) and nitrogen (N) were analysed by the certified Stable Isotopes and Instrumental Analysis Facility in Faculdade de Ciências of the University of Lisbon, using elemental analysis. Analytical data from needles and leaves are presented in

Table XII, and parameters for nutrient balance in foliage are shown in Table XIII (added as Appendix 1 in the reporting template)

Table XII: Relevant parameters for vegetation in the monitoring sites

Site code national	Site name	Sampling date	Dry mass/ 100 leaves / 1000 needles	C_{tot} (g/100g)	N_{tot} (mg/g)	P (mg/g)	Mg (mg/g)	K (mg/g)
625087	Mata Nacional de Leiria	08-05-2019	195.70	51.05	8.83	0.57	1.54	1.55
236130	Área Florestal de Sines	04-05-2019	7.220	50.77	16.14	1.00	1.64	2.04

Site code national	Site name	Sampling date	Dry mass/ 100 leaves / 1000 needles	C_{tot} (g/100g)	N_{tot} (mg/g)	P (mg/g)	Mg (mg/g)	K (mg/g)
89351	Mata Nacional Terras da Ordem	01-06-2019	24.47	50.33	10.82	1.08	3.27	1.51

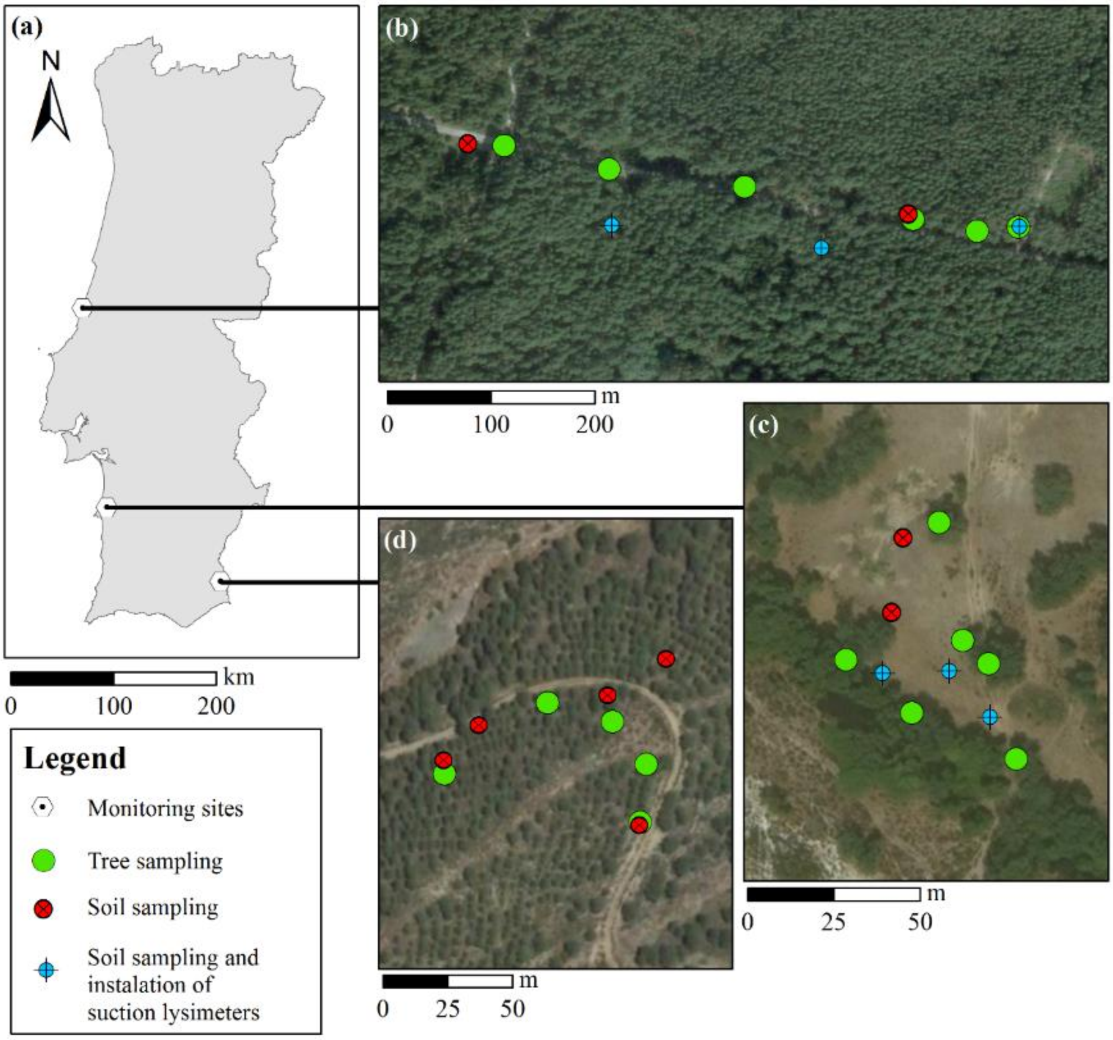

Figure 10: (a) Location of monitoring sites; (b) Sampling undertaken in Mata Nacional de Leiria; (b) Sampling undertaken in Área Florestal de Sines; (d) Sampling undertaken in Mata Nacional Terras da Ordem. Source of Satelite images: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Table XIII: Nutrient balance in foliage in the monitoring sites

Site code national	Site name	N/P	N/K	N/Mg
625087	Mata Nacional de Leiria	15.47	5.71	5.75
236130	Área Florestal de Sines	16.19	7.93	9.84
89351	Mata Nacional Terras da Ordem	10.00	7.14	3.31

Terrestrial ecosystem-solid matrix

Soil sampling in the monitoring sites (Figure 10) was done using an Edelman auger (Ø=8cm) and head. Sampling was based on indications of Cools & De Vos (2016). The number of sampling points per site was five. Mineral soil was collected at 4 fixed depths whenever possible (0-10cm; 10-20cm; 20-40cm and 40-80cm). Samples were not collected when the soil was close to field capacity.

Soil matrix parameters were determined for composite samples, which include 4 distinct depths of mineral soil in Mata Nacional de Leira and in Área Florestal de Sines (0-10cm, 10-20cm, 20-40cm and 40-80cm) and only one in Mata Nacional Terras da Ordem (0-10cm). In the former, due to a poorly developed soil profile, it was not possible to collect 5 samples and generate a composite sample for the remaining mineral soil depths.

The pre-treatment of soil samples for physico-chemical analysis followed the methods described by Cools & De Vos (2016). A composite sample was created by mixing equal quantities of each sample, using a minimum of five samples. Chemical analysis was performed for the < 2mm soil fractions of the composite samples, therefore the variance of the elements in the plot cannot be determined. Pre-treatment and chemical analysis of the composite samples followed indications of Cools & De Vos (2016). Relevant soil parameters and methods for their determination are presented in Table XIV.

Table XIV: Relevant soil parameters and methods for their determination

Parameter	Measurement method	Source of soil analysis method description
pH ($CaCl_2$)	pH-electrode	Soil analysis Method 6 (SA06) in ICP Forest manual, Part X, Annex I
pH (H_2O)	pH-electrode	
Total organic carbon	Dry Combustion at ≥ 900 °C	Soil analysis Method 8 (SA08) in ICP Forest manual, Part X, Annex I
Total nitrogen	Elemental analysis	Elemental analysis
Free H^+	‘German' method	

Parameter	Measurement method	Source of soil analysis method description
Exchangeable cations Al, Ca, Mg, K, Na	ICP	Soil analysis Method 10 (SA10) in ICP Forest manual, Part X, Annex I

Derived soil parameters include Cations Exchange Capacity (CEC), Base Saturation (BS), and Cations exchange (cations$_{ex}$). CEC was obtained by summing base cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and Mn^{2+}) and acidic cations (Al^{3+} and H^{+}) in cmol/kg (Robertson et al., 1999). According to Sono et al. (2014), BS is the percentage of CEC occupied by the basic cations Ca^{2+}, $Mg^{2+}$and K^{+}. In this report BS also includes Na^{+} as a basic cation given that its value was not negligible (

Table XVII). Exchangeable acidity was determined as the sum of exchangeable acid cations: Al, Fe, Mn and free H^{+} (Cools & De Vos, 2016). The parameter Cations$_{ex}$ (column R in the reporting template), is not defined or described in Cools & De Vos (2016) and was assumed to be relative to concentrations of exchangeable cations. This information is presented in a newly added sheet in the reporting template (Appendix 2) and in

Table XVII of this report. Relevant parameters for vegetation in the monitoring sites are presented in Table XV and

Table XVI. Exchangeable cations used in the determination of CEC, BS and Acidity are presented in

Table XVII.

Table XV: Relevant soil analytical parameters for mineral composite samples at the monitoring sites

Site code national	Site name	Sampling date	Sampling depth (cm)	C_{tot} (g/kg)	C_{org} (g/kg)	N_{tot} (g/Kg)	C/N
625087	Mata Nacional de Leiria	08-05-2019	0-10	19.30	12.700	0.86	22.34
			10-20	14.69	6.800	0.61	24.02
			20-40	8.61	4.700	0.34	25.29
			40-80	3.01	2.100	0.12	25.08
236130	Área Florestal de Sines	07-05-2019	0-10	7.64	6.800	0.62	12.27
			10-20	4.79	5.600	0.37	12.89
			20-40	3.23	3.800	0.27	11.93
			40-80	1.39	3.200	0.11	12.64

Site code national	Site name	Sampling date	Sampling depth (cm)	C_{tot} (g/kg)	C_{org} (g/kg)	N_{tot} (g/Kg)	C/N
89351	Mata Nacional Terras da Ordem	01-06-2019	0-10	35.06	30.800	1.83	19.18

Table XVI: pH, CEC, BS and acidity from composite samples collected in the monitoring sites

Site code national	Site name	Sampling depth (cm)	pH (H_20)	pH ($CaCl_2$)	CEC (cmol/kg)	BS (%)	$Acidity_{ex}$ (H+)
625087	Mata Nacional de Leiria	0-10	5.442	4.541	7.09	96.80	0.22
		10-20	5.445	4.495	2.82	94.40	0.16
		20-40	5.424	4.071	1.62	80.10	0.32
		40-80	5.400	4.034	0.73	68.10	0.23
236130	Área Florestal de Sines	0-10	5.582	4.636	3.11	94.60	0.17
		10-20	5.685	4.782	2.64	93.30	0.18
		20-40	5.831	4.890	1.94	93.00	0.14
		40-80	6.017	4.980	1.35	94.90	0.07
89351	Mata Nacional Terras da Ordem	0-10	5.696	4.956	11.76	98.70	0.15

Table XVII: Exchangeable cations determined from the analysis of composite samples collected in the monitoring sites

Site code national	Site name	Sampling depth (cm)	Ca (cmol /kg)	K (cmol /kg)	Mg (cmol /kg)	Na (cmol /kg)	Mn (cmol /kg)	Al (cmol /kg)	Fe (cmol /kg)
625087	Mata Nacional de Leiria	0-10	5.12	0.12	1.40	0.23	0.115	0.02	0.003
		10-20	2.03	0.04	0.48	0.11	0.097	0.03	0.005
		20-40	0.95	0.03	0.25	0.08	0.025	0.12	0.006

Site code national	Site name	Sampling depth (cm)	Ca (cmol /kg)	K (cmol /kg)	Mg (cmol /kg)	Na (cmol /kg)	Mn (cmol /kg)	Al (cmol /kg)	Fe (cmol /kg)
		40-80	0.33	0.01	0.10	0.06	0.010	0.10	0.018
236130	Área Florestal de Sines	0-10	1.98	0.11	0.81	0.05	0.003	0.05	0.014
		10-20	1.59	0.10	0.74	0.04	0.100	0.07	0.001
		20-40	1.10	0.08	0.59	0.04	0.084	0.07	0.002
		40-80	0.74	0.06	0.44	0.04	0.048	0.03	0.002
89351	Mata Nacional Terras da Ordem	0-10	5.12	0.12	1.40	0.23	0.024	0.02	0.002

Terrestrial ecosystem-liquid matrix

To collect water from the liquid matrix 9 suction lysimeters were installed per site, following indications of Nieminen et al. (2016). They were placed at 15-20cm, 35-40cm and 55-60cm depths (Figure 11), a total of three replicates per depth and overlapping with soil sampling locations (Figure 10).

In Mata Nacional Terras da Ordem, no lysimeters were installed due to the absence of a soil profile to accommodate 3 replicas at any of the mandatory depths (10-20cm, 20-40cm and 40-80cm).

Figure 11: Installation of suction lysimeters in Mata Nacional de Leiria monitoring site

The Lysimeters in Mata Nacional de Leiria and Área Floresta de Sines were installed in May and June of 2019, when the soil was not close to field capacity, therefore no samples could be collected at that time. The low precipitation and the sandy substrate prevented the conditions needed to extract water samples from the soil using suction lysimeters, which is only possible at field capacity.

The atmospheric deposition derived from precipitation is measured only in Monte Velho air quality monitoring background station (also EMEP reporting station) which assesses the air quality in the scope of the Ambient Air Quality Directive (Directive 2008/50/EC), and is equipped with precipitation collectors. Sampling and chemical analysis is based on the EMEP manual (Norwegian Institute for Air Research, 2002). This station is located approximately 8km from the Área Florestal de Sines monitoring site (Table XIX and Figure 14).

Regular measurements of precipitation amount and concentration of NH_4^+, NO_3^-, SO_4^{-2}, Na^+, Ca^{+2}, Cl^-, Mg^{+2} and K^+ collected in 2015 and 2016, account for 37 samples and are reported in the template.

An alternative source of information regarding nitrogen and sulphur deposition consists in the gridded modelling results from EMEP. These results comprise annual wet deposition maps with 10km resolution available up to 2016 and reported for 2015 and 2016. Concentration of oxidized and reduced nitrogen and oxidized sulphur were extracted from deposition maps at the monitoring sites. Wet deposition of oxidized and reduced nitrogen and oxidized sulphur (excluding sea salt contribution) were converted to concentration in the precipitation (concentration in the precipitation=wet deposition/precipitation) and are represented in Figure 12 (for 2015) and Figure 13 (for 2016) and in Table XVIII.

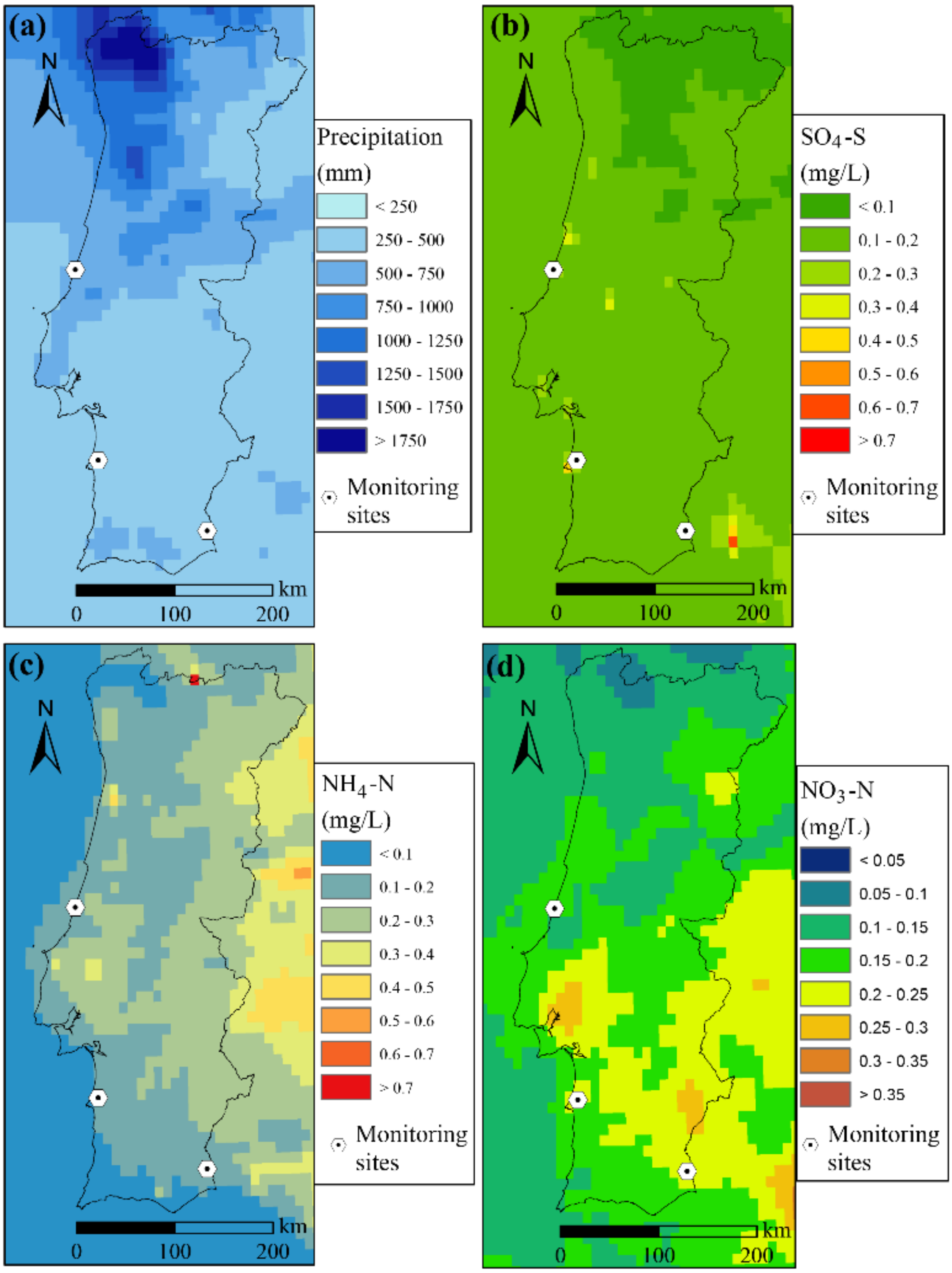

Figure 12: EMEP model results for 2015 for: (a) precipitation and (b) concentration in the precipitation of SO_4-S (excluding sea salt contribution), (c) NH_4-N and (d) NO_3-N

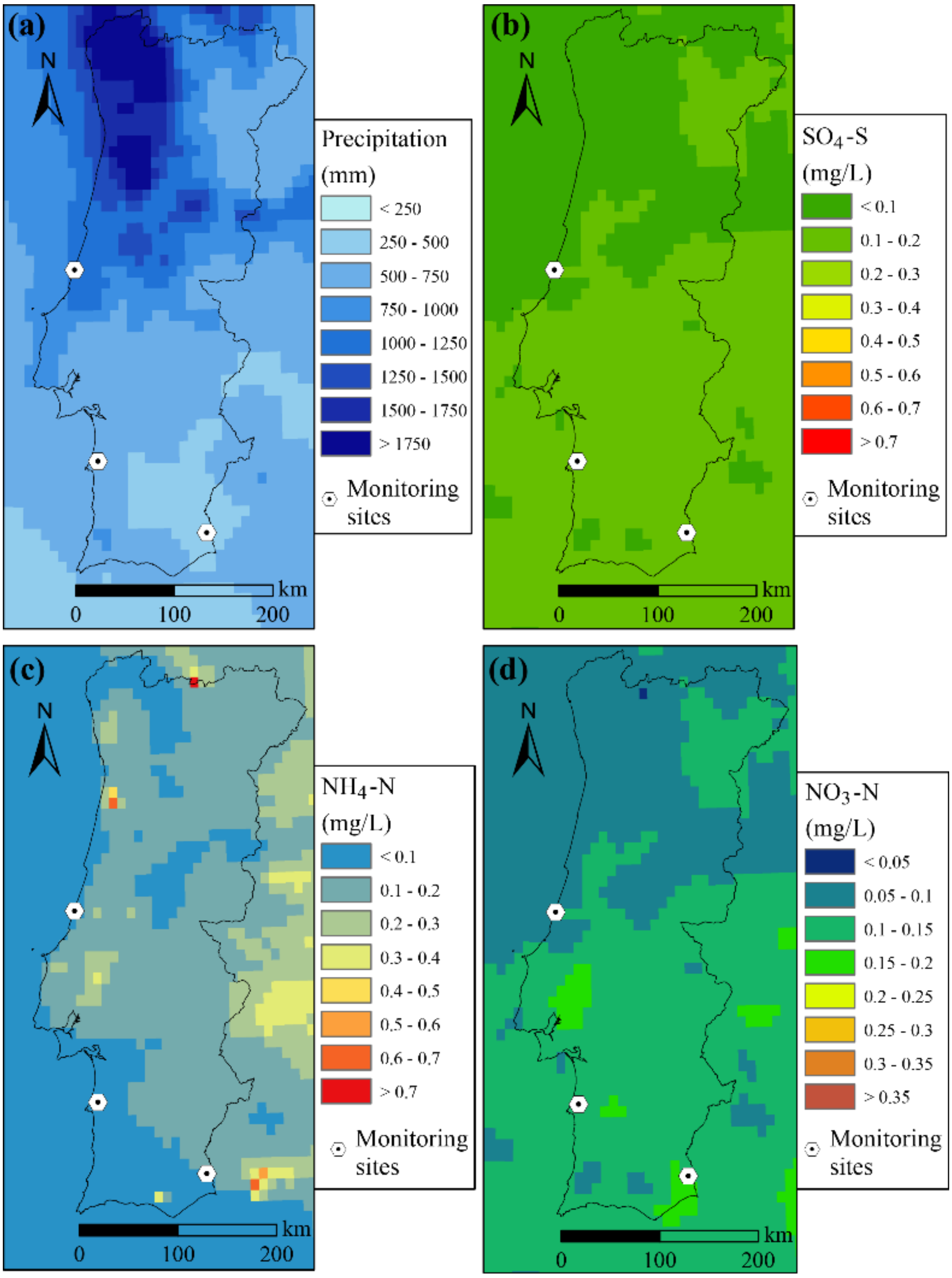

Figure 13: EMEP model results for 2016 for: (a) precipitation and (b) concentration in the precipitation of SO_4-S (excluding sea salt contribution), (c) NH_4-N and (d) NO_3-N

Table XVIII: Precipitation and concentration of N and S compounds in the precipitation based on wet deposition modelling results by EMEP

Monitoring site	Year	Precipitation (mm)	NH_4-N (mg/L)	NO_3-N (mg/L)	SO_4-S (mg/L)
Mata Nacional de Leiria	2015	563	0.1175	0.1454	0.1404
	2016	1039	0.0659	0.0928	0.0929
Área Florestal de Sines	2015	426	0.1270	0.2087	0.2113
	2016	653	0.0490	0.1281	0.1281
Mata Nacional Terras da Ordem	2015	375	0.1462	0.2176	0.1686
	2016	388	0.0956	0.1539	0.1539

O3-air quality-Carbon flux

The information regarding the atmospheric concentration of ozone, nitrogen oxides, and sulphur dioxide was extracted from Air Quality background monitoring stations under Directive 2008/50/EC. These stations are located nearest to the monitoring sites (Table XIX and Figure 14), at a distance of approximately 20km in Mata Nacional de Leiria monitoring site, 8km in Área Florestal de Sines monitoring site and 17km in Mata Nacional Terras da Ordem monitoring site.

Table XIX: Information regarding the air quality background stations nearest to the monitoring site, measuring O_3, NO_2 and SO_2 concentration

Monitoring site	Station ID	Station name	Latitude (DD)	Longitude (DD)
Mata Nacional de Leiria	2019	Ervedeira	39.92389	-8.89167
Área Florestal de Sines	4002	Monte Velho	38.07694	-8.79861
Mata Nacional Terras da Ordem	5012	Cerro	37.31250	-7.67861

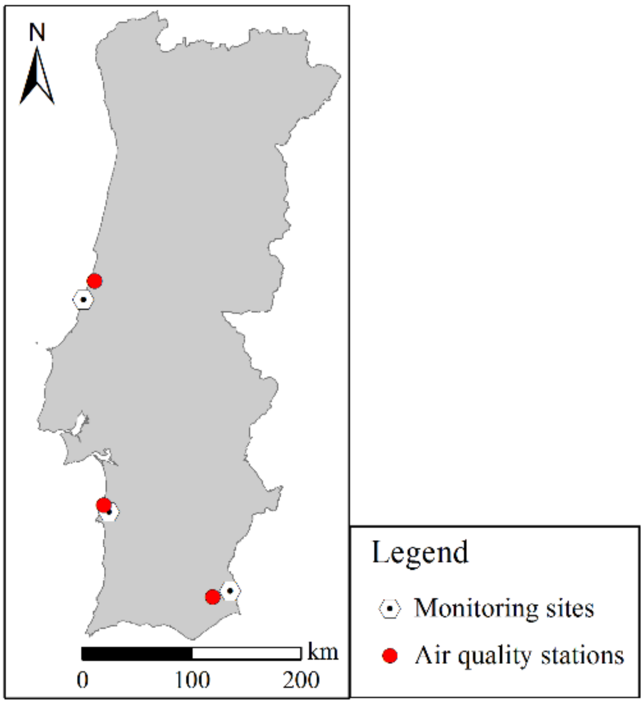

Figure 14: Location of air quality stations nearest to the monitoring sites

Air quality concentration data are mostly based on air quality monitoring stations from the Portuguese national network, which exists since 1995, except for ammonia. Data presented in this report goes back 4 years (from 2015 to 2018) and includes average annual concentrations of hourly data, standard deviation and yearly data coverage percentage (

AOT40-based critical levels for trees correspond to 5ppm*h (cf. Mills et al., 2017), corresponding to 10000µg/m3*hr. The AOT40 determined for the monitoring sites are generally higher, surpassing the double and sometimes reaching three times the critical levels, especially in the southern monitoring sites (Table XXI).

Table XXI and Table XXIII).

AOT40 was determined instead of Phytotoxic O_3 Dose (PODy). AOT40 determination was based on ozone concentrations measured at the air quality stations following the methodology described in Mills et al. (2017). Ozone hourly measured concentrations were corrected for the canopy height, using the ozone gradient presented in the most recent ICP vegetation manual (Mills et al., 2017) and assuming station inlets placed at a height of approximately 3m. Values used for canopy height and growth period were based on field observations and bibliographic references (Oliveira et al., 1994; Mutke et al., 2003; Vieira et al., 2013; Costa et al., 2016), respectively, and listed in Table XX.

Table XX: Canopy height considered for correction of ozone concentration in the monitoring sites and growing period of the trees

Monitoring site	Canopy height (m)	Growing period
Mata Nacional de Leiria	20	October-June
Área Florestal de Sines	10	March-June
Mata Nacional Terras da Ordem	5	May-September

AOT40-based critical levels for trees correspond to 5ppm*h (cf. Mills et al., 2017), corresponding to 10000µg/m^3*hr. The AOT40 determined for the monitoring sites are generally higher, surpassing the double and sometimes reaching three times the critical levels, especially in the southern monitoring sites (Table XXI).

Table XXI: Ozone atmospheric concentrations in air quality stations closest to the monitoring sites, from 2015 to 2018

Monitoring site	Reference date	Mean O_3 (µg/m^3)	O_3 Standard deviation (µg/m^3)	O_3 data coverage (%)	AOT40 (ug/m^3*hr)	AOT40 data coverage (%)
Mata Nacional de Leiria	2015	53.63	25.19	99.42	9933	99
	2016	54.12	26.07	96.63	9539	95
	2017	54.33	24.86	98.55	15100	98
	2018	67.86	21.97	52.33	13866	62
Área Florestal de Sines	2015	70.37	28.99	95.97	36622	99
	2016	78.58	26.73	61.78	31416	99
	2017	-	-	-	-	-
	2018	78.58	36.77	49.54	17761	63
Mata Nacional Terras da Ordem	2015	79.08	18.89	96.61	29875	100
	2016	79.18	17.30	88.71	26970	99
	2017	81.99	18.54	87.85	250032	96
	2018	77.97	22.29	94.13	27466	99

Determination of exceedances of flux-based critical level of ozone was based on modelled gridded EMEP POD for Mediterranean forests, available for 2015 and 2016, and comparison with critical levels of 13.7 mmol/m^2 projected leaf area, presented in the most recent (2017) Chapter 3: Mapping critical levels for vegetation in ICP vegetation manual (https://icpvegetation.ceh.ac.uk/chapter-3-mapping-critical-levels-vegetation). Yearly values were used instead of the advised 5-year average (Table XXII).

Table XXII: Exceedance of ozone concentration critical level parameters in the monitoring stations

Monitoring site	Reference date	Vegetation type (Eunis class)	Species	Exceedance of flux-based critical level of ozone (mmol/m^2 projected leaf area)
Mata Nacional de Leiria	2015	Mixed deciduous and coniferous woodland	*Pinus pinaster*	20.90
	2016			8.37
	2017			-
	2018			-
Área Florestal de Sines	2015	Broadleaved evergreen woodland	*Quercus suber*	14.47
	2016			3.27
	2017			-
	2018			-
Mata Nacional Terras da Ordem	2015	Coniferous woodland	*Pinus pinea*	5.63
	2016			0
	2017			-
	2018			-

The air quality monitoring stations under CAFE Directive do not measure ammonia concentrations. The values reported for ammonia correspond to EMEP modelled gridded concentrations (10km resolution) at the monitoring sites, available up to 2016, are reported for the years 2015 and 2016 (Figure 15). The standard deviation could not be determined, given that these EMEP model results correspond to annual average concentration maps.

Table XXIII: Average yearly atmospheric concentration, standard deviation and data coverage for NO_2 and SO_2 in air quality station closest to the monitoring sites from 2015 to 2018. Average NH_3 yearly concentration based on EMEP model results for 2015 and 2016

Monitoring site	Reference date	NH_3 (µg/m^3)	NO_2 (µg/m^3)	NO_2 Standard deviation (µg/m^3)	NO_2 data coverage (%)	SO_2 (µg/m^3)	SO_2 Standard deviation µg/m^3)	SO_2 data coverage (%)
Mata Nacional de Leiria	2015	0.54	5.90	4.39	99.10	2.13	3.80	39.83
	2016	0.56	5.38	3.98	95.31	3.28	5.39	6.83
	2017	-	5.99	5.01	46.18	-	-	-
	2018	-	3.29	3.54	45.56	4.44	6.39	80.66
Área Florestal de Sines	2015	0.59	5.85	2.74	99.21	5.49	2.40	60.30
	2016	0.70	5.00	1.33	99.02	2.44	3.01	60.91
	2017	-	3.25	1.40	45.75	3.82	2.07	45.61
	2018	-	2.58	0.92	85.78	4.68	2.25	93.01
Mata Nacional Terras da Ordem	2015	0.56	2.84	2.38	99.71	3.47	9.14	1.83
	2016	0.59	3.24	3.77	86.82	2.48	3.80	10.10
	2017	-	3.70	2.12	33.15	4.27	9.90	66.12
	2018	-	1.47	0.85	81.53	7.24	4.73	98.29

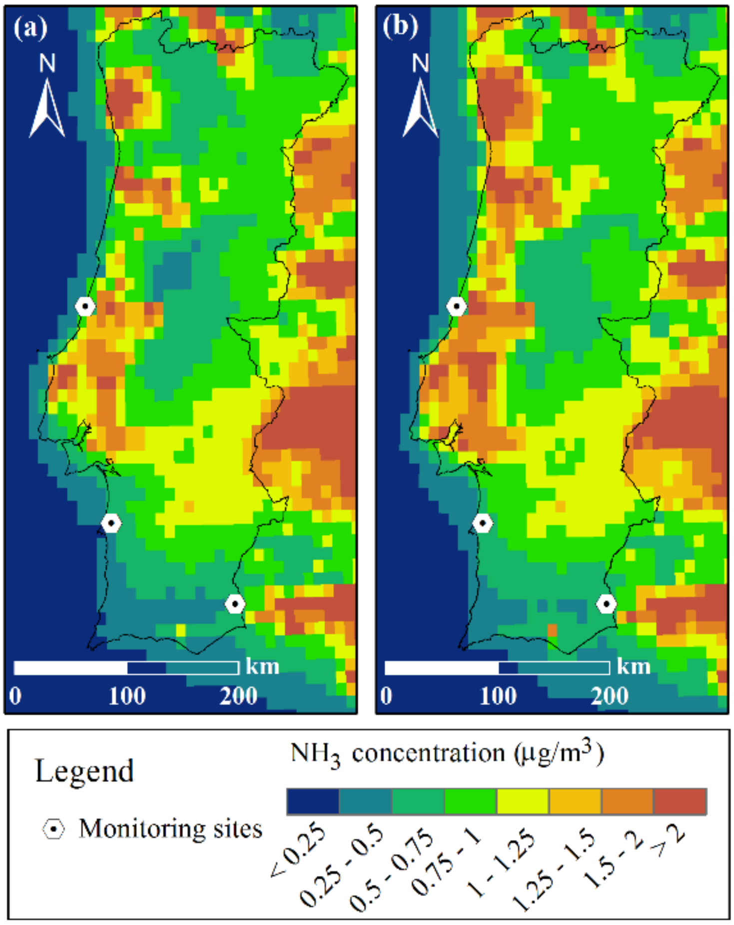

Figure 15: (a) EMEP modelled NH_3 concentration for 2015; (b) EMEP modelled NH_3 concentration for 2016

Foliar damage based on crown condition assessment can be indicative of drought or high concentration of air pollutants other than ozone (Sousa-Silva et al., 2018a; b). In addition, some meteorological occurrences, such as severe storms, hail and late frosts can harm the leaves and needles and contribute to the fostering of plagues that damage the vegetation (Sousa-Silva et al., 2018b). Monitored ozone effects in crown condition, radial growth and foliar visible symptoms detected in Mediterranean forests are not compatible with ozone maximum exposure levels at monitoring sites (Paoletti, 2006). Due to soil moisture deficit frequent in Mediterranean ecosystems, the uptake of ozone by plants is limited due to inhibited stomatal aperture (Emberson et al., 2000), indicating that the Mediterranean forest vegetation is adapted to ozone levels (Paoletti, 2006). Given the observed failure of these parameters in Mediterranean forests, the application of foliar damage as indicative of ozone effects is still under evaluation and will not be reported in this reporting cycle.

Regarding the net carbon flux monitoring no available information is available at the monitoring sites. The only information regarding carbon fluxes is the one listed in the European Fluxes Database Cluster (http://www.europe-fluxdata.eu/home/sites-list) and it is distant from the monitoring sites and prior to 2008.

Freshwater ecosystems

Sampling and analytical methods used in the collection of parameters in the freshwater ecosystem monitoring sites followed the EU Water Framework Directive (Directive 2000/60/EC, 23rd of October 2000) methodologies. Parameters collected were analysed at the Portuguese Environment Agency Laboratory and results are detailed in the reporting template.

Final Remarks

The monitoring network was design to provide information for the parameters described in Annex V of the new NEC Directive. The sampling dates recommended/indicated in the ICP forest manual where followed whenever possible. The low precipitation values in Portugal, and in the monitoring sites, associated with the sandy substrates, generated low water contents in the soil and hindered the collection of water samples using suction lysimeters.

The selection of the monitoring site was based on scientific and on practical criteria, in order to guarantee the continuity of the field's characteristics throughout the next decade.

The methodologies for terrestrial ecosystems were mainly based on IPC manuals. For the evaluation of ozone effects in the vegetation, the methodology is not yet fully agreed for Mediterranean countries and, for that reason, application of these parameters is still under evaluation.

Some of the parameters of the reporting template, identified in the report, are not clearly described in the cited reference manuals. These include management (vegetation and soil) in reporting sites and $cations_{ex}$, in (terrestrial ecosystems-solid matrix) in soil acidity and eutrophication description.

Information concerning hourly air pollution data cover was provided together with yearly parameters and was added in the respective comment sections of the template.

Information listed in the Annex V of the new NED directive, such as nutrient balance in foliage and concentration of exchangeable cations, was added in new excel spreadsheets named Appendix 1 and 2 in the reporting template submitted to the Commission.

Based on the feedback from the Commission, we are now in the process of selecting additional monitoring sites for terrestrial ecosystems that: (1) are representative of Portuguese ecosystems; (2) comprise areas subject to an air pollution gradient; (3) include sensitive ecosystems, such as peatlands.

As reported in this document, the major difficulty during field surveys was to collect water from the soil, due to both low precipitation and sandy substrates that do not retain water. To increase sampling efficiency, a research project is under way to determine the precipitation amount and time interval required to extract water samples from the soil types at the monitoring sites. We anticipate that future findings will generate an increase in sampling frequency.

In what concerns the identification of foliar damage, we aim to explore the use of multispectral imaging in differentiating damage caused by toxic levels of ozone from other origins, such as drought.

Finally, we anticipate evaluating what are the best models available for determining exceedances of critical loads and levels in the Mediterranean, particularly in Portugal, for future reporting.

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