The Second State of Natural Resources Report (SoNaRR2020)

Assessment of the achievement of sustainable management of natural resources: Air Quality

Natural Resources Wales

Final Report

About Natural Resources Wales

Natural Resources Wales's purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales's well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales is an evidence-informed organisation. We seek to ensure that our strategy, decisions, operations, and advice to Welsh Government and others, are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

Title: **SoNaRR2020** Assessment of the achievement of Sustainable Management of Natural Resources: Air Quality

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Restrictions: None

The Second State of Natural Resources Report (SoNaRR2020) contents

This document is one of a group of products that make up the second State of Natural Resources Report (SoNaRR2020). The full suite of products are:

Executive Summary. Foreword, Introduction, Summary and Conclusions. Published as a series of webpages and a PDF document in December 2020

The Natural Resource Registers. Drivers, Pressures, Impacts and Opportunities for Action for eight Broad Ecosystems. Published as a series of PDF documents and as an interactive infographic in December 2020

Assessments against the four Aims of SMNR. Published as a series of PDF documents in December 2020:

SoNaRR2020 Aim 1. Stocks of Natural Resources are Safeguarded and Enhanced

SoNaRR2020 Aim 2. Ecosystems are Resilient to Expected and Unforeseen Change

SoNaRR2020 Aim 3. Wales has Healthy Places for People, Protected from Environmental Risks

SoNaRR2020 Aim 4. Contributing to a Regenerative Economy, Achieving Sustainable Levels of Production and Consumption

The SoNaRR2020 Assessment of Biodiversity. Published in March 2021

Assessments by Broad Ecosystem. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Coastal Margins

Assessment of the Achievement of SMNR: Enclosed Farmland

Assessment of the Achievement of SMNR: Freshwater

Assessment of the Achievement of SMNR: Marine

Assessment of the Achievement of SMNR: Mountains, Moorlands and Heaths

Assessment of the Achievement of SMNR: Woodlands

Assessment of the Achievement of SMNR: Urban

Assessment of the Achievement of SMNR: Semi-Natural Grassland

Assessments by Cross-cutting theme. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Air Quality

Assessment of the Achievement of SMNR: Climate Change

Assessment of the Achievement of SMNR: Energy Efficiency

Assessment of the Achievement of SMNR: Invasive Non-native Species

Assessment of the Achievement of SMNR: Land use and Soils

Assessment of the Achievement of SMNR: Waste

Assessment of the Achievement of SMNR: Water Efficiency

Updated SoNaRR evidence needs. Published as a data table on web in March 2021

Acronyms and Glossary of terms. Published as a PDF in December 2020 and updated in 2021 as a data table on the web

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1. Headline Messages

Poor air quality is one of the largest environmental risks to ecosystems and health in Wales. The majority of air pollutants have declined in Wales in recent decades; however, concentrations of ammonia, a form of nitrogen, and ozone are trending upwards and impacting on ecosystems. Legislative, technological, infrastructure, market forces and changes in society's behaviour will all be needed to improve air quality in Wales.

Air pollution adversely affects biodiversity and has led to widespread changes to species distribution and to the quality of habitats in Wales. This threatens the conservation status of many habitats and reduces the ability of ecosystems to deliver their services. Clean air is vital for sustaining life and the natural balance of ecosystems. Air pollution levels have impacts on all eight ecosystems and on ecosystem services.

Nitrogen emissions from the UK and Europe continue to be above damage thresholds resulting in widespread exceedance of critical loads (deposition) and critical levels (atmospheric concentrations) of ammonia. This pollution damages not only vegetation but human health and many man made materials.

Agriculture is the greatest source of ammonia air pollution and damage to habitats in Wales

In Wales, 88%, in 2018, of sensitive habitats exceed their critical load for atmospheric nitrogen, down from 98% in 2009. Almost 60% of habitat or species ‘features’ on European protected sites are adversely affected by nitrogen deposition (Rowe et al., 2020). There are 45 designated Air Quality Management Areas (AQMA) in Wales where national air quality objectives for nitrogen dioxide are not being achieved. One AQMA, located in Port Talbot, is designated for particulate matter pollution. Air pollution concentrations and related risks are higher in these areas; however, adverse health effects can occur at concentrations below current air quality standards. The whole population is affected to some extent by being exposed to air pollution every day.

Air pollution shortens lives and effects well-being outcomes by contributing to chronic illness. Quantifying the health impacts of air pollution is difficult, however it is estimated that the burden of long-term air pollution exposure is the equivalent of 1,000 to 1,400 deaths, at typical ages, each year (Royal College of Physicians, 2016).

Air pollution can originate from the same sources which contribute to climate change. Actions taken to reduce emissions of air pollutants are also likely to reduce greenhouse gas emissions.

2. Introduction

Clean air is a critical natural resource and is essential in protecting not only human health, but also Wales's natural and built environment. Although air pollution from industry and transport has declined in recent decades, nitrogen-containing air pollutants continue to cause significant environmental harm where previous emissions of sulphur caused widespread acidification of water resources (See the Freshwater chapter) and damaged trees and forest soils.

Nitrogen and Ammonia

Most of the plants that underpin terrestrial ecosystems evolved in an environment where there are low nutrient levels (nitrogen). These plants have evolved strategies to cope with the lack of nutrients and cannot survive when exposed to the high levels that result from pollution. Loss of plant diversity causes knock-on effects across entire ecosystems, as seen in the dwindling number of insects and birds across Wales today. A recent report by Plantlife, "We Need to Talk about Nitrogen" (Plantlife, 2017), provides a comprehensive and recent synthesis of nitrogen impacts in Wales.

Almost 60% of habitat or species 'features' on European-protected sites exceed their critical level for ammonia and suffer from nutrient enrichment, acidification and direct damage from the toxic effects of nitrogen deposition, primarily caused by emissions from traffic and agriculture (Rowe et al., 2020). An "exceedance" is the amount of excess acid or nitrogen deposition above the critical load. Critical levels refer to the concentrations of gaseous pollutants above which direct adverse effects on sensitive vegetation may occur; critical level exceedances are the amount of gaseous pollutant above the critical level.

Ammonia

All air pollutants have declined in Wales in recent decades except for ammonia and ozone. Ammonia and nitrogen pollution from agriculture is harming 56% of Wales's land area and is having an adverse effect on the most sensitive habitats for plants and wildlife (Guthrie et al., 2018) with 26% of sensitive habitats affected. In Wales in 2016, 88% of sensitive habitats exceed their critical load for nutrient nitrogen, down from 98% in 2009 (Rowe et al., 2020). All ecosystems may be affected, due to the diversity of the Welsh landscape and the transient nature of ambient air pollution.

More than half of Wales now experiences ammonia concentrations that are too high for lichen- and bryophyte-rich ecosystems to function properly; these include ancient woodland, bog, heathland and acid grassland (Figure 1). The pressure on functionality has negative implications for the services provided by those ecosystems and for many of their component species (Bosanquet, 2019). Ammonia emissions have been increasing in Wales since 2011 (Figure 2).

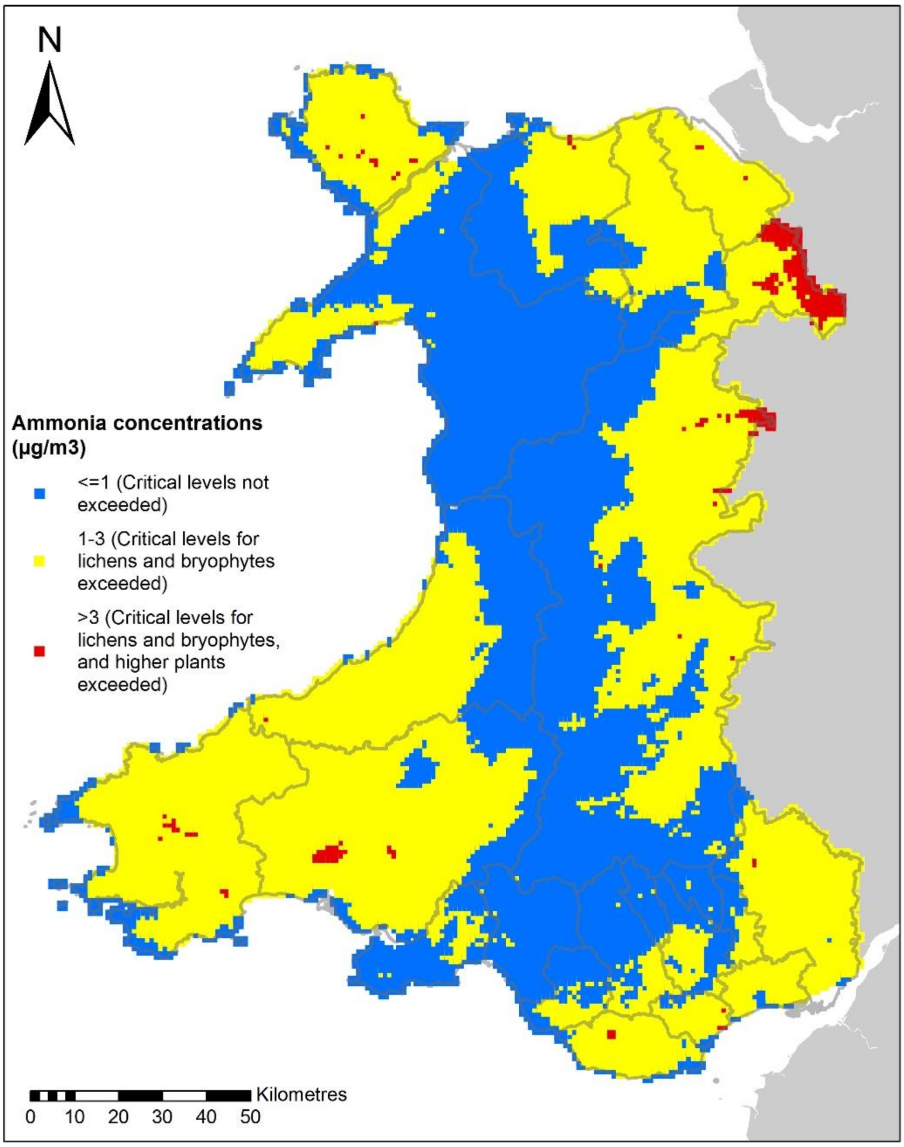

Figure 1 Ammonia concentrations in Wales (Source Rowe et al. 2020)

While the level of other pollutant emissions have fallen, the level of ammonia has risen since 2013 and is likely to increase further if measures to control agricultural emissions are not carried out.

Nitrogen Oxides

Ambient levels of nitrogen dioxide (NO_2) have generally decreased in Wales over the past twenty years, mainly as a result of decreasing fossil fuel-based power generation and improved regulation of fuels (in particular, diesel). Over the past 5 years this progress has stalled, with ambient levels staying broadly similar. NO_2 is the subject of all Air Quality Management Areas (AQMA) in Wales, except for Port Talbot. The main source of NO_2 is road transport, which accounts for nearly a third of all NO_2 emissions in the UK.

Nitrogen oxides (NOx) contribute significantly to nitrogen deposition in all ecosystems, especially in upland Wales where the impacts from industrial and transport emissions are often very distant from pollution sources. NO_2 also reacts with other pollutants in the presence of sunlight to form ozone which can further impact the environment through oxidative damage to vegetation, including crops.

NOx also has direct impacts on human health, causing respiratory and cardiovascular effects. Encouraging the use of the cleanest modes of transport for freight and passengers, active travel and the creation of urban green space, are likely to be key in reducing emissions in the future.

Ozone

Ozone (O_3) is an irritant to the airways of the lungs, throat and eyes. It can also harm agricultural crops, forests and habitats and also many man-made materials such as plastic, rubber and metal, with socio-economic impacts as a result.

Ozone is not emitted directly from any source in significant quantities but is formed by reactions between other pollutants in the presence of sunlight. Whilst its formation is influenced by meteorological factors and transboundary pollution events from Europe and beyond, in Wales, steps can be taken to reduce emissions of the main ground-level ozone precursor pollutants from sources such as traffic and agriculture.

In 2018, measured ozone in Wales met air quality target values for health and for the protection of vegetation.

Currently, significant pollution episodes (peaks) are reducing; however, background levels are slowly increasing. The critical level of ozone for semi-natural grasslands is already exceeded in large parts of Wales, and as progress is made in reducing nitrogen dioxide emissions, due to the complex chemistry involved, background ozone pollution may continue to trend upwards.

Particulate Matter

Particulate matter (PM) is the term for a mixture of solid particles and liquid droplets found in the air. PM can be emitted directly from a source, known as primary PM, whereas PM can also form in the atmosphere due to chemical reactions between pollutant gases, known as secondary PM. Common anthropogenic sources of PM are from industry, combustion, including industrial and domestic, and automotive use, such as exhaust, brakes, tyres. However, the impact from natural sources like disturbed dusts, sea-salt, spores, and pollen can also be significant.

Particulate matter is classified according to its size and this classification is used in concentration measurements. PM_{10} is the concentration of particles that are less than or equal to 10 µm in diameter; similarly $PM_{2.5}$ describes the concentration of particles that are less than or equal to 2.5 µm in diameter. The size of particles is directly linked to their potential for causing health problems. Small particles less than 2.5 micrometres in diameter pose the greatest problems because they can get deep into the lungs and bloodstream leading to respiratory problems. When exposure to particulate matter reduces lung function, it also reduces the ability of people to access nature and benefit from other ecosystem services; as a result, this also reduces their quality of life. A growing body of evidence also indicates that the impact of pollution goes beyond physical health and can impact human well-being and mental health.

In Wales, there is only one AQMA for particulate matter and this is associated with local industry in Port Talbot.

The impact on the environment can be wide-ranging and includes reduced visibility, in other words haze, acidification of watercourses, crop damage, and it can also affect ecosystem diversity. Corrosion caused by chemicals and soiling caused by particles can lead to economic losses and, more importantly, to the destruction of our cultural and built heritage - an important component of Welsh identity.

Overall concentrations of $PM_{2.5}$ in most of Wales are below WHO guidelines, although there are hotspots in industrial and densely populated urban areas. Non-exhaust road transport emissions, domestic and industrial emissions contribute to the local peaks in urban areas. Domestic wood and coal burning also make a significant contribution along the north coast and in urban areas, including the large urban populations in Swansea and Cardiff. Natural irreducible sources, such as sea salt, natural, rural and urban dusts, and biogenic secondary organic aerosols, do however account for around a third of the WHO standard for $PM_{2.5}$ (10 µg/m3) over areas of south Wales.

Figure 2 shows emissions of ten air pollutants normalised to provide the relative rate of decline since 1990 (Jones et al., 2019).

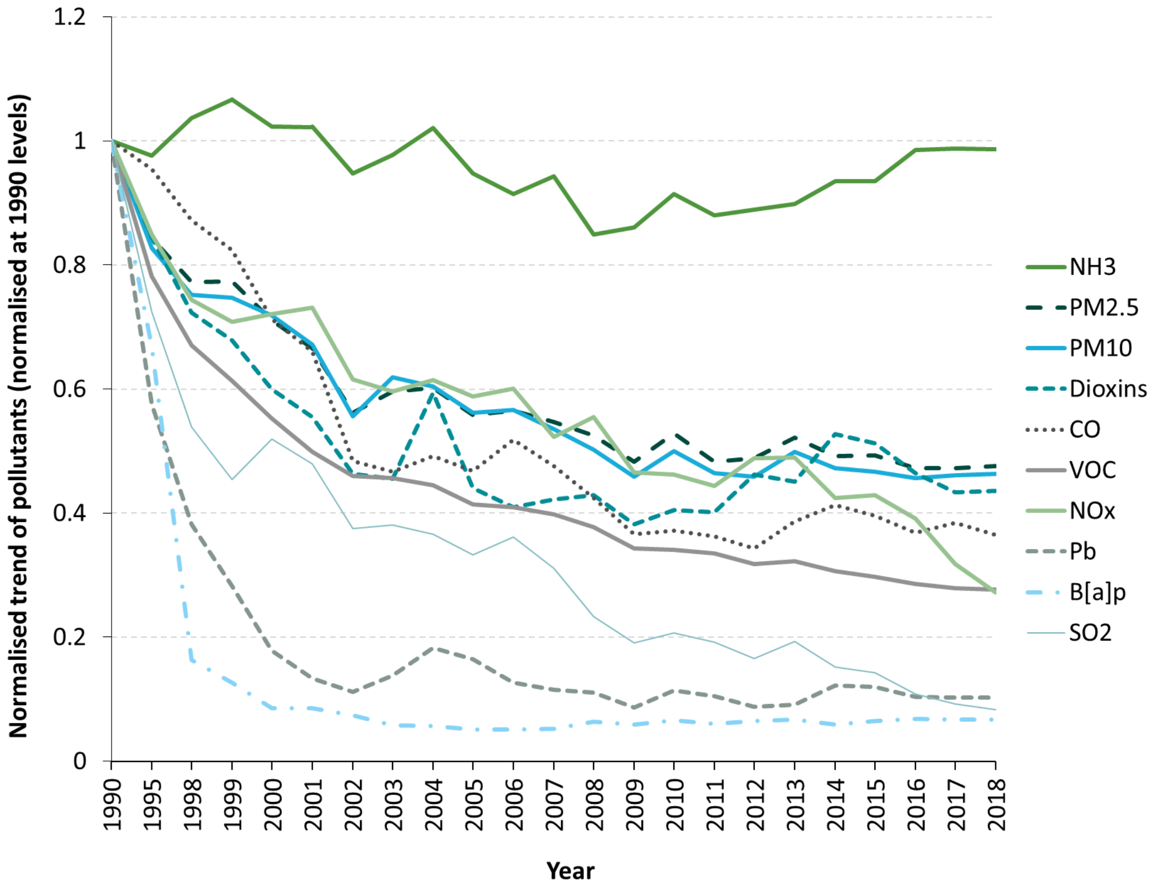

Figure 2 Normalised trends for all pollutants in Wales (Jones et al., 2019)

Sulphur Dioxide

The main source of sulphur dioxide is industrial emissions. Annual averages have decreased significantly since 1992 at all UK long-term monitoring sites and were below the EU limit value in 2016. This reflects large reductions in the amounts of coal and fuel oil being used for energy generation and other purposes following the tightening of national and international emission standards.

Metallic Pollutants

Metallic pollutants are generally emitted from industrial processes and fuel combustion. Metallic pollutants monitored in the air include lead, cadmium and nickel. Annual average levels of lead and cadmium have both reduced by more than half since 2004. Metallic pollutants in Wales are generally well below EU target and limit values except for the Swansea Urban Area which continues to exceed the EU target values for nickel. These nickel exceedances are attributed to emissions from industrial sources and work is ongoing with various stakeholders to deliver compliance with the target value as soon as practicable.

Persistent Organic Pollutants

Persistent Organic Pollutants (POPs) are synthetic chemicals which include polychlorinated biphenyls (PCBs), dioxins, and polycyclic aromatic hydrocarbons (PAHs). PAHs are a large group of toxic and carcinogenic compounds. The main sources of PAH emissions to air are industrial sources and the domestic burning of coal and wood. Benzo[a]pyrene is one of the more toxic PAHs and is monitored as a 'marker' for the group.

The most significant source of B[a]P in Wales is from the steel works located in Port Talbot. Measured concentrations have frequently exceeded the Air Quality Objective of 0.25 ng/m^3, but have never exceeded the EU target value of 1 ng/m^3. Improvements are being made at the steel works to minimise emissions to the environment, which primarily originate from the coking process.

3. State and Trends (Aim 1)

Summary Assessment of State and Trends and Future Prospects

The following table (Table 1) gives a brief description of the past trends and future prospects for Air Quality. These are assessed to be:

- Improving trends or developments dominate;
- Trends or developments show a mixed picture, or
- Deteriorating trends or developments dominate.

Further information is provided to put this in context.

Table 1 Key message – past trends and future prospects for air quality

Time Period	Rating	Description
Past trends (10–15 years)	Deteriorating	Ammonia emissions are rising.
Past trends (10–15 years)	Mixed picture	Overall ambient air quality in Wales continues to improve. Ground level ozone concentration is rising. Local areas of elevated concentrations of particulate matter and nitrogen oxide continue to be problematic. In Wales acidity, mainly from Sulphur dioxide emissions, has decreased from 90%- 72% between 2015-2017. Further reduction will be more difficult to achieve due to reduced industrial emissions. In Wales, nutrient nitrogen exceedance of critical loads has decreased from 98% to 86% between 2015 and 2017. Nitrogen pollution continues to be a significant issue.
Future Prospects (Outlook to 2030)	Mixed picture	Emissions of ammonia and $PM_{2.5}$ are currently forecast to rise. The full uptake of measures, which will require a significant reduction in agricultural ammonia in the Clean Air Plan (Welsh Government, 2019), will help reverse this forecast. The introduction of the Sustainable Farming Scheme (SFS) should also deliver significant cuts in ammonia emissions from agriculture. It is anticipated that there is to be continued decline of pollution following the Clean Air Act to enhance existing legislation. Ambitious industrial decarbonisation projects have the potential to make a significant contribution to improving air quality.

Robustness: Robust data based on audited UK reporting (Defra and DAs).

This chapter on air quality looks at how each ecosystem is affected by air pollution and shows the benefits that each ecosystem provides in terms of removing certain pollutants from the air. It is important to note that, although each ecosystem is capable of removing pollutants from the air, it is often – if not always – to the detriment of that ecosystem.

Mountains, moorlands and heaths

Wales has over 240,000 hectares, or 5% of the UK, of mountains, moorlands and heaths (MMH) whose soil and vegetation are sensitive to the atmospheric deposition of sulphur and nitrogen. The main threats to this ecosystem from air pollution is via eutrophication from nitrogen deposition in the uplands, and direct ammonia effects to lowland heath and wetland close to intensive livestock and poultry rearing.

MMH habitats can help improve air quality as they remove pollutants from the atmosphere, particularly fine particulate matter ($PM_{2.5}$). Physically, the amount of pollution MMH have removed from 2007 to 2017 has fluctuated, but decreased overall by 3.5%, from 6,740 tonnes to 6,500 tonnes. Beyond 2017, pollution removal by MMH areas is projected to continue to decrease to 6,300 tonnes in 2030, as a result of less pollution being emitted into the atmosphere and declining hectares of this important ecosystem (Jassi and Dutton, 2019).

Semi-natural grasslands

Wales has around 192,000 ha of semi-natural grasslands, around 6% of the UK total, and this is primarily affected by 3 main pollutants: nitrogen, ozone and acid deposition.

Unfertilised semi-natural grassland is particularly affected by nitrogen deposition, which can change the species composition, favouring some grasses at the expense of herbs, bryophytes and lichens. Herb-poor, species-poor grassland provides fewer food sources for biodiversity and reduced nectar sources for pollinators.

Ammonia has similar eutrophication and acidification effects on semi-natural grassland, but impacts are closer to source, with the highest concentrations often associated with intensive poultry and dairy enterprises.

The critical level of ozone is exceeded for large parts of Wales and this can result in ozone tolerant species out-competing those that are less tolerant; higher ozone concentrations can also result in reduced growth. Finally, grasslands that are moderately acidic are particularly at risk, resulting in species loss via acid deposition.

Grasslands can also absorb pollution from the atmosphere, and based on the proportion of grassland in Wales, these ecosystems have the potential to reduce pollutant level as outlined below (Table 2).

Table 2 Estimated amount in tonnes of common air pollutants removed by grasslands in Wales (Jones et al., 2017)

Pollutant	Tonnes removed per annum by semi natural grasslands in Wales (averaged 2015-2030)
PM_{10}	80
$PM_{2.5}$	50
Sulphur dioxide	181
Ammonia	526
Nitrogen dioxide	90
Ozone	8,250

Enclosed farmland

Enclosed farmland is a vital habitat in terms of food production, the provision of landscape, recreation and other cultural benefits. This ecosystem can also have negative effects including greenhouse gas emissions, diffuse water pollution and losses to biodiversity. It is difficult to quantify the impact of air pollution on this particular ecosystem due to the localised impacts of ammonia from livestock masking the other effects of pollution.

This ecosystem acts mainly as a source of pollutants and emits high levels of methane and ammonia from manure spreading and livestock housing.

The filtration services provided by enclosed farmland are significant with estimates that enclosed farmland removes around 11% of the $PM_{2.5}$ removed by vegetation (Office for National Statistics, 2018).

This will vary by location and the type of vegetation within the farmland.

Woodlands

Woodlands are known to contribute to improving overall air quality, not just in the wider rural environment but in urban areas. Increasing woodland cover in Wales can bring benefits of improved air quality, particularly where woodland is adjacent to agricultural or industrial buildings, urban or transport corridors. Welsh Government’s ‘Woodlands for Wales Strategy’, refreshed in 2018, sets out targets for increasing woodland cover, as well as the diverse range of benefits offered by both conifer and broadleaved woodland towards multiple environmental, social and economic outcomes. The ‘right tree in the right place’ is an important consideration to ensure all the ecosystem services that woodland provides, including, but not limited to, carbon capture, are maximised. Tree planting is one of many options to improve green infrastructure and is consistent with the ambition set out in the Clean Air Plan (Welsh Government, 2019) to improve air quality.

Woodlands are affected mainly by nitrogen deposition and ammonia with large areas of the Welsh woodlands exceeding the critical level for ammonia and critical load for nitrogen. Lowland woodland is particularly affected by ammonia from nearby agriculture, but even in less intensively farmed areas, such as the Meirionnydd Oakwoods and Bat Sites SAC, nitrogen deposition impacts are significant.

In 2015, an estimated 16,211 tonnes of PM_{10} and 145 tonnes of sulphur dioxide were absorbed by forests in Wales. The annual value of removing PM_{10} in Wales in 2015 was estimated at £385 million at 2015 prices. The annual value of removing sulphur dioxide in Wales in 2015 was estimated at £0.3 million at 2015 prices (Forest Research, 2017).

The Net Present Value (NPV) asset value of pollution absorption, estimated in terms of the ability of forests to provide air quality regulation services into the future, 50 years, was estimated at around £11.2 billion for PM_{10} and £9.8 million for sulphur dioxide, at 2015 prices, based on average pollution levels over the period 2011–15 (Forest Research, 2017).

Nature based solutions to improving air quality, such as tree planting and green infrastructure, also have wider benefits that contribute to all the Well-being Goals.

Freshwater

Air pollution can impact on freshwater habitats as the deposition of nitrogen and ammonia affects waterborne plants. There is no evidence to show that freshwater has any regulating effects on air quality; wet deposition, covered in the Freshwater chapter, demonstrates the adverse impact on water quality.

Urban

The urban ecosystem is affected by air pollution in much the same way as the other ecosystems mentioned; the plants and species richness of the urban ecosystem is adversely affected by the same pollutants but in differing proportions. Humans are also the main species in the urban environment, and therefore, the effect of air pollution in terms of health impacts strongly influences the urban ecosystem. This is covered in the Urban chapter.

Coastal margins

Atmospheric pollution from nitrogen, sulphur and ozone influences the vegetation and soils of coastal margin habitats. Nitrogen deposition and ammonia pollution exacerbate dune stabilisaton, which has been identified as a major threat to dune biodiversity, and reduces species diversity in saltmarsh and coastal grasslands. Shipping and transboundary nitrogen pollution are often significant causes of damage to the coastal margin ecosystem, but adjacent intensive agriculture can have locally profound effects.

Marine

Air pollution causes the most short-term measurable damage to water quality when toxic chemicals fall from the air as gas, dust, or when rain rinses these chemicals to the ocean and waterways which lead to the ocean.

Air pollution from land and marine sources can cause pollution of the marine environment largely through air pollutant deposition. Water quality can be impacted by nitrogen pollution and by airborne dust containing metals, including mercury which can bioaccumulate in marine life, and PAHs.

Reducing coal burning and fossil fuel usage will reduce the amount of man-made mercury entering the sea. From 1 January 2020, the maximum sulphur content of marine fuels decreased from 3.5% to 0.5% globally – reducing air pollution and protecting health and the environment.

Trends, pressures, threats, issues and future prospects

Overview of the effect of nitrogen deposition and ammonia

- There has been a reduction in the areas of nitrogen-sensitive habitats in the UK and the exceedance of nutrient nitrogen critical loads has decreased from 75.0% or 54,785 km^2 in 1996 to 57.6% or 42,049 km^2 in 2017 (Rowe et al., 2020).
- The Average Accumulated Exceedance for all Welsh habitats combined for nutrient nitrogen has declined by one-third, from 9.5 kg N per ha per year in 1996 to 5.2 kg N per ha per year in 2017 (Rowe et al., 2020).
- The nutrient nitrogen critical loads are exceeded for more than 80% of the areas of six nitrogen sensitive habitats in all years: calcareous grasslands, unmanaged beech woodland, unmanaged oak woodland, other unmanaged woodland, managed conifer and managed broadleaved woodland (Rowe et al., 2020).
- Almost 100% of the area of unmanaged beech woodland in Wales has exceeded nutrient nitrogen critical loads in all years; however, the magnitude of exceedance, expressed as Average Accumulated Exceedance, has decreased from 22.7 kg N per ha per year in 1996 to 11.4 kg N per ha per year in 2017 (Rowe et al., 2020).
- There is virtually no exceedance of nutrient nitrogen critical loads for saltmarsh in any year, due to a combination of the high critical load for this habitat and lower deposition in coastal areas (Rowe et al., 2020).
- Agricultural ammonia emissions have been steadily rising in recent years in Wales and this poses an increasing risk to sensitive Welsh habitats. A range of ammonia reduction measures via the sustainable farming scheme (SFS) can reverse this trend and enhance biodiversity protection

Overview of acidification effects of habitats

- The area of acid-sensitive habitats in Wales with exceedance of acidity critical loads has fallen by over a fifth, from 95.7% in 1995–97 to 77.5% in 2016–18 due mainly to decreased industrial emissions of sulphur dioxide (SO_2) (Rowe et al., 2020).
- The magnitude of the acidity exceedance, expressed as the Average Accumulated Exceedance, in Wales has decreased by 70%, from 1.36 to 0.42 keq per ha per year in 1995–97 and 2016–18 (Rowe et al., 2020).
- Of the acid-sensitive habitats mapped, dwarf shrub heath occupies around 5% of Wales and exceedance of acidity critical loads has reduced by over 25% between 1995–97 and 2016–18 (Rowe et al., 2020).

- Freshwater habitats in Wales have also seen an improvement, with a 38% reduction in area not exceeding acidity critical load when compared with 1996 data (Rowe et al., 2020).

Designated sites with acid-sensitive feature habitats

Across the UK, the percentage of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) exceeding acidity critical loads for one or more features has decreased substantially, falling from more than 90% to 70% in 2018. In Wales, roughly 70% of designated sites have exceedance of acidity critical loads for one or more features (Rowe et al., 2020).

Designated sites with nitrogen-sensitive feature habitats

- Reductions in the percentage of designated sites in the UK with exceedance of nutrient nitrogen critical loads, for one or more features, between 1995–97 and 2015–2017 are small, reflecting the smaller reductions in nitrogen deposition compared to acid deposition over this time period (Rowe et al., 2020).
- Wales has seen the largest reduction, of 21.4%, in the percentage of SPAs with nutrient nitrogen critical load exceedance over the same time period in the UK. However, there are only 14 SPAs in Wales exceeding nitrogen critical loads compared with other areas of the UK (Rowe et al., 2020).
- 63–84% of designated sites in Scotland and 83–98% of designated sites in England, Wales and Northern Ireland currently have exceedance of nutrient nitrogen critical loads for one or more features (Rowe et al., 2020).

Exceedance of ammonia critical levels

- In Wales, the area exceeding critical levels has remained approximately the same over the period 2009–2017 (Rowe et al., 2020).

Wales land area

- From 2015 to 2017, 56% of Wales and over 60% of land area received ammonia concentrations above the critical level set to protect lichens and bryophytes of 1 $\mu g/m^3$; in the UK as a whole, this is 60% (Rowe et al., 2020).
- The UK land area with ammonia concentrations above 1 $\mu g/m^3$ has slightly decreased, from 63.9% in 2009–11 to 62.9% in 2017 (Rowe et al., 2020). Of more concern are the localised impacts of new ammonia sources associated with the rapid expansion of intensive poultry developments (Aazem and Bareham, 2015).
- Less than 1% of Wales land area receives ammonia concentrations above the critical level set to protect higher plants of 3 $\mu g/m^3$; this ranges from 0.1% of Scotland to 12.4% of Northern Ireland and 3% of the UK overall (Rowe et al., 2020).
- The UK land area with ammonia concentrations above 3 $\mu g/m^3$ has slightly increased, from 3.7% in 2010 to 5.1% in 2016 (Rowe et al., 2020).

Nitrogen-sensitive habitats

- In Wales, 58% of the area of nitrogen-sensitive habitats receiving ammonia concentrations are above 1 $\mu g/m^3$; this compares to <3% in Scotland and 60.6% in Northern Ireland.

- In Wales, <0.1% of the area of nitrogen-sensitive habitats receive ammonia concentrations above 3 $\mu g/m^3$; the situation is similar in Scotland, but in England the figure is higher at over 1%. In Northern Ireland, just over 3% of the area of nitrogen-sensitive habitats have concentrations above 3 $\mu g/m^3$ (Rowe et al., 2020).

Designated sites

- Between 52%, SPAs, and 70%, Sites of Special Scientific Interest (SSSIs), of designated sites in the UK currently receive ammonia concentrations above 1 $\mu g/m^3$ anywhere across a site. The percentage of sites with exceedance of the 1 $\mu g/m^3$ critical level has fallen by <5% between 2010 and 2016 for all site types (Rowe et al., 2020).
- Between 53 and 73% of designated sites in Wales currently receive ammonia concentration above 1 $\mu g/m^3$ (Rowe et al., 2020).
- Between 4.7%, SSSIs, and 9.3%, SPAs, of designated sites in the UK currently receive ammonia concentrations above 3 $\mu g/m^3$ anywhere across a site. The percentage of designated sites with exceedance of this critical level has risen by 1–4% between 2010 and 2016 (Rowe et al., 2020).
- Between 3 and 5% of designated sites in Wales currently receive ammonia concentrations above the critical level of 3 $\mu g/m^3$ anywhere across a site (Rowe et al., 2020).

Statutory Air Quality Trends

All pollutants have declined in Wales in recent decades, except for ammonia and ozone. Data from the 'Air Quality in Wales' website (Welsh Government, 2021) confirms that no monitoring sites in Wales exceeded any Air Quality Strategy (AQS) Objectives, or corresponding EU limit values, for carbon monoxide, sulphur dioxide, benzene or lead during 2018.

The annual limit value for NO_2 has been exceeded in Cardiff and Caerphilly, at Hafod-yr-ynys, and at five other locations on the motorway and trunk road network in Wales (2017). The hourly limit value for NO_2 has been achieved in all locations throughout Wales, with the exception of Hafod-yr-ynys (2017). All exceedances are primarily due to traffic. There is work ongoing to achieve compliance with EU limit values for nitrogen dioxide in the shortest time possible.

Air quality EU target values are not being achieved, in 2019, in the Swansea Urban Area for nickel, nor for B[a]P in Port Talbot (Welsh Government, 2021). Both pollutants are linked to industrial processes and work is ongoing by relevant stakeholders to address this issue.

4. Assessment of Resilience (Aim 2)

Ecosystem resilience is adversely affected when the natural cycles are put out of balance by human activity. In contrast with many other pollutants, nitrogen can change form and travel a long way once released into the environment. As it moves through the bio-geochemical pathways, the same nitrogen atom can cause a sequence of negative effects – in the atmosphere, in terrestrial ecosystems, in freshwater and marine systems, and on the climate.

The way nitrogen behaves in the atmosphere is complex: nitrogen could be emitted as nitric oxide (NOx) from a car, further combine with oxygen to form NO_2, causing direct impacts on lung function, then go on to create ozone at ground level, which can directly impact habitats and cause smog. This can then be converted into nitric acid leading to the acidification of habitats. Or, for example, an ammonia molecule emitted from agriculture can combine with NOx from a power station to form a fine particle, again causing a wide range of health problems when inhaled in sufficient quantity.

When finally removed from the atmosphere, ammonia can cause direct impacts on habitats reducing biodiversity by allowing nitrogen loving species to dominate and removing sensitive species like bryophytes; it can also lead to increased nitrogen in the soil which runs off into rivers and marine environments. Ammonia emissions from agricultural sources are increasing in Wales.

Understanding the way pollutants interact will help to design interventions to prevent unintended consequences. For example, encouraging the deep injection of manure into soil will reduce the amount of airborne ammonia but can increase nitrate leaching. Applying fertiliser only during the growing season can reduce nitrate loss but increase nitrous oxide emissions.

Ground-level ozone damages agricultural crops, forests and plants by reducing their growth rates and has negative impacts on biodiversity and ecosystem services.

Solutions to air quality problems in Wales are both transboundary and national/regional. Long-term sustainable solutions need to be sought for these issues. Tree planting and woodland ecosystem development across Wales needs to be enhanced and modelling indicates that this could have a significant impact both on air quality and the contribution to mitigating the effects of climate change. This strategy will also help with reversing habitat loss and potentially reducing flooding which encompasses many of the themes that are being targeted. This will help to reduce the impact of particulate matter and other pollutants.

In terms of air quality, the diversity and extent of ecosystems are directly affected by the amount of nitrogen deposition. Critical loads define the amount of acid or nitrogen deposition above which significant harmful effects are expected to occur to sensitive habitats.

Placing critical levels on a statutory footing in the same way as ambient air quality limits will drive the large changes required to reverse biodiversity loss.

Overall, the situation is improving, but the degree of exceedance means that air pollution remains a threat to ecosystem resilience and extent for the foreseeable future.

5. Ecosystem Services for well-being

A growing body of evidence indicates that the impact of air pollution goes beyond physical health and can impact on human well-being due to people’s personal connections to the richness of their natural environment. The health impacts from air pollution, for example exposure to particulate matter reducing lung function, reduces people’s ability to access nature and benefit from other ecosystems services; it therefore affects their quality of life. Measures to combat air pollution, for example green infrastructure, can help transform urban and rural spaces by improving enjoyment and promoting positive behavioural changes. In addition, the cultural services imparted by ecosystems often depend on nitrogen-sensitive biodiversity, for example, in flower-rich meadows or lichen-draped woodlands.

Air pollution affects ecosystems in a number of ways, altering basic ecosystem functions such as species composition, primary production, in other words plant growth, and bio-geochemical cycling. This in turn affects the ecosystem services and therefore the benefits that humans get from the environment such as timber, clean drinking water and an appreciation of nature. Therefore, air pollution impacts on the provision of all ecosystem services.

Assessment: Healthy places for people, protected from environmental risks (Aim 3)

Welsh Government is committed to building healthier communities and better environments. Clean air has a central role in creating the right conditions for better health, well-being and greater physical activity in Wales. In September 2017, Welsh Government published its national strategy, ‘Prosperity for All’, which sets out a cross-government commitment to reducing emissions and delivering vital improvements in air quality through planning, infrastructure, regulation, and health communication measures.

The existing vegetation in Wales takes up a significant amount of air pollutants. Restoring land cover and changing land use practice to maximise the regulating provision of the ecosystems can further reduce air pollutants. Studies have shown that this approach could be more beneficial than traditional abatement technologies and can be especially effective in combination. Changing the way emissions are regulated to a system where the effort and financial burden are focused to produce the best environmental effect is an opportunity to maximise these regulating services. The approach will also result in multiple benefits in line with sustainable management of natural resources (SMNR) principles and the aims of the Natural Resources Policy.

Assessment: Regenerative Economy (Aim 4)

The drive for decarbonisation gives us the opportunity to remove some pollutants from the waste gas stream while utilising the gas for other purposes. Many researchers and innovative companies are looking at ways to re-use CO_2 instead of storing it. CO_2 can be used directly in a range of applications such as enhanced oil recovery, food preservation, or to make decaffeinated or fizzy drinks.

CO_2 can also be converted into other chemicals and products through a number of chemical, biological and mineralisation processes. In this way, CO_2 can be reimagined not as a waste, but as a resource which can be used to make a wide range of useful products such as fuels, construction materials, chemicals, and plastics. These processes are variously referred to as carbon capture and use/utilisation (CCU), carbon dioxide utilisation or carbon recycling.

The process of Low Temperature Oxidation (LoTox) has been used to remove NOx from industrial emissions; this results in the production of nitric acid, which can be used in a wide range of manufacturing processes.

Both of these techniques fit well with the decarbonisation goal and the use of emissions in the manufacture of useful products, strengthening the principle that there should be no waste produced.

6. Synergies and Trade-offs

The drive towards a low carbon economy comes hand in hand with the drive to improve air quality. The reduction in the use of fossil fuels has a subsequent effect on fewer products of combustion such as NO_x and sulphur oxides (SO_x). The opportunity to develop a hydrogen based economy will also help achieve this.

The hydrogen economy is a phrase coined to capture the many possible uses of hydrogen to replace carbon-rich fossil fuels. Hydrogen can be used for heat and to power vehicles through direct combustion or in fuel cells to produce electricity. An advantage of hydrogen is that it is energy dense making it suitable for long range transport and can be stored either as a gas or in the form of ammonia.

The combustion of hydrogen only produces water and is therefore a pollutant-free fuel; this, however, is entirely dependent on how it is produced.

Currently, most hydrogen is produced from natural gas, known as grey hydrogen; however, this is energy intensive and adds to CO_2 emissions. One possible way to reduce the impact in future is to use methane from agricultural sources rather than natural gas; this approach could have multiple benefits as it would reduce the amount of ammonia released from manure spreading.

The use of renewables, including solar and wind for the electrolysis of water to produce hydrogen and oxygen, is a more sustainable solution, known as green hydrogen. The cost of renewable energy continues to fall and this will enable hydrogen to become a viable way of moving and utilising energy. Evidence indicates that society is at the point where renewable energy will gain parity of cost with fossil fuels and now is the time to encourage growth of the hydrogen economy in Wales.

The benefits of green hydrogen are that it will drastically reduce carbon emissions, improve air quality and create new, green jobs across Wales. Hydrogen is also a practical solution as it does not require behaviour or societal change to implement; it is simply a matter of infrastructure and political will. People can continue to use personal transport and the technology for using hydrogen to heat homes already exists. Hydrogen powered ships, trains and cars are all now available and flight tests of hydrogen powered aircrafts are underway.

In Wales, there are two clusters of industry actively working to achieve a reduction in their carbon emissions: HyNet in north east Wales and the South Wales Industry Cluster. Hydrogen plays an important role in both and the hydrogen economy in Wales is set to grow.

Caution must however be exercised as with each development in technology there comes a set of negative consequences that must be managed correctly. The direct burning of hydrogen can form thermal NO_x; therefore, the use of fuel cells is a better option. However, the production of fuel cells makes use of platinum and polytetrafluorethylene which carry their own negative impacts on the environment.

7. Opportunities for action to achieve the sustainable management of natural resources

The sustainable management of air quality will require action across all ecosystems and in all areas of life.

There are many opportunities that can be realised to help in this goal:

- Maximise the exposure reduction potential of vegetation in the urban and semi-urban ecosystem via additional planting and appropriate selection of species, including but not limited to expanding green infrastructure such as green roofs (Berardi et al., 2013).
- Reducing emissions is always the most effective way of improving air quality. In order to ensure this occurs whilst building a sustainable industrial base industry, government and other stakeholders must drive the decarbonisation of major industry and electricity production and maximise the synergies. Decarbonisation will result in fewer emissions due to fuel changes from more polluting fuels to cleaner alternatives and the use of carbon produced will also result in the reduction of other pollutants.
- Part of the decarbonisation of industry relies on the use of hydrogen as a fuel. Welsh industry can also play a major role in the production of hydrogen for use in the automotive sector. Private vehicles are a source of NO_x pollution, maximising

the hydrogen economy and the introduction of fuel cells. Ensuring hydrogen is produced from renewable sources is key to reducing the pollutant load in air. (see the energy chapter). See SWIC case study below for benefits of decarbonisation and SMNR principles in action.

- Ensure good agricultural practice benefits from farm payments (see the enclosed farmland chapter).
- Create measurable limits such as nitrogen critical loads and levels, and target limits in the same way that concentrations of pollutants in ambient form receive mandatory limits. This would require public bodies to produce action plans to achieve the critical levels and help reverse the loss in biodiversity associated with nutrient loss (see the biodiversity chapters).
- Reduce the concentration of the statutory ambient air quality limits to help drive further reductions in emissions.
- SMNR duties currently only apply to NRW, where many of the changes required to achieve good air cannot be achieved by NRW alone. If the SMNR principles were adopted by all public bodies in Wales, it would enable cohesive solutions.
- Applying the SMNR principles to urban and transport planning will help achieve a fully integrated transport system across Wales, including the promotion of active travel.
- The SMNR principles will also require plans and projects to be assessed in terms of multiple benefits; air quality could benefit from this approach.
- Ammonia pollution is a central theme of the Air Quality chapter and is a key pollutant in Wales. In order to reduce emissions of ammonia, any replacement of agricultural payments must drive agricultural reform in terms of what is produced and where it is produced. Again, the application of the SMNR principles to the creation of a replacement scheme will ensure positive outcomes.

8. Case study

Industrial clusters: How to improve air quality, reduce carbon emissions and grow a sustainable industry

In Wales, 40% of carbon emissions come from industry, with half of this from steel production. Across south Wales, there are a wide range of industries that contribute to the carbon emissions and to local air quality problems. The South Wales Industry Cluster (SWIC) was created in 2019 with representatives from industry, energy providers, utilities, Welsh Government, academic institutions and NRW working together to decarbonise the industry by 2050.The goal of the cluster is:

> "providing economic development and new business growth by the delivery of net zero carbon emissions by decarbonisation of industry in Wales".

A series of feasibility studies are currently underway on 12 decarbonisation projects; these include using hydrogen to reduce iron ore in steelmaking, fuel switching to hydrogen and natural gas, the use of ammonia as an energy storage vector, improving the efficiency of gas turbines, carbon capture and using solar to produce hydrogen. All of these will have positive impacts on air quality that go hand in hand with reducing the carbon output from major industries.

The cluster is an example of the application of the SMNR principles in action. The SWIC is an agile collaborative group that can react to changing priorities and innovation. The actions identified happen at various scales from an all-Wales approach to carbon capture to site-specific fuel switching projects. The collaborative nature of the group enables multiple benefits to be identified outside of decarbonisation, maximising the efficiency of business and improvements to air quality. The projects identified are a mix of quick wins that can have an almost immediate effect and long-term goal setting for carbon zero before 2050.

The collaboration with academies and regulators can also ensure that preventative action is built in to the projects to ensure that perverse outcomes are not realised, where possible increasing the use of natural solutions to help towards increasing biodiversity and build ecosystem resilience.

9. Evidence Needs

Air quality monitoring in Wales is primarily undertaken by Local Authorities and through several national networks managed by the Welsh Government. These networks report air pollution levels in Wales that can assessed against regulatory requirements and provide evidence for air quality researchers, health professionals, the public and environmental bodies.

Expansion of the air quality monitoring network in Wales, in both the urban and rural environment, would help strengthen our evidence and reliance on computer modelling, to better understand the scale and impact of key pollutants such as ammonia on the environment. Better data sharing as a result of new legislation, especially within the Agricultural sector, will also allow us to target our interventions and policy to ensure pollution can be minimised

Expansion and revision of the network is already proposed within the ‘Clean Air Plan published by Welsh Government which will help:

- underpin any new targets set for key pollutants for both the environmental and health impact
- have a focus on reducing risks at the most sensitive receptors
- complement existing legislative regimes where possible
- consider the potential combined role of new and traditional technologies to assess exposure risks, reduce gaps in coverage and support communications of air pollution in high risk areas

Natural Resources Wales is already having active discussion with Welsh Government regarding expansion of the network to improve or evidence base.

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