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Forest monitoring in Poland: legal foundations and scope of the programme

Paweł Lech ✉, *Robert Hildebrand*, *Jadwiga Małachowska*

Forest Research Institute, Department of Forest Resources Management, Sękocin Stary, Braci Leśnej 3, 05-090 Raszyn, Poland, e-mail: P.Lech@ibles.waw.pl

Abstract

Year 2024 marks the 35th anniversary of forest monitoring in Poland. It is the first and only Europe-wide harmonized research programme to assess the health of the forest environment. In this article, we refer to international legal documents and acts of the Polish Parliament, based on which the forest monitoring programme has developed in recent years and is currently being implemented. We also present the scope of monitoring research, considering all activities carried out in Poland. The results of forest monitoring provide a reliable identification of the key factors influencing forest health in both the short and long terms, as well as information on the condition of forests and a comprehensive assessment of the pace and direction of change in forest ecosystems. It provides the scientific basis for policy decisions on air pollution control and can contribute to forestry issues such as the impact of climate change on forests, the contribution of forests to climate change mitigation, sustainable forest management and forest biodiversity.

Key words

Air Convention, forest health assessment, forest biodiversity, air pollution, deposition, ICP Forests

Introduction

The second half of the 20th century was a time of dynamic economic development in the world, especially in Europe. As a result of industrial progress, climate change and the steady increase in the concentration of carbon dioxide and gaseous pollutants in the air, forests came under unprecedented pressure. This triggered processes of eutrophication and acidification of the environment, which led to a change in the basic environmental conditions for tree growth and, as a result, to a deterioration in the condition of forests and sometimes even to their death. An example of such phenomena was the decline of spruce stands in Central Europe (Poland, the Czech Republic and Germany) in the late 1970s (Innes 1993; Bytnerowicz et al. 2002), as well as large-scale wind damage (Gardiner et al. 2020) and fires (Costa et al. 2020), which occur from time to time and have intensified in recent decades. Increasing threat to the forest environment, on the one hand, and the desire to ensure stability, durability and the ability to provide timber, protect biodiversity, sequester carbon dioxide and neutralize air pollution, on the other hand, led to the need to reliably assess the health of forests. This was reflected in the dynamic development of monitoring programmes and national forest inventories in many countries around the world. Nowadays, large-scale studies on forest health cover almost 85% of the

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world's forest resources and are conducted in over 110 countries worldwide (FAO 2016). European forest monitoring, coordinated by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), is an example of such a programme (Gessler et al. 2022).

In Poland, forest monitoring is performed since 1989 (Dunikowski 1988), providing information on forest condition and factors shaping it. Over the past 35 years, a system of observations, measurements and analyses has been established, initially exclusively to assess the impact of air pollution on the health of forest stands and gradually extended to periodic and continuous measurements and observations of the basic components of the forest ecosystem. Currently, forest monitoring is carried out on a similar scale in most European countries based on a harmonized methodology (Manual… 2020–2022). The results of the studies and observations carried out under the programme are an important source of information on the state of forests and the changes taking place in them, both in individual countries or in regions and throughout Europe (Lech et al. 2024a,b; Michel et al. 2023; Potočić et al. 2021).

International and national legal bases of the forest monitoring programme in Poland

Widespread air pollution and concerns about damages to human health and stability of ecosystems caused the UN ECE Convention on Long-range Transboundary Air Pollution (CLRTAP, Air Convention) to be adopted and signed in Geneva in 1979 (UN ECE 1979). The Convention entered into force in 1983, and in 1985, the International Co-operative Programmes on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was established to conduct monitoring and research of the effects of air pollution on forests. Poland signed and ratified the Convention in 1985 (Ustawa 1985) and joined the ICP Forests in 1989. At present, 42 European countries as well as the United States of America and Canada are participating in the Programme, which includes assessments according to harmonized and standardized methods following ICP Forests Manual. The development and implementation of the forest monitoring programme in Europe has been carried out with the financial support of the European Union, either directly or through financial instruments such as Forest Focus (Regulation 2003) or Life+ (Regulation 2007). The EU NEC Directive (Directive 2016) also refers to the methods mentioned in the Air Convention, including those used by ICP Forests to collect and report data on the impact of air pollution on the forest environment. The relevant passage is as follows:

Article 9, item 2: 'The methodologies laid down in the LRTAP Convention and its Manuals for the International Cooperative Programmes may be used when collecting and reporting the information listed in Annex V'.

The Directive also obliges Member States to report on the results of monitoring research, including the results of forest monitoring in selected monitoring plots.

Forest monitoring studies will become even more important in light of the adopted New EU Forest Strategy for 2030 (European Commission 2021) and the resulting Regulation of the European Parliament and of the Council on a monitoring framework for resilient European forests (COM 2023). It obliges Member States to monitor forests in the EU, proposes methods (remote sensing and territorial monitoring) and obliges countries to report the results to the EU. This document is currently under discussion between interested parties, and it is expected that the final solutions will largely overlap with the scope and methods of ICP Forests monitoring.

The legal basis for the implementation of the forest monitoring programme in Poland besides the abovementioned LTRAP Convention and the EU directives and regulations is the resolutions of the Polish parliament. This is the Act of September 28, 1991, on Forests (Ustawa 2023), which imposes on the State Forests Enterprise the obligation to '... initiate, coordinate and conduct a regular assessment of the condition of forests and forest resources and to forecast changes in forest ecosystems' (Art. 13a, item 1, subsection 1). The monitoring activities are also directly related to the Act of July 20, 1991, on the Inspection of Environmental Protection (Ustawa 1991), on the basis of which the State Environmental Monitoring (PMŚ) was established in Poland, and the Act of April 27, 2001 – Environmental Protection Act (Ustawa 2001), which defines the objectives, tasks and structure of PMŚ. Article 26, item 6 of this Act, states: 'State environmental monitoring shall include information obtained on the basis of monitoring studies on (...) the state of environmental resources,

including forests'. The provisions of the above-mentioned legal acts indicate the location of forest monitoring within the PMŚ, as a separate task within the Nature Monitoring subsystem, with the following objectives: '... providing information on the health status of forests and the processes leading to deformations of their structure and function in order to shape forest policy and management of forest ecosystems and improve the quality of the country's natural environment' (GIOŚ 2020).

The legal provisions also define the institutional structure of forest monitoring programme (FMP) in Poland, which includes supervisory bodies (Chief Inspectorate for Environmental Protection, Department of Forestry and Nature Protection of the Ministry of the Climate and Environment and the General Directorate of State Forests), two financing bodies (National Fund for Environmental Protection and Water Management as well as the State Forests Enterprise) and the institutions responsible for carrying out forest monitoring activities. In this last category, the Forest Research Institute, which has been responsible for the coordination and implementation of the FMP since the beginning of the programme, should be mentioned above all. At various times, the Office of Forest Management and Forest Geodesy and representatives of the forest administration as well as experts and specialists from various scientific units have also been involved in the implementation of some FMP research tasks.

Scope and characteristic of country-wide forest monitoring in Poland

FMP in Poland covers all basic components of forest ecosystems and factors affecting forest health. The observations and measurements relate to the forest stand, undergrowth, soil, meteorological conditions, air pollution, precipitation chemistry and soil solutions, which describe the current state of the forest and allow monitoring of processes and trends of spatial and temporal changes in ecosystems, identification of existing threats and cause–effect relationships between environmental factors and the condition of forests. The results of the research and analyses carried out make it possible to take rational and active action against processes that threaten the stability of forests, that is, to initiate the reconstruction of forest stands and apply appropriate forms of protection of forest resources.

Forest monitoring infrastructure

Forest monitoring studies are conducted in Poland in a network of Level 1, Level 2 and Intensive Monitoring (IM) plots (Fig.) (Wawrzoniak and Lech 2011). Since 2006, the Level 1 plots have been located in a regular 8 km × 8 km network, which ensures the representativeness of the data at the regional level (RDSF, voivodeships and nature-forest regions) (Tab.) and in relation to the main native, forest-forming tree species/genders in Poland: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L) H.Karst.), fir (*Abies alba* Mill.), pedunculate oak (*Quercus robur* L.), sessile oak (*Quercus petraea* (Matt.) Liebl.), European beech (*Fagus sylvatica* L.), silver birch (*Betula pendula* Roth.) and black alder (*Alnus glutinosa* (L.) Gaertn.). The Level 1 plots are in stands that are over 20 years old. They consist of 20 trees with a diameter at breast height of at least 7 cm that grow closest to the centre of the plot and are subject to an annual health assessment. The list of Level 1 plots changes each year – if a stand is removed, the plots are given 'pending' status and are 'returned' for measurement and assessment once the new stand has reached the age of 21 years. The Level 1 plots in a 16 km × 16 km network form a Europe-wide network of plots on the basis of which studies on the condition of forests in Europe are carried out under the auspices of ICP Forests.

In the years 1994–1995, 148 Level 2 plots were established. They were located in 40- to 90-year-old pine (100 plots), spruce (22 plots), oak (14 plots) and beech (12 plots) stands in forests managed exclusively by the State Forest Enterprise. In addition to analysing the health of the forests, periodic studies are carried out on these plots on the soil, the growth of the stands, the mineral nutrition of the trees, the floristic composition and the natural regeneration. In the years 2007–2022, the trees on 15 Level 2 plots (11 plots with spruce, 3 with pine and 1 with oak) were removed so that since then, no more investigations on the trees have been carried out on these plots, only phytosociological and soil studies.

The structure of the forest monitoring observation plots also includes 12 IM plots, which were created from Level 2 plots in 2009 and have been subject to the most extensive observations, measurements and analy-

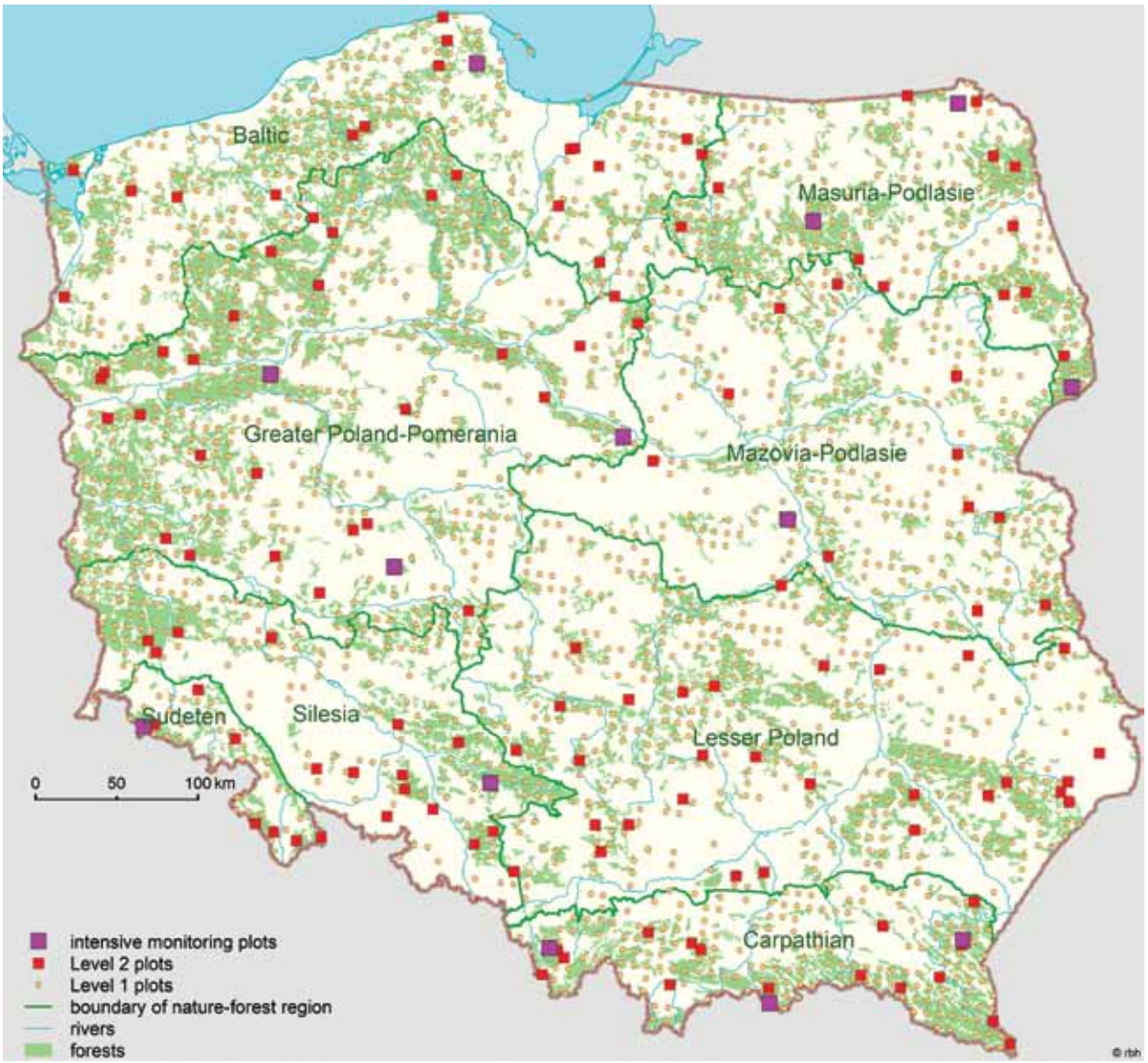

Figure. Location of Level 1, Level 2 and Intensive Monitoring plots in Poland in 2022 (Lech et al. 2024b)

ses since the beginning of 2010. In addition to the studies conducted on the Level 1 and Level 2 plots, they also include measurements of basic meteorological parameters, the concentration of gaseous pollutants in the air, ion deposition on the open space (above the tree canopy) and under the tree canopy, and the chemistry of soil solutions. The aim of these studies is to assess the impact of anthropogenic (air pollution) and abiotic (weather conditions) stress factors on forest ecosystems. Due to the dieback and removal of the spruce stand in the IM plot in the Bielsko forest district, the studies on this plot were terminated in 2012 and transferred to the newly established IM plot in the Piwniczna forest district.

An important element of the forest monitoring infrastructure is the Laboratory for Chemistry of the Natural Environment at the Forest Research Institute, where chemical analyses of collected water, plant and soil samples as well as air pollutant passive samplers are carried out. The laboratory is a certified and accredited by the Polish Accreditation Center (Accreditation Certificate No A740) equipped with modern analytical equipment and an experienced team of highly qualified

Table. Number of Level 1 and Level 2 plots in natural-forest regions of Poland by ownership categories in 2023

Natural-forest regions	Ownership categories										
	State Forest Enterprise		Level 1							total	
	Level 1	Level 2	national parks	other state owned	county owned	private	land communities	agriculture cooperatives	other	Level 1	Levels 1 and 2
Baltic	251	23	3	4	3	23	0	1	1	286	309
Masuria-Podlasie	156	14	7	2	2	46	2	1	0	216	230
Greater Poland-Pomerania	416	25	2	11	1	52	0	3	0	485	510
Mazovia-Podlasie	120	16	5	4	2	170	1	0	2	304	320
Silesia	136	16	0	3	5	10	0	0	0	154	170
Lesser Poland	201	27	3	10	9	160	13	0	3	399	426
Sudeten	33	8	1	2	3	2	0	0	0	41	49
Carpathian	89	19	12	3	6	74	2	0	0	186	205
Total	1402	148	33	39	31	537	18	5	6	2071	2219

staff. Samples sent to the laboratory are subjected to a rigorous analysis procedure in accordance with applicable Polish and international standards:

- pH – potentiometric method according to PN-C-04642-7:1999
- Electrical conductivity – conductometric method according to PN-EN-27888:1999
- Dissolved organic carbon (DOC) – by spectrophotometry in infrared according to PN-EN 1484:1999
- Fixed nitrogen (TNb) – chemiluminescence/electrochemical method according to PN-EN 12260:2004
- Cl^-, NO_3^-, SO_4^{2-} and PO_4^{3-} anions – by ion chromatography (IC) according to PN-EN ISO 10304-1:2009
- NH_4^+ cations – by ion chromatography (IC) according to PN-EN ISO 14911:2002
- Content of the elements Ca, Mg, Na, K, Fe, Al, Mn, Zn, Cu, Cd and Pb – by means of atomic emission spectrometry with inductively coupled plasma ICP-OES according to PN-EN ISO 11885:2009

The scope of forest monitoring in Poland

1. Monitoring the health of forest stands, including observation of morphological characteristics of the tree crowns (defoliation, discolouration, shading of the crown, number of needle years, needle length or leaf size, structure of shoot growth, type of crown thinning, proportion of dead branches, presence of secondary shoots, seed yield and flowering intensity) and assessment of the occurrence of tree damage symptoms and their causes (including the location of the damage, the type of damage symptom, the category and class of the causative factor and the size of the damage): This assessment is carried out annually for all types of plots. In 2023, there were a total of 2,204 permanent observation plots on which a total of 44,080 trees were assessed (Małachowska et al. 2024).
2. The mineral nutritional status of pine, spruce, oak and beech is assessed every 4 years on the basis of chemical analyses of needles and leaves collected from selected standing trees on Level 2 plots. The content of N_{tot}, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn, AL, Cd and Pb is determined. The first analyses of the mineral nutritional status of trees were carried out in 1997. In 2021 (the date of the last study), a total of 125 leaf samples (from beech and oak stands) and 1,078 samples of pine and spruce needles (separately for the last two sets of needles) were collected and analysed (Kowalska 2023).
3. The measurement of stand volume and growth is carried out every 5 years from 1994 (conifer stands)

or 1996 (hardwood stands) on Level 2 plots and comprises the measurement of the diameter at breast height of all trees with a DBH of more than 7 cm and the height of selected trees of the dominant species on the plot (pine, spruce, oak, beech) and admixed species. These measurements are used to determine the volume of the tree stand growing on the plot and the increase in volume since the last measurement cycle. Last dendrometry measurements were carried out in 2019 (Dudzińska 2020).

4. The soil analyses include physical and chemical soil parameters such as bulk density, particle size determination, pH, TOC, N_{tot}, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe, Na, Pb and Al in soil samples taken from five levels of mineral soil (0–5 cm, 5–10 cm, 10–20 cm, 20–40 cm, 40–80 cm) and the organic level. The soil samples originate from all 148 Level 2 plots. In the years 1995–2007, the soil analyses were carried out every 5 years, thereafter every 10 years. The last cycle of these analyses took place in 2017 (Sztabkowski 2019).
5. Monitoring of the floristic composition, horizontal structure, species diversity of forest floor plants and natural regeneration has been carried out every 5 years on the Level 2 plots since 1997. The basis for the floristic and geobotanical analysis is phytosociological surveys, which are carried out from mid-May to the end of August (twice on plots with dominant deciduous tree species). All species of vascular plants, bryophytes, ground lichens and lichens occurring on dead wood, tree trunks and branches as well as on rocks and stones are included in the inventory, and their abundance is determined in relation to the surface area of the available substrate. The horizontal structure of the ground cover is studied on part of the main phytosociological plot. The occurrence and structure of natural regeneration is also assessed within the plot. The last survey of ground vegetation on Level 2 plots took place in 2023 (Cacciatori 2024; Małachowska 2024; Solon 2024).
6. The monitoring of meteorological parameters includes measurements of the following parameters: air temperature [°C] at 2 m and 0.5 m height and on the ground (at 5 cm height), soil temperature [°C] at 5 cm, 10 cm, 20 cm and 50 cm depth, relative humidity [%] at 2 m height, soil moisture [dm^3/m^3] (on selected plots), total solar radiation [W/m^2], wind speed [m/s], wind direction [°] and precipitation [mm]. The measurements are carried out by automatic meteorological stations in a continuous cycle in the vicinity of 12 intensive observation plots (Kluziński 2024).
7. Air quality monitoring involves the measurement of SO_2 and NO_2 concentrations in the air using the passive method, in which the samplers are exposed monthly. The samplers are placed at a height of approx. 2 metres above the ground surface, usually near the meteorological station and the above canopy (or open air) precipitation collectors. These measurements have been carried out on 12 intensive monitoring plots since 2009 (Kowalska 2024a); in previous years, there were even more air quality measurement points (Lech 1997).
8. The monitoring of ion deposition in the open and under the canopy of the tree stand (including stem flow in plots with beech) has been carried out on 12 intensive monitoring plots since 2010. In both cases, the volume, electrolytic conductivity, pH value and chemical composition of the precipitation are determined: the content of Ca, DOC, Nog, K, Mg, Na, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, Al, Mn, Fe and heavy metals (Cd, Pb, Cu, Zn) as well as the alkalinity in samples with a pH value above 5. All precipitation samples are collected monthly with three collectors located at a distance of at least 50 metres from the edge of the forest and with up to 25 samplers under the canopy of the trees over the entire plot (Kowalska 2024b).
9. The chemical composition of the soil solutions has been monitored since 2010 on 12 intensive monitoring plots with 20 lysimeters at a depth of 25 and 50 cm (10 at each depth). The samples are taken monthly when the soil is not frozen. As with the other water samples, the chemical analyses determine electrolytic conductivity, pH, Ca, DOC, Nog, Mg, K, Na, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, Fe, Mn, Al, Cd, Cu, Pb, Zn and alkalinity in samples with a pH above 5 (Kowalska 2024c).

Quality assurance (QA) and quality control (QC)

Quality of data is essential in forest monitoring. To secure its quality, a process of quality assurance and quality control is applied in each step of the investigation

of concern, from the definition of the objectives to the comparability of the data in space and time to data storage, processing and reporting. Data quality is a cross-cutting issue as it is of concern for all the surveys and for all the various steps within a survey. QA and QC activities include training at national and international levels (coordinated by ICP Forests), methods for recording measurements and assessments to prevent incorrect values being entered, procedures for checking and validating of data while recording on the recording devices in the field or during the data transfer to databases, procedures for correcting incorrect data when preparing reports, ring tests to check the quality of chemical analyses carried out in the laboratory and control of field work.

Every year, around 50–65 employees take part in forest monitoring activities depending on the scope of the programme each year. Most of them are involved in examining the health of the forest stands, followed by dendrometry measurements, phytosociological and soil studies, collecting precipitation and soil solution samples and operating meteorological stations. All these activities are preceded by training workshops consisting of a detailed presentation of the objectives and methodology of a particular activity, practical exercises and a review of the skills of the trainees. An important element of the training is also the presentation of the requirements and recommendations for health and safety in the workplace. Fieldwork in teams of two is also a rule, whereby at least one of the people forming the team must have experience of carrying out a particular task from the previous observation/measurement cycle. An important element of QC is also the control of the accuracy of the field work, in particular, the assessment of the health condition of the tree stands. In this case, a special control group carries out a re-measurement of about 5% of all plots (in 2023, there were 110 such plots). The results obtained by the control group are compared with the measurement results of the teams, and if significant differences or errors are found, co-operation with the people concerned is discontinued. Training and exchange of experience also take place at international level and are organized by the ICP Forests Programme Coordination Centre. These include inter-calibration courses, online photo tests of crown condition, ring tests of chemical analysis, and data checks during data transfer to the ICP Forests database.

Forms of presentation, utilization and dissemination of the forest monitoring results

The basic output of forest monitoring in Poland, which presents the monitoring results, is the annual report entitled 'Forest condition in Poland in ... on the basis of monitoring studies' (Lech et al. 2024a), which is submitted to the Chief Inspectorate of Environmental Protection. The reports reflect the scope of surveys and observations carried out in the previous year. The results of the assessment of the forest health are presented in detail, and the most important environmental factors are characterized, including weather conditions, air pollution and the deposition of chemical compounds in the country's forest areas. They also contain an overview of the state of forests in Poland in relation to the state of forests in the European countries. The reports are also summarized (Lech et al. 2024b). The reports and summaries are presented on the Forest Monitoring website, which is updated annually (https://www.gios.gov.pl/monlas/index.html). Most of the results of forest monitoring are also included in the 'Report on the condition of forests' prepared every year by the Forest Research Institute and submitted to the Polish Parliament. The most important results of the monitoring are also forwarded to the so-called Forest Data Bank (https://www.bdl.lasy.gov.pl/portal/).

Forest monitoring data relating to the natural environment are made available to external users free of charge in accordance with the law in force in Poland and the EU (Ustawa 2008). This applies both to the data collected in the forest monitoring database of the Forest Research Institute and to the data originating from Poland and relating to Poland contained in the ICP Forests database. In both cases, the transfer is made upon written request and with the consent of the data administrator/owner in Poland with the consent of the Ministry of Climate and Environment, the Chief Inspectorate for Environmental Protection and the General Directorate of State Forests. Every year, several such applications by scientific institutions are approved in Poland, and several dozen requests for access to monitoring data from across the world are submitted to ICP Forests Program Coordinating Centre, which are then used to carry out research projects and prepare scientific publications.

Scientific publications are an important way of utilizing and disseminating the results of forest moni-

toring. Each year, several dozen articles based on monitoring data from across Europe are published in prestigious international journals, including *Nature*, *Nature Communications*, *Nature Climate Change*, *Global Change Biology*, *Science of the Total Environment*, *New Phytologist*, *Forest Ecology and Management*, *Environmental Pollution*, *Ecological Indicators*, *Ecology Letters* and many others (see http://icp-forests.net/page/scientific-publications). Many of these publications use data originating from and related to Poland. The authors or co-authors of some of these publications in recent years were also scientists from our country – see Puletti et al. (2019), Lech et al. (2020), Pilotto et al. (2020), Seidling et al. (2020), Zielonka et al. (2021), Cacciatori et al. (2022), Wohlgemuth et al. (2022), Salomón et al. (2022), de Wergifosse et al. (2022), Verstraeten et al. (2023), Lech & Kamińska (2024), Anthony et al. (2024).

Ending notes

The forest monitoring programme provides reliable information that enables the development of rational forest and environmental policy in Poland and in Europe. It also fulfils the legal obligations arising from the international conventions adopted and ratified by Poland and from national laws. The results of forest monitoring provide a comprehensive assessment of the pace and direction of change in forest ecosystems and the identification of key factors influencing forest health in both the short and long terms. It provides the scientific basis for decisions on air pollution control and can contribute to other aspects relevant to forest policy, such as the impact of climate change on forests, the contribution of forests to climate change mitigation, sustainable forest management and forest biodiversity. The fundamental objectives of the programme from a country perspective have thus been achieved. Besides that, the monitoring system and the monitoring data both in Poland and in Europe can also be used for international processes of environmental policies, such as the FAO Global Forest Resources Assessment (FRA) and the future Global Forest Survey (GFS), to the Forest Europe process (formerly: Ministerial Conference for Protection of Forests in Europe (MCPFE)), the Convention on Biological Diversity (CBD), the Framework Convention on Climate Change (UNFCCC) and the European Commission. The latest example of the use of ICP Forests monitoring data for environmental policy processes at the European level is the National Emission Ceilings (NEC) (Directive 2016). Article 9 of the NEC Directive requires EU Member States to monitor the negative impacts of air pollution on ecosystems (including forests). Therefore, many parties to the convention use ICP Forests data to fulfil their reporting obligations for the EU. Finally, the monitoring infrastructure built over more than three decades can also contribute to terrestrial research infrastructures within new international consortia such as the long-term ecological research (LTER) network or research projects.

The history and practice of the forest monitoring programme in Poland reflect the process of continuous development and adaptation of the scope of research to new, emerging challenges and threats to the forest environment. This is also the case at present, as forests are increasingly affected by negative factors caused by climate change, such as droughts, fires, storms, outbreaks of insect pests and epiphytosis of infectious diseases. Therefore, the prepared European Union Forest Monitoring Regulation (COM 2023) states: 'A European-wide forest monitoring system should be set up to collect and share forest data that will support informed decision making, for example, by allowing to identify, assess, and address forest hazards, risks and damages in a timely manner'. In this context, the extensive use of satellites and other space instruments is envisaged to be complemented by periodic airborne imaging campaigns and Earth observation technologies.

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