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DYNAMIC MODELLING OF POLISH FOREST SOIL RESPONSE TO CHANGES IN ATMOSPHERIC ACID DEPOSITION

The VSD model was applied to simulate the dynamics of soil reaction to changing acid deposition for 48739 forest sites of 1 km^2 size each. Taking account of the emission reduction scenario agreed under the Gothenburg Protocol, the calculations were run to answer the question of whether this agreement suffices to allow recovery and prevent further acidification of Polish forests and to identify regions where further emission reductions are indispensable. To this end target load functions for the years 2030, 2050 and 2100 as well as the time of damage and a delay in forest recovery were calculated for all forest sites under consideration. The output of these calculations shows that in target year 2030 about 19% of the sites analyzed will be protected when deposition is not changed after 2010. This means that no deposition reduction is required in this target year. For target year 2100 the contribution of these safe sites increases to 20%. In the case of the main fraction making ca. 80% of the sites analyzed, target load functions exist and target depositions can be calculated for selected target years. For a portion of sites the target loads cannot be achieved even at the lowest background depositions. This applied to 1.2% of sites for the target year 2030 and to 0.2% for 2050, while for 2100 it is not the case. Based on the constant deposition rates resulting from the Gothenburg Protocol, the recovery from the conditions of exceeding allowable soil chemical parameters is possible for 1.52% of sites, while damage may happen to about 10% of sites until 2100.

1. INTRODUCTION

Once the Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone adopted in Gothenburg in 1999 has entered into force, the process of its review started. According to the Protocol statements the adequacy of its obligations and the progress made towards the achievements of its objectives are the basic subjects of this review. Recent scientific findings mainly based on the effect-oriented activities of the Working Group on Effects, a sub-body of the Convention on Long-Range Transboundary Air Pollution, show that a considerable reduction of the extent and magnitude of excess acidification would be achieved in 2010 due to the

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sulfur and nitrogen emission cuts determined by the Protocol obligations [1]. Nevertheless still some areas, also in Poland, will remain under the permanent ecological risk being posed by exceeding critical loads of acidity. This means that current Protocol commitments are insufficient to prevent these areas from further acidifying in a long-term scale and that additional measures are required to protect them. Another important question that the Protocol review should answer, addressed to areas where critical loads are not exceeded, is when ecosystems will recover in response to the settled emission reductions. Both questions may only be answered using a dynamic approach to estimate the response of ecosystems to changes in atmospheric acid deposition, thus dynamic models are considered the most appropriate practical tools. A number of dynamic models to simulate acidification of soils and surface waters have been developed, tested and successfully applied to specific integrated monitoring sites in various countries, but for the Pan-European application a new Very Simple Dynamic (VSD) model has been constructed in order to support the integrated assessment of emission reduction scenarios [2]. The VSD model was applied to assess chemical reaction in Polish forest soils and consequently the damage and the delay in their recovery due to changing acid deposition.

2. LINKS BETWEEN STEADY-STATE AND DYNAMIC APPROACHES

Critical load concept supporting the Gothenburg Protocol is based on a steady-state approach where critical loads are constant depositions that do not damage the functioning and structure of ecosystem in a long-term perspective. Thus this concept refers to the situation where equilibrium between a given deposition and biochemical status of an ecosystem is reached. However, under natural conditions the equilibrium practically cannot be kept due to processes delaying for decades the ecosystems response to relatively fast deposition changes. The VSD model identifies the magnitude of critical loads and areas where they occur and gives information on time of both the damage and a delay in their recovery as well as determines target loads, e.g., the maximum deposition allowed a certain ecological goal within a fixed time horizon to be reached. To perform these functions the model structure connects the steady-state critical load approach with dynamic interpretation of ecological processes in such a way that any VSD output has to be coherent with the calculations from critical loads. This consistency is also required by integrated assessment model RAINS [3] that allows us to evaluate the cost-effective and technically-feasible scenarios of emission reduction.

Therefore the input data acquisition for the VSD model was focused on the extension of existing critical load data base to the data necessary for the model operation.

3. CRITICAL LOADS DATA BASE

Recently updated critical load data base [4] for Polish forest ecosystems was applied. Three parameters of the critical load function for acidity, i.e., $CL_{max}(S)$, $CL_{min}(N)$, and $CL_{max}(N)$, have been derived using the Simple Mass Balance model [5] and addressed to forest ecosystems as the most widespread sensitive indicators of sulfur and nitrogen deposition in Poland. The spatial resolution applied for mapping critical loads and their values exceeding the permissible ones was based on a 1 km × 1 km grid cell. Accordingly 88383 single sites were subject to modelling. The long-term average values of input parameters necessary for calculating critical loads were derived from national or single site measurements. Data from 1468 I-level and 148 II-level forest monitoring sites provided the main input to calculations [6]. From this monitoring of soil physical and chemical properties, base cation depositions and vegetation parameters were derived. Default values of denitrification fraction, nitrogen immobilization, and gibbsite equilibrium constants have been obtained through an extensive review of available literature data or adopted from the *Manual for Modelling and Mapping* [5]. For woodland mineral/organomineral soils the critical chemical threshold $[Al]_{crit}= 0.2$ eq·m.$^{-3}$ was used.

Geostatistical smoothing techniques were used for plotting interpolated critical load maps of 1 km × 1 km grid resolution from monitoring sites maps.

4. VSD MODEL DATA BASE

In addition to data already stored in the critical load data base, the parameters characterizing the cation exchange process and nitrogen balance have been derived and recorded in the VSD model data base. These are soil bulk density, cation exchange capacity (CEC), base saturation, exchangeable cation fractions and C/N ratio. All of the data are based on the II-level forest monitoring records [6] assigned to the following four soil horizons: O – 0.05 m, A/E – 0.10 m, B – 0.30 m and C – 0.40 m. While VSD is a single-layer model, the input data were averaged over the entire rooting zone of 0.5 m depth. These parameters (except C/N ratio) multiplied by soil layer thickness produce the pool of exchangeable cations.

Cation exchange constants based both on the Gaines–Thomas and Gapon exchange reactions were adopted form the *Manual for Dynamic Modelling of Soil Response to Atmospheric Deposition* [2]. Historic sulfur and nitrogen deposition sequences contained in the VSD model were applied.

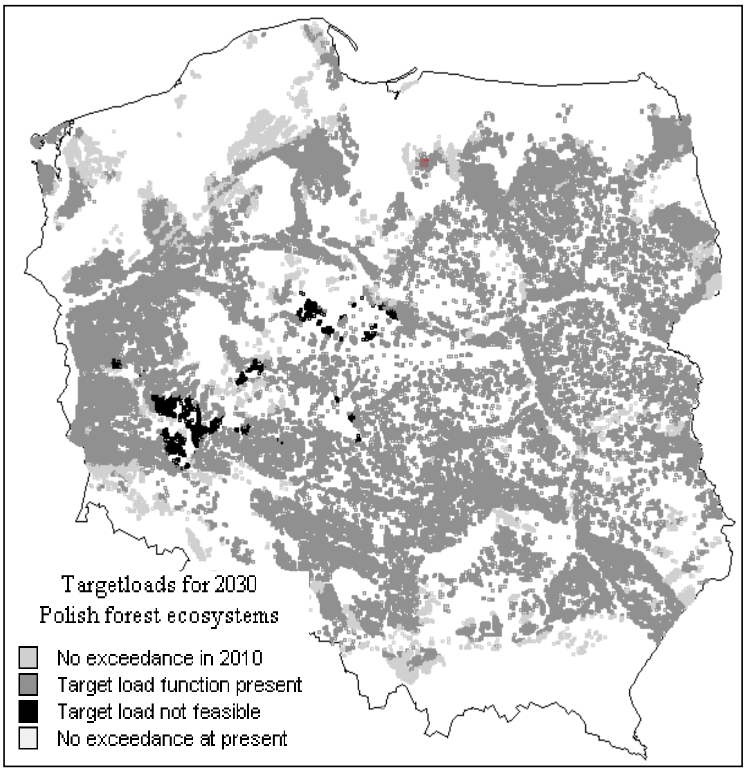
5. RESULTS AND DISCUSSION

Basic calculations were preceded with a preliminary step aimed at the omitting in further calculations all these sites where critical loads are not exceeded in 2010 and the adopted chemical criterion is not violated. There is no need to calculate target loads for such sites. This operation resulted in a decrease in a total number of 88383 forest sites gathered in the national data base to 48739 sites for which further tests were performed. Table 1 summarizes the VSD model results with three possible cases distinguished and the figure illustrates their spatial distribution for the target year 2030.

Table 1

Number and per cent of forest sites assigned by the VSD model to three situations characteristic of dynamic response of forest soil to changing acid deposition

Status	Target year					
	2030		2050		2100	
Ecosystems safe in target year	9368	19.2%	9481	19.5%	9632	19.8%
Target load function exists	38767	79.5%	39175	80.4%	39107	80.2%
Target load not feasible	604	1.2%	83	0.2%	0	0.0%



Spatial distribution of results of target load calculations

Ecosystem safe in a target year is the ecosystem whose critical load is not exceeded and the chemical criterion is not violated. As can be seen from table 1, 19.2% of forest sites in 2030 to 19.8% in 2100 are safe in the considered target years when acid deposition remains at the level corresponding to the Gothenburg Protocol obligations.

The next step in the model calculations was to find the sites which are safe in a given target year with the background deposition determined by EMEP MSC-W, i.e., the lowest possible deposition caused by non-anthropogenic emissions only. This group of sites appeared to be the biggest making up to 80% of all processed sites.

The third group of the sites selected from the data base by the VSD model is composed of the sites for which target loads are not feasible, i.e., the chemical criterion cannot be reached in the target year even at depositions reduced to background values. There are 1.2% of such sites for the target year 2030 and 0.2% for 2050, while for 2100 it is not the case.

Figure shows how the dynamic characteristics is spatially distributed over the Polish forests. Forest sites, where target loads are not exceeded in the three target years and with the deposition of 2010, mainly occupy the northern and southern parts of the country, being the less sensitive to acid deposition. The biggest central part is taken by the sites for which the target load functions exist for the all target years under consideration. The sites for which target loads do not exist, because the chemical criterion cannot be met, are located in the most sensitive areas, partly in the central but mainly in the west-southern Poland.

The calculations of the time of ecosystem damage and a delay in its recovery in the period 2010–2100 were based on the sulfur and nitrogen deposition scenarios for 2010 resulting from the Gothenburg Protocol.

Table 2 presents the number and contribution of sites for which relevant delay times were identified as well as contribution of sites in which recovery or damage took place before 2010 and after 2100.

Table 2

Number and per cent of forest sites in which the times of damage (DDT) and the delay in forest recovery (RDT) were identified and contribution of sites in which recovery or damage took place before 2010 or after 2100

	2010–2100			2010<		>2100	
RDT	743	1.52%	Recovered	8889	18.24%	16	0.03%
DDT	4902	10.06%	Damaged	15802	32.42%	18387	37.73%

Only in 11.6% of the sites, being constantly exposed after 2010 to acid deposition resulting from the Gothenburg Protocol, the recovery or damage may occur within the time span considered. The recovery from the conditions of exceeding permissible soil chemical parameters is possible for 1.52% of sites while damage may happen to about 10% of sites until 2100.

Sites for which damage may take place before 2010 or after 2100 amount to about 70% of the total being considered. But only about 18% of the sites may recover before 2010, whereas after 2100 their recovery is practically impossible.

6. CONCLUSIONS

The predictions of dynamic model indicate that although the implementation of the Gothenburg Protocol will substantially reduce the area of Polish forest ecosystems exposed to excessive acid deposition, their considerable part is still threatened with potential acid pollution because the permissible levels of acid depositions are often exceeded. This indicates that further reduction of sulfur and nitrogen emission beyond the Protocol's obligations have to be considered within its intended review.

ACKNOWLEDGEMENT

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DYNAMICZNE MODELOWANIE REAKCJI GLEB LEŚNYCH POLSKI NA ZMIENNĄ ATMOSFERYCZNĄ DEPOZYCJĘ KWAŚNĄ

Dynamiczną symulację reakcji gleb na zmienną depozycję kwaśną dla 48739 powierzchni leśnych o wymiarze 1 km × 1 km każda przeprowadzono za pomocą modelu VSD. Przyjmując scenariusz redukcji emisji siarki i azotu, uzgodniony w ramach Protokółu z Göteborga, wykonano obliczenia, których

celem było zbadanie, czy uzgodniona redukcja emisji umożliwi odnowę i zapewni ochronę polskich lasów przed dalszym zakwaszeniem. Następnym celem tych obliczeń było wskazanie obszarów, na których dalsza redukcja emisji jest wskazana. Dlatego obliczono funkcje ładunków docelowych dla lat 2030, 2050 i 2100 oraz czasy uszkodzeń i opóźnienia odnowy ekosystemów leśnych na wszystkich badanych powierzchniach. Wyniki obliczeń wykazały, że w docelowym 2010 roku 19% analizowanych powierzchni będzie chronionych, jeśli depozycja siarki i azotu nie ulegnie zmianie po 2010 roku. Oznacza to, że w tym roku docelowym redukcja depozycji nie jest wymagana. W docelowym roku 2100 udział chronionych powierzchni wzrośnie do 20%. Wykazano, że dla głównej części analizowanych powierzchni, stanowiącej ok. 80% wszystkich badanych, funkcje ładunków docelowych istnieją i można dla nich wyznaczać depozycje docelowe dla wybranych horyzontów czasowych. Stwierdzono także, że dla części powierzchni funkcji ładunków docelowych nie da się wyznaczyć nawet przy najniższych depozycjach tłowych. Dotyczy to 1,2% powierzchni dla roku docelowego 2030 i 0,2% dla roku 2050, dla roku 2100 zaś takich przypadków nie stwierdzono. Przy depozycjach siarki i azotu ustalonych na poziomie dyktowanym przez postanowienia Protokółu z Göteborga odnowa gleb leśnych, na których dopuszczalne depozycje zostały przekroczone, jest możliwa na 1,52% powierzchni, uszkodzenie ekosystemów leśnych natomiast może w tych warunkach nastąpić na ok. 10% powierzchni do roku 2100.