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TECHNICAL METHODS OF PREVENTING AND LIMITING THE EFFECTS OF NATURAL DISASTERS CAUSED BY SEVERE WEATHER CONDITIONS IN POLISH FORESTS

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ABSTRACT

Climate change observed in recent years has led to a rise in the frequency and magnitude of meteorological phenomena such as violent storms, intense rainfall or extreme heat events, which have triggered floods, mass land movements, droughts and wildfires. The intensification of severe weather conditions has put a strain on forest stands in many regions of Europe. Weather-related stressors are considered a leading factor in the degradation of forest stands and the growing susceptibility of trees to pathogenic agents. The new dynamic situation has substantially altered conditions for forest management in Poland. Long-established management methods have had to be revised, while new approaches need to be developed to face the emerging or aggravated threats to forests. It has become apparent in many cases that silvicultural techniques alone will not be sufficiently effective and thus should be supported or supplemented by technical solutions to respond adequately to the altered conditions. This study and the obtained findings are discussed in terms of engineering solutions applied in forests to optimise the road network, limit the effects of natural hazards, implement hydrological restoration and enhance water storage. The article presents management of natural hazards and adopted engineering approaches from a Polish perspective. Case studies of applied solutions to prevent and limit the damaging effects of natural hazards and disasters on forests are included.

Keywords: engineering solutions, extreme weather events, forest protection, limiting forest damage

EFFECTS OF SEVERE WEATHER ON POLISH FORESTS – INTRODUCTION

Water management – drought and flooding

Forests in Poland contribute largely to biodiversity, but are under growing pressure from the effects of climatic hazards due to climate instability (Jabłoński, 2019; Jabłoński et al., 2013). Decreasing water resources require more accurate storage monitoring and implementation of effective hydrological restoration projects and application of dedicated engineering solutions. While water resources of Poland are among the poorest in Europe, water conditions are vital for the growth and development of tree stands and sustaining forest habitats. A large share of water balance inputs in Poland is used by forest vegetation that covers almost a third of Polish territory.

In recent years Polish winters have become milder. While the share of snow storage in the water balance has reduced, droughts often occur in early spring, with the very onset of the growing period. Rising

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temperatures, higher evapotranspiration totals and extended warm periods increase the risk of drought damage to the forest during the vegetation period. In order to limit the consequences of unstable water availability for forest vegetation, numerous projects of local water storage and hydrological restoration are being implemented in state-owned forests in Poland. These involve constructing dams, medium and large reservoirs and larger-scale hydrologic restoration projects made by basin managing authorities and other parties.

The frequency and intensity of floods and the total area endangered by floodwater have increased in Europe since the end of the nineteenth century (Paprotny et al., 2018). It is estimated that about 40% of industrial losses resulting from natural disasters have been caused by floods (Poprawa and Rączkowski, 2003). High variability and decreasing stability of river flow regimes, and thus the growing intensity of extreme hydrological events, increases the impact of floods as an ecological stressor for forests (Arnell, 1994; Hannah et al., 2006; Mikac et al., 2018; Stahl et al., 2010). Over the last 30 years there have been numerous flood events in valleys of medium and large rivers in Poland. These events often occurred locally and only covered some sections of river valleys. However, in 1997 and 2010 long-term river flooding occurred in the entire basin of the Oder and the Vistula of south Baltic and affected valleys of many medium and large rivers in the area (Grela et al., 1999; Maciejewski et al., 2011a; 2011b). The 1997 flood resulted in prolonged surface floodwater stagnation and sub-surface waterlogging, and in consequence deterioration of forest stand growth on active terraces.

Due to usually favourable growth conditions, the high fertility of valley habitats and good access to water the fluvial terraces are attractive sites for growing trees of high commercial value (Okoński, 2019). Forestry practices favouring those locations are related with good natural growth in the valleys of such species as pedunculate oak and European ash, whereas other tree species that do not occur naturally in river valleys are also included. A good example in this respect is provided by Scots pine, which grows well in sandy soils of valley floors in Central Europe (Danielewicz, 2008). Generally, there is a preference towards tree species that tolerate changeable and periodically shallow sub-surface water levels and exhibit resistance to the impact of river flooding. Management of commercial tree stands in river valleys needs to consider flooding damage hazards (Kozlowski, 2002). Numerous factors modify tree resistance to floodwater. The main factors are connected with species tolerance of anaerobic conditions caused by stagnant water and environmental characteristics of river regimes, especially the frequency, magnitude, annual distribution and duration of flooding, local physiographic and habitat conditions, mainly the shape of the river valley and landforms, soil layer permeability in the river valley bottom, etc. (Glenz et al., 2006).

Forest fire

While Polish forests are exposed to a moderate wildfire risk (Szczygieł, 2012), they are considered among the most flammable in Central Europe (Dobrowolska, 2008). In the case of most individual fire events in Poland forest fires usually consume relatively small areas (Szczygieł, 2012). The average annual number of forest fires in Poland is 8,500, leading to over 7,000 ha being burnt (Grajewski et al., 2019). The most remarkable fire events occurred in Polish forests in 1992, where 9,000 ha of forest was burnt in the Rudy Raciborskie Forest Unit and almost 6,000 ha in the Potrzebowice Forest Unit. In both cases the fire was initiated by jammed train brakes. Unlike some other European countries, in Poland the rising number of forest fires or the increasing average burnt area have not been confirmed to be linked to climate change. The high efficiency of the fire protection and control system employed in Polish forests is viewed as a decisive factor resulting in these favourable statistics (Grajewski, 2017a; 2017b).

Prevention and limitation of fire damage can be achieved by introducing firebreaks in locations important for forest protection, coupled with early detection systems and proper access to burning areas by fire-fighting teams and equipment. Studies have been conducted to optimise the fire access road density and layout, which resulted in implementing new directives on planning the road network in the state forests.

According to Polish law regulations, owners and managers of forests covering over 300 ha are required to monitor and patrol forests to detect fires and raise the alarm. Owners are obliged to maintain the water supply for fire-fighting purposes, maintain fire access roads assigned in the management plan for fire-fighting, adequately mark water supply locations, maintain fire-fighting equipment stations, and consult fire-fighting aspects of their forest management and national park protection plans with local fire-fighting authorities to identify the most fire-vulnerable forests.

Mass movement

Flood and heavy rainfall may activate mass movement, also known as mass wasting, causing substantial local damage to forests in Poland. Research conducted in 27 European countries has revealed that about 6.5% of mass movement events recorded between 1995 and 2014 might be linked to floods. It was also noted that mass movement events immediately followed rainfall episodes in about 90% of the cases (Haque et al., 2016). In Poland the Carpathians (about 6% of the country's land area) are most susceptible to landslides, accounting for 90–95% of all landslides in this country. In general, 30% of Poland's area is mass movement prone (Grabowski et al., 2008; Poprawa and Rączkowski, 2003) and numerous landslides occur in forests, since the share of forest cover is high in most mass movement susceptible areas in Poland, such as e.g. the Carpathians, share of forest area from 31% in the Beskidy to 83% in the Bieszczady Mountains.

In Poland landslides are initiated primarily by precipitation and snowmelt, which activate filtration and deep infiltration processes coupled with saturation of loose sediment layers on slopes (Gorczyca 2004; Gil and Długosz, 2006; Starkel, 2006). Landslides occur after maximum soil saturation is reached in the wake of heavy rainfall, while a combination of the event duration and rainfall intensity provides a sufficient amount of water. In the Carpathians the mass wasting is usually initiated on slopes receiving more than 200 mm of precipitation in total, since the effect of a rainfall event usually lasts for only several days (Gil and Długosz, 2006).

The pattern of the reactivation of dormant landslide locations and activation of previously stable adjacent slopes prevails in Poland (Gil and Długosz, 2006). Over 20 years of monitoring (starting with a very wet year of 1997) have revealed an increasing landslide activity, with serious events being noted every year.

Mass movements often cause significant damage to technical infrastructure such as buildings and roads. Monitoring indicates that landslides threaten 500 sites in the central part of the Polish Carpathians alone (Poprawa and Rączkowski, 2003). Each year the forest sector suffers from substantial damage caused by mass land movements. The losses affect not only forest engineering structures, e.g. roads and bridges, but also individual trees and entire forest stands. Landslides destroy trees, cause mechanical tree damage, reduce tree growth, deteriorate timber quality and reduce revenue from prospective harvests (Mozgawa and Kwaśny, 2010).

Strong wind

In August 2017 a derecho called "the storm of the century" passed over Poland (Pistol and Flaga, 2018). Due to the disastrous impact of the storm in just one night affecting over 45,000 ha, about 8 million m^3 of timber were lost in damaged or fallen trees, equivalent to 20.8% of the annual harvest (Raport…, 2018). Seidl et al. (2017) predicted that severe weather events will become more frequent because of global warming. Hence multi-faceted response measures should be undertaken to prevent and limit the effects of wind damage to forests.

The main effect of strong wind events on forests is often connected with the resulting thousands of fallen trees, which have to be removed very quickly. Efficient clearing of windfall-affected forest areas results from the necessity to ensure road passability, prevent the loss of value and technical quality of windthrows and windsnaps, decrease fire risk and provide appropriate conditions for new plantings. Removing windthrows and windsnaps in large areas is a technical challenge posing a hazard both to human operators and to equipment.

AIM

The article aims to present our findings and studies concerning the effects of severe weather conditions and weather-related natural disasters on forests in Poland. The review is intended to provide a background to show implemented technical solutions and approaches dedicated to preventing or limiting damage to forests caused by natural disasters. The methods were developed to minimise the impact of damage on forests in Poland thanks to the collaboration between researchers, forest authorities and other stakeholders. The presented solutions and approaches aiming to counteract the impact of severe weather events on Polish forests may provide some hints or inspiration for forest managers and decision-makers in other countries coping with similar problems.

CASE STUDIES. TECHNICAL SOLUTIONS LIMITING THE EFFECTS OF NATURAL DISASTERS IN POLISH FORESTS

The mitigation of scarcity of water resources in lowlands and in a mountain forest

Based on the Karnieszewice and Stuposiany Forest Districts

To prevent the scarcity of water resources and augment water availability in river basins various programmes dedicated surface runoff have been introduced. The reservoirs classified as small-scale water retention facilities retain 0.83 billion m^3, while the total volume is 4 billion m^3 (6.5% of the average annual runoff). Such small-scale water retention measures are often employed in systems to augment water resources in forest areas.

Apart from reservoirs and other engineering stuctures used to retain water, wetlands, being water-dependent ecosystems, may also provide water for adjacent areas. Natural and transformed wetlands cover over 4 million ha in Poland (13% of the total land area), substantially modifying water resources at the national level (Mioduszewski and Pierzgalski, 2009). Transformed wetlands are often subject to ecological restoration and water resource alteration projects that employ environmental engineering methods. Various approaches have been applied to manage and assess the effects of these projects on forests. Miler et al. (2007) proposed the process to follow a specific pattern: current inventory, identification of abiotic and biotic hazards, establishing the range of passive and active protection methods, establishing protection task hierarchy, constant monitoring and reporting of ecological effects after implementation. The State Forests National Forest Holding, which manages over 80% percent of forested land in Poland, is an active participant in water resource alteration programmes. More than 75% of the State Forest districts nationwide have participated in these water storage programmes over the last 30 years. The most prominent programmes completed in the last decade were implemented in lowland and mountain forests. The hydrologic goals of the lowland programme are to increase water resources available to the forest by slowing down surface runoff, and to provide water to restore wetlands and water-dependent forest habitats. Other hydrologic goals for mountainous areas were to protect forests and other areas from erosion, floods, mass movements caused by heavy rainfall and to support biodiversity by providing habitats for water-dependent species.

The Karnieszewice Forest District has participated in the hydrological restoration programme dedicated to lowland forests, a typical example for the Polish Lowlands as far as water resource problems are concerned. The district manages over 17,000 ha of forests dominated by Scots pine (52%), beech and oaks (20%) growing in a mosaic of drought-vulnerable fresh habitats varying in fertility. The local hydrologic system was transformed by extensive drainage and stimulation of channel runoff as a result of past water management. The project included restoration of 7 dammed lakes and silted reservoirs, building of 17 damming structures, such as weirs or embankments to slow water flow in streams, rivulets and other channels and restore semi-natural hydrologic conditions.

The Stuposiany Forest District, located in the Carpathians is an example of a forest district, which has participated in the programme assigned for mountainous areas. The district area is 95 000 ha and lies on a low mountain range (536 m to 1015 m a.s.l.). The forest cover is 98% and the main tree species are beech (40%), fir (32%) and spruce (18%). The main hydrologic problems include flash floods and water erosion, as well as scarcity of open water to support biodiversity. The hydrologic alteration project for Stuposiany involved building reservoirs to retain and manage runoff from wet meadows (7 new and one restored). The technical solutions applied for these reservoirs provided breeding and wintering sites for amphibian and bird species.

Providing passability of fire access roads through a waterlogged soil area

Inadequate quality paving of both regular and fire access roads in the forest road network is still a common problem in Poland. Insufficient load-bearing capacity of the subgrade found in some road sections is regularly recognised as a leading cause of poor road quality. Forest management authorities often seek help of researchers and designers to find effective technical solutions to provide required passability of challenging road sections and maintain coherency of the local forest road network.

We present the results of our study to work out optimal solutions to improve problematic sections at poor subgrade conditions caused by high groundwater levels and insufficient bearing capacity of organic soils. We recommend four low-cost variants of road pavement structure: geotextile with planar underlay, geotextile with half-mattress underlay, 0/31.5 mm aggregate and medium sand (Grajewski et al., 2015; 2019). These variants of road construction methods were examined in test road sections to assess their suitability for forest applications. Polypropylene geotextiles with track reinforcement were tested in cooperation with ViaCon Polska Ltd. The material innovation consists in strengthening the fabric in two 60-centimetre wide strips typically used by vehicle wheels. The geosynthetic could provide higher strength parameters in road surface zones where the highest pressure is applied. The application of geotextiles in narrow forest roads appears to be a promising solution to the problem. Furthermore, the required strength parameters are achieved at a lower price. The tensile strength in both directions on the strengthened strips was 35 $kN \cdot m^{-1}$, while outside the strengthened lanes it was 18 $kN \cdot m^{-1}$ with a maximum elongation of 13% and 14%, respectively. Dynamic puncture resistance in the strengthened strips was 10.6 mm in the strengthened lanes and 13.8 mm in the non-strengthened lanes. Static puncture resistance in the strengthened strips was 4.3 kN and 3.6 kN in the non-strengthened strips. Water permeability was $9.0 \cdot 10^{-3}$ and $2.1 \cdot 10^{-2}$ $m \cdot s^{-1}$ for both solutions. Six months after commissioning of the road the first assessment of surface load parameters was conducted using a lightweight deflectometer (ZFG 3000 GPS with 10 kg drop weight, Zorn Instruments) and a single-sensor static plate load tester (HMP PDG Pro, Prüfgerätebau GmbH).

The examination of each road upgrading variant produced similar results in terms of load-bearing capacity. Contrary to expectations, no differences were indicated for the geotextiles. The differences were minor and recorded mainly for aggregate and sand pavements. However, according to the static plate load test results the planar geotextile layouts were less favourable than the half-mattress layouts. The benefits of the half-mattress layout may appear over a more extended period. The test results for the variants of road construction technologies strongly support the recommended introduction of these solutions in forests. It should be stated that the proposed technologies are sufficient to support fire trucks and other fire-fighting vehicles, although they are not adequate to support heavy load vehicles such as timber transport vehicles (Czerniak and Grajewski, 2014; Kamiński, 2012). Adapting these road sections to timber haulage will require adding a suitable reinforcing layer or layers to the existing subgrade.

Flooding damage of forest stands in the Oder valley in 1997

Lessons learned to develop a flood mitigation approach for forests

The Middle Oder river valley (located 502 km to 510 km from the river mouth) was selected to examine the influence of river flooding on commercial pine forest stands and to find solutions to limit the damaging effects of flooding on forests. The section of the river valley was severely flooded during the 1997 flood. The research sites were set in eight locations along the river valley between 2.5 km to 4.0 km from the active channel, with forest stands ranging from the sapling to mature stand stages (20 to 90 years old). Soil and water conditions were examined in test soil bores and pits. For comparison, eight other sites of matching stand and habitat features were established outside flooded areas on neighbouring abandoned terraces. Under normal conditions, the tree stands on these research and control sites, take up soil water from the aeration zone as groundwater is beyond the reach of actively growing tree. Except for the 1997 flood event, the influence of the river as a stressor for trees, either through surface flooding or through hydraulic connection with groundwater, was never observed. Surface flooding of the research sites in 1997 began on 13th July and lasted for up to six weeks. The effect of floodwater on tree stands was examined in the period of 1998–2002 (Czerniak et al., 2002).

Floodwater stagnating in forests disturbed tree growth in pine stands led to a deterioration of stand health and, as a consequence, caused tree dieback or disintegration of some forest stands. Forest stands aged between 20–40 years during the culmination of height growth were most sensitive to flooding when the water stagnated for over six weeks at 0.8–1.2 m height above the ground level. These forest stands rapidly declined during the three years following the flood; almost 75% of the trees died, while 60% of the remaining trees were in a very poor health condition. Mature forest stands flooded for over six weeks responded by a health decrease in about 20% of the trees, but the process of tree dieback occurred very rarely. For maturing forest stands between 70–90 years of age flooded for 5–6 weeks a deterioration of their health status was observed in 10–15% of the trees and it was with limited dieback. Shorter flooding periods of less than five weeks had no significant influence on tree health condition. The height increment of pine trees was reduced by about 20% after the flooding for all the stand stages before maturity when surface flooding lasted for three weeks or longer. The most substantial reduction of height growth was recorded in the first and second years after the flood. Growth in height was restored relatively rapidly, within 4–5 years following the flood. Annual ring width was reduced in the post-flood period compared to the pre-flood period in both flooded stands and control forest stands. However, typical negative pointer years did not occur directly after the flood, as the annual ring width growth was relatively regular, and the recovery period was probably prolonged over time. An exception was found in the stands of decreased health that suffered long-term flooding (of at least four weeks), for which the increment reduction after the flood was notable. The flood in 1997 occurred after droughts of the 1980s and early 1990s. Hence, the floodwater was both an ecological stressor for long term flooded stands and a factor stimulating tree ring growth of forest stands that had not been flooded for a long time (Czerniak et al., 2002). The post-flood study revealed that maturing forest stands were worth preserving because of their stronger resistance to flooding disturbances, greater commercial value, and shorter-term prospects of timber harvest. However, preventive removal of the forest stands, in which decay is substantial and regeneration prognosis poor, is unavoidable.

Mass movements

Stabilising landslides and securing roads in the Stuposiany Forest District

The Stuposiany Forest District, located in the southeast part of Poland (the Eastern Carpathians, the Bieszczady mountain range, forest cover 98%) was selected as an example of the application of mass movement control solutions in Polish forests.

The area of the forest district is mountainous, characterised by a structural nappe with transverse tectonic dislocations, which cut the layers of sandstone and slates, where deep river valleys had developed. The difference of the terrain surface elevation reaches around 700 m. A high saturation of soil and high groundwater levels, as well as high water stages in the local river system are typically found in spring due to winter thawing and snowmelt and in summer due to heavy rainfall, which are the typical annual periods of mass movement risk.

The main access road in the Stuposiany Forest District (Road 19) has been under constant risk from landslides of weathered masses. One of the most vulnerable sections of the road is constructed across the landslide area, with the slope beneath the road intensively eroded by the Roztoki River. The masses of the landslide colluvium are moved when the slope is waterlogged, blocking the road and causing extensive damage.

The slope (the top 861 m to base 800 m a.s.l.) of this road section has been stabilised applying a bioengineering method. A cribwork structure was constructed along the slope, and a root- and stem-division method was applied to provide revegetation of the protected slope. To secure the landslide beneath the road, about 4–6 rows of cribs were fixed. The slope above the road was secured by one row of cribs at various heights. The structure employed debarked round logs placed horizontally in the scarp; the logs were fastened by a bracing system of sharpened poles inserted into the slope at the right angle to the slope surface. In the niches between the logs, shrubs were planted, while between the cribwork structures 5.0 m-wide ledges for passage were established. The rows of cribs beneath the road were designed to be 6.0 m high and 5.0 m wide.

Slope reinforcement covered the zone up to 54 m from the valley floor. Thus, the road became secure and passability within the forest district was maintained. The bioengineering method employed to secure the slope, as opposed to traditional concrete and metal technical protection, was selected for ecological reasons. The primary function was to provide slope strength and stability, which was achieved through the penetration of plant roots into the soil structure. The additional advantage was the protection of the slope against erosion, rockfall and wind.

Plants have improved the water regime of the soil through interception and evapotranspiration. This is particularly important in areas prone to landslides because water is one of the main triggers for clay movements on slopes. Therefore, it is advisable to extend monitoring of the slope beyond the section of the road already secured to cover the adjacent area. The analysis of the digital elevation model reveals a texture differentiation in the slope surface, implying deformation of the weathered slope cover, thus indicating a potential landslide hazard.

Availability of post-hurricane forest areas

Hurricane-affected forest areas are usually inaccessible by road and transport paralysis makes it difficult to assess the damage on the ground and thus respond adequately. Such conditions occurred in Poland in 2017. In numerous districts it was necessary to provide immediate access to forests. Unfortunately, standard road construction technologies take time and are expensive to implement. Post-event rapid wood deterioration lay behind the need to develop a new technology of temporary road construction employing concrete slabs in post-disaster areas. The reinforced concrete self-draining slab technology was developed in cooperation between the Department of Forest Engineering, the University of Life Sciences in Poznań and the industry stakeholders (Betard Company Ltd., Poland). The technology passed field and laboratory tests, being currently in the patent pending process.

Compared with standard technology, the advantages of the developed slabs include shorter construction cycle, increased structural stability, improved traction control, the ability to facilitate drainage of the road surface and driving uphill, as well as exposed aggregate surface for improved slab aesthetics.

DISCUSSION

We present various technical approaches applied to limit the damaging effects of severe weather conditions on forests in Poland. The presented concepts and technical solutions can raise objections by scientists who claim that engineering interference with the environment is not beneficial as a rule. We think that an appropriate design and execution of engineering structures can mitigate potential negative environmental impact. In Poland forests cover is 30%, of which more than 40% is under area-oriented forms of nature conservation, 38% of the State Forests (over 2.8 million ha) are covered by the Natura 2000 network of nature protection areas. As a principle, the approaches described in this paper have been developed to be compliant or support the Natura 2000 protection objectives to preserve habitats and species.

Water resource management

Two national-scale water management programmes have already been completed in the State Forests in Poland, while a new programme is currently underway. The main aims of these programmes are to mitigate drought effects, protect water-related ecosystems, adapt forests to climate change, and limit the effects of water erosion and floods. The hydrologic effect of the finished programmes is 2.5 million cubic metres of stored water in thousands of sites in lowland and mountain forests.

Forest management approaches employed for river alluvia should recognise the risk of damage caused by severe floods, since management practices do not have sufficient potential to limit flood losses adequately. Modifying the species and age structure of forest stands cannot usually produce a satisfactory effect in limiting damage in the case of long-term floods. Sometimes redefining the aims of forest management is the only solution left. Supporting forest renaturalisation while recognising floods as a natural ecological process seems to be a reasonable choice (Czerniak et al., 2008, EEA, 2019; Göthe et al., 2016; Hornung et al., 2019; Kamiński et al., 2011; Koprowski et al., 2018). The heaviest floods are difficult to control even by the most advanced river and valley water engineering systems. The priority of flood protection is to secure people, settlements and industrial areas (Dumieński and Tiukało, 2016; EEA, 2019; Głosińska, 2014). During the heaviest floods in Poland, the levees were occasionally breached intentionally to create improvised polders in areas of lower protection priority, such as forests and agricultural land (Maciejewski et al., 2011a; 2011b; NIK, 2013). Under these circumstances management of river valleys needed to be revised considering the needs and expectations of the stakeholders. Nowadays, within the integrated management of rivers developed and implemented after the 1997 and 2010 floods the water management in the river valleys has been altered. This systemic approach supports the creation of polders mainly on sites that will benefit ecologically from flooding. The adopted solutions aim at limiting the negative impact of flooding on settlements and critical industrial sites, while planning of polders in the ecological spatial system of river valleys also includes needs of forest management to protect these forests that should not be flooded. The flood protection system focuses on controlling the flood wave by water reservoirs, dry reservoirs, polders and levees. Local drainage systems are prepared to efficiently drain floodwater from the bottom of the river valley for strict floodwater protected sites (Głosińska, 2014; Matczak et al., 2017; NIK, 2011; 2013; Pawlaczyk, 2020).

The systemic flood control approach has been introduced, for instance, in the Domaszków-Tarchalice polder system in the Middle Oder valley. The implementation is a multi-partner cooperation between WWF Poland, the State Forests, the local government, valley and river management institutions and the German Federal Environmental Foundation. The polder was established in an alluvial valley (about 600 ha) that was opened for flooding by removing some sections of levees and constructing a system of embankment overflows to enable floodwater to enter the floodplain forest, oxbow lakes and meadows managed by the State Forests (Królikowska et al., 2015). The system reduced flooding exposure of the commercial forest covering about 2000 ha downstream in the Oder valley. These are pine monocultures located in the valley section that was flooded in 1997 and the conducted investigations led to the formulation of flood protection recommendations (Czerniak et al., 2002).

Landslides

In order to prevent the consequences of landslides in Poland the Landslide Counteracting System (SOPO) has been implemented. The project is financed by the government (the Ministry of the Environment) and was coordinated and implemented by the Polish Geological Institute – the National Research Institute. The main aims of the programme include a detailed survey of the landslide areas and the areas where the landslide hazard is the highest, creating documentation, and monitoring selected locations. The programme was initiated in 2006 after numerous landslide incidents, which led to infrastructure damage and significant material losses, especially in 1997, and in the period of 2000–2002. Before implementing the programme estimated number of landslides was about 20,000. The inventory conducted by SOPO has indicated about 60,000 landslides so far, but it has been assessed that approx. 100,000 landslides may be inventoried (Poprawa and Rączkowski, 2003; Wójcik and Wojciechowski, 2016).

The results of the SOPO survey are stored in a database and mapped to present the location, range, and activity level of the landslides, together with the documentation in the form of information cards created for each landslide following the respective recommendations (Grabowski et al., 2008; http://geoportal.pgi.gov.pl/portal/page/portal/SOPO). The data indicating these geological hazards are being used for land management and planning.

About 60 landslides are currently being monitored within the state geological survey programme, where the movements are registered using the depth measurement method (inclinometer measurements) and the surface measurement method (measurement with the GNSS satellite navigation system and laser scanning). Hydrogeological observations of groundwater tables and precipitation are also recorded. The surveillance and monitoring systems are often set up by the road administration and local government bodies during construction works to secure and protect the area against landslides (Wójcik and Wojciechowski, 2016).

Fire protection

The fire protection infrastructure, such as road networks providing fire access, is a crucial forest management element. Forest roads can also alter spatial patterns of ignitions, as well as modify and limit fire boundaries. Roads can function as supplementary firebreaks supporting safer and more effective wildfire management (Katuwal et al., 2016; Narayanaraj and Wimberly, 2012; Simpson et al., 2019; Yocom et al., 2019). Therefore the distance between any point in the forest and the nearest public road (excluding motorways and expressways) or a forest road functioning as fire access should not exceed 0.75 km or 1.50 km, depending on the assumed fire hazard category of the forest (the National Law and internal regulations of the State Forests). Fire access roads in forests serve the same function as fire roads in urban areas and provide the basic transport network to execute all tasks, including planning and organising rescue and firefighting missions (internal regulations). There is about 107,000 km of forest roads within the State Forests, of which almost 47% can serve as fire access roads (Czerniak et al., 2016; Trzciński and Czerniak, 2017).

Contemporary research on fire protection infrastructure is focused on optimising the utilisation procedures of fire access roads for rescue, operation of fire vehicles, tactics and fire-fighting methods (Grajewski, 2019; Grajewski et al., 2019). The research concerns optimising the network density and geometric parameters of fire access roads, developing new technologies to increase load-bearing capacity (Czerniak and Kamiński, 2003; Kamiński, 2007) and optimising the efficiency of supervision and the commissioning process for constructed fire access roads. Despite the high annual costs of modernising road networks in the State Forests the needs continue to be extensive. Fire access road systems still require improvement, especially in terms of the load-bearing capacity of these roads (Grajewski, 2019).

A fundamental problem of fire protection in forests is to provide an appropriate amount of water for firefighting. The water supply system includes natural lakes and ponds, reservoirs, rivers, other water bodies and underground water. The basin permeability is a common problem in the case of availability of water resources. Therefore, water bodies and water retention structures constructed within water management programmes in the State Forests are adapted to provide water for firefighting. Forest areas of the highest fire risk require establishment of strategic water supply points. The difference from the basic water supply points results from their greater water storage capacity and the potential of servicing at least three firefighting vehicles and fuelling them simultaneously (Przysiecki and Fijałkowski, 2015).

The approaches presented in the article show that it is feasible to limit the damaging effects of drought, flood, fire and landslides on forests by applying engineering methods. However, it is not possible to efficiently secure tree stands against strong winds. Modifying the forest stand structure and stand management methods can decrease susceptibility of trees to wind damage; however, as practice shows, a majority of forest stands cannot resist the negative impact of strong winds. Therefore, assuming that storms will continue to damage forest stands, it is necessary to focus on developing procedures that more accurately predict storms, estimate the damage and immediately provide technical solutions to limit losses.

CONCLUSIONS

We have shown that forests may be protected to some extent against the effects of severe weather conditions by the application of engineering solutions. Such solutions contribute to protecting both commercial forests and habitats, valuable plant and animal species, including large mammals (the European bison, bear and wolf), which are considered important components of the biosphere in Europe. The selection of any particular approach has to be adequate, not only to meet specific needs, but each implementation of engineering structures and methods requires potential side effects to be addressed and reduced during the planning and designing stage.

Extreme weather, droughts and torrential rain events are becoming increasingly frequent. Dry periods are often intertwined with wet spells forcing modification of water management methods applied in forests. Today, efforts are focused on securing water availability to sustain forest habitats and support the growth and development of forest stands. Water storage alteration at various spatial scales through the implementation of water engineering solutions is the leading water management practice to pursue this goal. The assessment of completed water storage projects and implemented engineering solutions usually reveals various hydrological, ecological and positive functional effects on the forest environment within a short period, such as e.g. increased soil moisture content, improved tree health and growth conditions, greater biodiversity, and even a rise in forest value for tourism and recreation.

Damage caused by extreme flooding, especially during the 1997 and 2010 events, forced forest authorities to redefine approaches and priorities of management in alluvial forests. Systemic methods have been developed through the cooperation of all stakeholders in integrating better protection against flooding within management practices of rivers and river valleys. The strategy of mixing strict protection for some parts of the river valley with reduced protection and measures enabling flooding in other sites is central to this approach. Some parts of river valleys were opened for floodwater to create polders and control flood waves, thus allowing other valley parts to be protected from flooding. The State Forests National Forest Holding benefits from these systems, since valuable commercial forests, vulnerable to flooding, gain protection, while forests benefiting from flooding are usually included in the polder system. The water engineering systems have been introduced to support this strategy. The State Forests participated in introducing these systems and integrated them into the water management practice in forests. The effectiveness of this approach was confirmed during the flood on the Oder in 2020.

Engineering methods and solutions provided passability of fire access roads in poorly performing sections by altering the load-bearing capacity of road pavements. The engineering upgrading of road networks facilitated strengthening of fire protection systems in forests. The use of geotextiles has been proven a particularly effective, low-cost solution helping to significantly reinforce narrow forest roads. The performance of geosynthetics as an environmentally neutral, low-cost material has potential for broader application in the construction of road pavements of unbound aggregates. Thanks to the use of geosynthetics the thickness of expensive aggregate layers may be reduced without loss of their load bearing capacity. The application of a geosynthetic mattress allows to raise the road surface without extending the width of the right of way.

Mass movements, especially over the last two decades, caused increased material losses. Removing or reducing landslide damage often exceeds the financial capacities of the local authorities and land managing parties. The most widely applied methods to secure landslides include concrete retaining structures, e.g. systems of poles, retaining walls, buttresses, grillage, etc. reinforced by steel anchors. Geosynthetics can also be used in the protection of shallow landslides. These methods are widely discussed in geoengineering literature. Less popular approaches of slope stabilisation need to be focused on by forest authorities. Environmentally friendly and ecologically neutral solutions to be promoted, employ natural materials (stone, wood, reed, fascine). Bioengineering structures provide an optimal solution in protecting slopes against erosion by altering soil moisture, controlling surface drying, forming crevices, and reinforcing soil surfaces. These natural solutions are gaining in popularity. The landslide control project in the Stuposiany Forest District is a good example of this trend, although steel, concrete and geosynthetics still dominate. These methods are dedicated to forests and areas of high natural value, which require protection against landslides.

Forest damage caused by severe weather may not be effectively limited without an efficient road network. Therefore, the fire access road network is an essential component of the forest fire protection system, which has to be maintained and modernised to sustain operational capability. The technical solutions developed for the State Forests have facilitated establishment of road sections of inadequate load bearing capacity on waterlogged soils under all weather conditions. The experience gained during the clearing of windthrows and windsnaps over thousands of hectares after the 2017 storms in Poland indicates that immediate actions are crucial. An efficient network of temporary and logging roads is a necessary asset to accomplish this task. Module slabs made of various materials have been proven to be the most beneficial solution. The most effective solutions in Poland involve reinforced concrete slabs placed along the tyre track line. These slabs can be stored and re-used if another occasion for their need arises.

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TECHNICZNE METODY ZAPOBIEGANIA I OGRANICZANIA W LASACH POLSKICH SKUTKÓW KLĘSK POWSTAŁYCH W WYNIKU EKSTREMALNYCH ZJAWISK POGODOWYCH

ABSTRAKT

Zmiany klimatu, obserwowane w ostatnich latach, manifestują się wzrostem częstości i intensywności zjawisk pogodowych takich, jak silne burze, wiatry, opady deszczu, fale upałów, susze. Ich konsekwencją jest wzrost w lasach szkód powstałych w wyniku powodzi, ruchów masowych, niedoborów wody, pożarów, wiatrów oraz pogorszenia stanu zdrowotnego drzewostanów w Europie. Czynniki stresu ekologicznego powiązane z klimatem zwiększają podatność drzewostanów na wiele wtórnych zagrożeń chorobowych i szkód. Ta nowa, bardzo dynamiczna sytuacja zmieniła znacząco warunki prowadzenia gospodarki leśnej w Polsce. Ustalone dotychczas podejścia i sposoby wymagają weryfikacji oraz wypracowania rozwiązań nowych w celu sprostania pojawiającym się wyzwaniom i zagrożeniom. Stało się oczywiste, że działania z zakresu hodowli lasu w tych warunkach powinny być wspierane aktywnie różnymi rozwiązaniami z inżynierii ekologicznej i budowlanej, aby zapewnić ich lepszą efektywność. Praca jest próbą przedstawienia aktualnej problematyki dotyczącej rozwiązań inżynieryjnych stosowanych na potrzeby ochrony, przeciwdziałania i ograniczania skutków ekstremalnych zjawisk pogodowych w polskich lasach. Wykorzystano badania własne oraz odniesiono się do innych rozwiązań stosowanych w lasach w zakresie optymalizacji sieci dróg leśnych, ograniczania skutków pożarów, powodzi, ruchów masowych i szkód od wiatru, kształtowania warunków wodnych i zapobiegania suszy. Przedstawiono też przykładowe rozwiązania inżynieryjne stosowane w Polsce.

Słowa kluczowe: infrastruktura inżynieryjna, ekstremalne zjawiska pogodowe, ochrona lasu, ograniczanie szkód