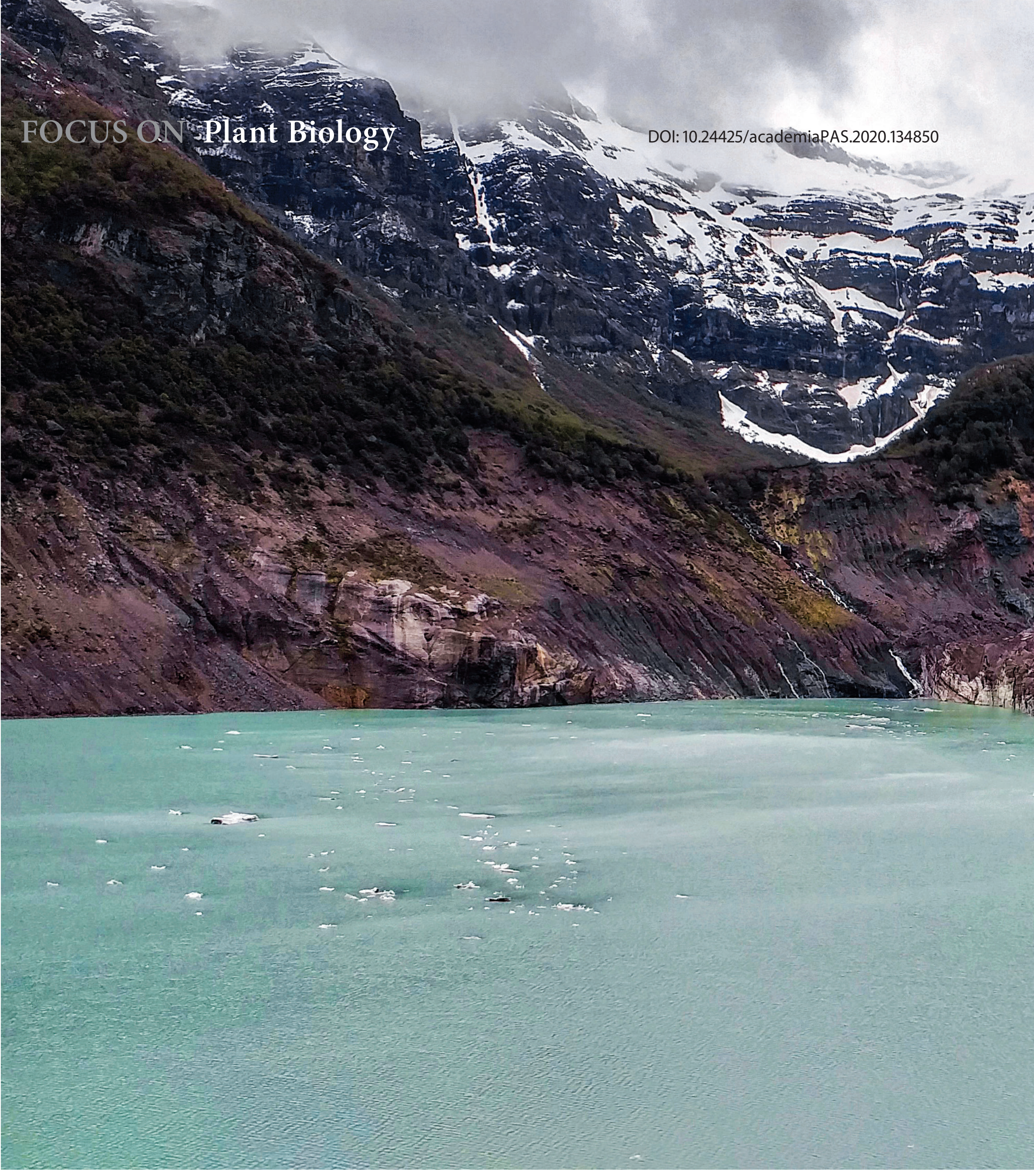
DOI: 10.24425/academiaPAS.2020.134850



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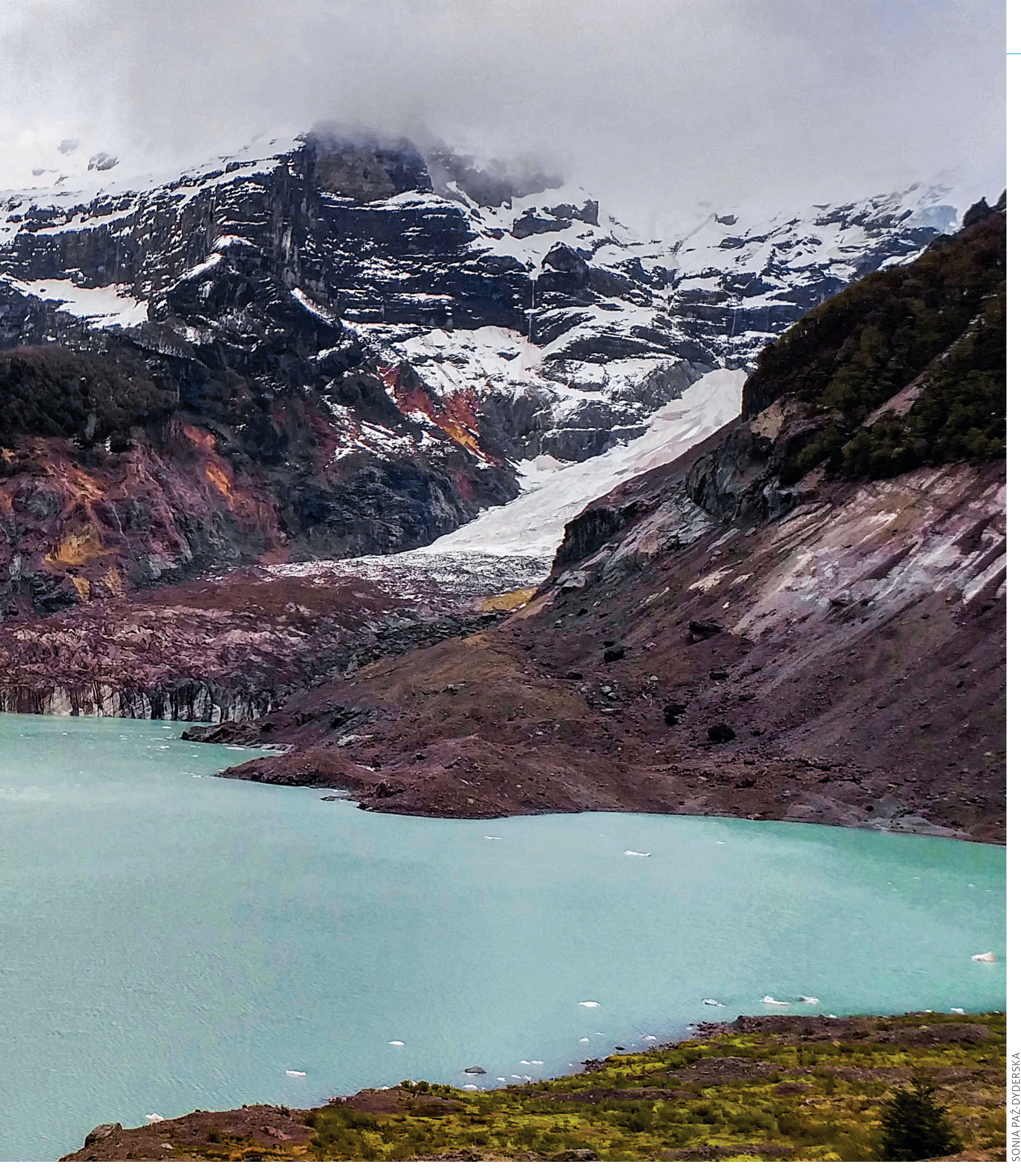
Between Water

Water is essential for plant growth and development, and the degree of its availability significantly shapes ecosystems in different climate zones. How does an overabundance or deficiency of water affect the flora in Poland and different parts of the world?



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The rocky subsoil, low temperatures and persistent snow cover make it impossible for forests to grow in alpine ecosystems. The Ventisquero Negro glacier in Patagonia, Argentina

AND FOREST

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Plants produce nutrients through photosynthesis: they use energy provided by sunlight to convert water and atmospheric carbon dioxide into simple sugars and oxygen. Water overabundance and water shortage can both hamper photosynthesis; plants in different ecosystems have developed a range of mechanisms to counter this. Water availability is a key factor shaping the flora of all regions.

Low water availability – Arctic and alpine regions

Polar regions are an example of ecosystems where high volumes of water are stored away. The function-

MARCIN K. DYDERSKI

Mountain and boreal forests are dominated by coniferous trees such as spruces, and low shrubs such as blueberries in the understory. Here: the Stołowe Stołowe Mountains National Park, Poland

ing of such ecosystems is largely determined by their location: high latitudes mean prolonged nights and days (or vice versa) and extremely low temperatures. For that reason, the water in polar regions is frequently inaccessible to vegetation. Additionally, the freezing of water inhibits plant succession into inhospitable regions. Polar regions are covered in permafrost which can reach even a few hundred meters below ground. Only a few plant species are able to grow there, when the surface thaws briefly during the short, cool summer. The fact that water is available only for short periods of time with long intervals in between makes it impossible for trees to survive. Such conditions are only suitable for small, resistant plants such as mosses, algae or small vascular plants including small shrubs. The prostrate nature of such taxa (organisms grouped together based on a certain distinctive trait), such as dwarf willows, is the perfect adaptation for survival in regions characterized by strong winds: the plants actually rely on such winds for reproduction, to spread pollen, seeds and spores across long distances. Their small, thick leaves are resistant to excess transpiration and frost. Additionally, since such leaves are highly resilient, the plant saves energy by avoiding the need to replace them frequently.

The flora in alpine regions is adapted in a similar way. Here, high elevations mean low temperatures and high precipitation levels. In high mountains snow is more common than rain, which affects local vegetation. In Poland, alpine plants can be found in the upper zones of the Tatra Mountains. They grow above the treeline – a natural boundary above which the environmental conditions are too harsh for trees to survive. Plants which grow in alpine zones are highly specialized. The presence of species known to be relics of the ice age is evidence that species highly adapted to the harsh climate date back a long time. They likely arrived in the Tatra Mountains during the glaciation of the European continent when the lowlands – now densely populated – were dominated by tundra. As forests gradually spread across the plains, alpine plant populations were cut off from those growing in polar regions. However, persistent low temperatures at high elevations, high precipitation levels and the composition of mountain soil allowed many of them to survive until the present day. Perhaps the best known examples of relic species growing in the Tatras are the low, prostrate mountain avens and dwarf willows. Unfortunately, climate change – which is especially rapid in mountain ecosystems – is making these species highly endangered. In turn, many lowland species are changing habitats by colonizing more northerly zones or shifting higher above sea level. In the meantime, alpine plants which have their ecological niches in high mountain regions have “nowhere to run away.”

Periodic water deficiency – boreal and mountain forests

In subalpine regions and boreal climates (covering subarctic regions at latitudes between 50 and 70 degrees), with their short summers and long, cold winters, temperatures are slightly higher and water is readily available to plants for periods long enough to allow trees to grow. Such regions are dominated by species adapted to water shortages during the winter months. Since plants contain high volumes of water, freezing temperatures can damage them: water expands as it freezes, destroying cells or even entire tissues. This is why boreal regions and upper mountain zones are dominated by coniferous trees. They are better adapted to low temperatures – their sap is resinous, with a lower freezing point, their trunks are protected by thick bark, and their conical branch arrangement accumulates less snow, the weight of which can break branches. Thick needles are more frost-resistant than fine leaves, and their small surface area limits transpiration. These adaptations also allow coniferous trees to keep their needles throughout winter. Frost-resistant needles thus serve the tree for a long time, and the more adverse the conditions, the longer the plant benefits from its needles. For example, the Scots pines widely found in Poland maintain

SONIA PAŻ-DYDERSKA

The high temperatures and abundance of water in tropical climates create the perfect conditions for equatorial rainforests dominated by trees. Here: the Doi Inthanon National Park, northern Thailand


SONIA PAŹ-DYDERSKA

The Atacama Desert in northern Chile is one of the driest places on Earth. The extreme conditions only support the growth of very few highly specialized plant species

their needles for around three years, while those in northern Scandinavia may keep them for up to seven years. The few deciduous trees that can be found in boreal and subalpine forests have adapted to the severe climate by evolving narrower vessels transporting water from the roots to the leaves. Another important mechanism is shedding leaves before winter; discarding the part containing the highest volumes of water and entering a dormant phase helps trees survive the harsh winters.

Due to climate change, the next fifty years could bring major changes to the composition of flora in boreal and subalpine regions. Species adapted to cool climates are yielding ground to deciduous trees from warmer regions. Since evolving suitable adaptations tends to come at a cost of losing competitive advantages, trees such as pines and spruces are gradually being replaced by oaks and beeches.

Plentiful water – tropical rainforests

Unlike in subpolar and mountain regions, plants in tropical forests never face water deficiency, so the main factor limiting their development is competition for sunlight. Tropical forests are dominated by species able to grow quickly and create large leaves with highly efficient photosynthesis. The leaves are replaced regularly, since as the tree grows taller the leaves located lower down become shaded. Tropical plants are not affected negatively by rapid transpiration rates (due to large leaf surface areas), since the high rainfall rates mean they are able to immediately restore lost moisture. However, plant growth is still a subject to certain limitations, such as the plant's hydraulic ability to transport water (due to water pressure in vessels), the energy required to build tissues and the mechanical strength needed to support the weight of heavy tree trunks. The latter two factors represent a certain economic trade-off – trees can grow higher at the cost of wood density by building tissues with thinner walls or larger vessel diameters; however, to reach greater heights, the wood still must be sufficiently dense to bear its own weight. High air humidity also means that plants do not necessarily require access to soil and can grow on the bark or even on the leaves of other plants. Such species which grow on other plants (known as epiphytes) can create dense, interwoven layers reaching the canopies. Epiphytes are a highly diverse group, including mosses, lichens, liverworts, ferns and even lianas, orchids and bromeliads. Some tropical forests date back millions of years, since they grow in regions which never experienced glaciation, therefore they are home to many species with ancient evolutionary histories, found only in those habitats and nowhere else. This is why destruction of tropical forests poses such a great threat to biodiversity.

Hot and dry conditions – deserts, steppes and savannahs

Dry tropical and equatorial climates support the formation of savannahs, steppes or – under extreme water deficiencies – deserts. Plant ecosystems here are strongly affected by the ratio of precipitation levels and evapotranspiration (the volume of water lost through direct evaporation from water and soil, and from transpiration). Periodic water supplies have a powerful effect on the life strategies of plants growing in such regions. Zones with clearly marked dry and rainy seasons support the growth of various species of grasses.

Although deserts are some of the harshest environments on Earth, it would be wrong to assume that all deserts are just indistinguishable expanses of sand dunes. Individual desert regions have distinctive geological profiles and different chemical compositions, which in turn affects the potential of a given location to support plant growth. For example, some regions of the Atacama Desert in northern Chile are habitats for up to a dozen species of plants highly adapted to the arid conditions. Plants found in such hostile regions invest their resources in the production of thorns or small, tough leaves which are frequently coated in wax. This is similar to strategies employed by plants in polar regions, since they have a common goal of reducing transpiration, achieved by growing hardy, resilient leaves. Most desert plants grow extremely

Riparian forests in small river valleys are dominated by alders and ashes. Here: the Bogdanka Valley in Poznań, Poland

MARCIN K. DYDERSKI

slowly. Some species like cacti store water for use during droughts in their organs, e.g. leaves or stems. Sporadic and irregular yet abundant rainfall can cause the phenomenon known as desert blooms, when the ground rapidly becomes covered by carpets of dazzling flowers. These plants are very different from those usually found in desert regions. Delicate fronds with large, attractive flowers are not similar at all to the rachitic shrubs or cacti. The brief abundance of water completely changes desert landscapes.

Steppes and savannahs also have limited availability of water, although less limited than deserts. The rainy season brings to life lush grasses, shrubs and trees, providing high quality nutrients to animals. Due to water deficiency and damage caused by herbivores, trees and shrubs tend to grow at some distance from one another. Dense thickets can only be found near temporary watercourses or ponds. Steppes and pampas are treeless grassland plains; plants which grow in such climates tend to show similar characteristics, and many of them have either wide-spread shallow roots, or deep roots. These strategies allow them capture water during rainfall events, or tap into water stored deep in the soil. Much like in desert regions, the leaves of shrubs and trees here tend to be small to reduce transpiration. Their tough surfaces also make them less attractive to herbivores. Grass stems and leaves are more delicate, making them highly appealing to herbivores. However, their photosynthesis is more efficient and the energy cost of growing new leaves is lower.

Forest landscapes of temperate climates

In the temperate zone, e.g. in Poland, climate conditions are highly suitable to the terrain being dominated by forests – rainfall levels and long vegetation periods limit factors preventing tree growth to minimum. Here, plants experience the same problems as in other climate zones – there is a period of limited water availability (winter) when trees reduce their activity. There are only a few locations where non-forest formations can maintain a permanent presence, apart from the subalpine zone and sand dunes; these are generally marshlands or meadows with vegetation similar to that found on steppes.

Polish forests vary depending on the availability of water in the soil. The lowest water content is found in podzolic soils and psamments (poorly developed sandy soils); they are highly permeable and poor in nutrients, which limits the number of tree species they can support. Such regions are dominated by Scots pines, creating forests similar to those in boreal regions. Moderately fertile and less permeable soils are dominated by mixed forests, mainly comprising oaks and beeches with some Scots pines. More fertile regions are dominated by highly diverse deciduous forests full of beeches, oaks, lindens, sycamores and hornbeams. In the most fertile soils, water is so readily available that there is a risk of its overabundance; they are home to riparian and swamp forests. The main difference between them is that riparian forests grow next to

Riparian forests in major river valleys are comprised of willows. Here: the Warta Valley in Poznań, Poland

MARCIN K. DYDERSKI

free-flowing watercourses while swamp forests grow in stagnant water. Both types of forests are affected by seasonal fluctuations in water levels.

Riparian forests

Riparian forests vary in composition and appearance depending on the nearest watercourse. Banks of streams are usually covered with copses of alders and ashes, with a dense undergrowth dominated by alliums in spring and tall herbaceous plants in summer. In river valleys, the flora changes with the distance from the watercourse. Thickets of almond willow, basket willow, and purple willow grow on the riverbanks. Their flexible, fast-growing branches are resistant to flooding and damage by ice floes. A little further away from the river, in zones which flood every few years on average, there are fast-growing willows and poplars whose roots can survive being submerged in water for prolonged periods. Other species cannot survive such conditions for more than a few years. Zones which flood rarely support the growth of elms, ashes and alders.

Regular flooding makes the soils of riparian forests adjacent to major rivers extremely fertile by depositing fine material containing nutrients. This means they are densely populated with numerous plant species with a wide range of adaptations to sunlight levels. We can find there creeping plants such as hops, ivies and knotweeds, geophytes (herbaceous plants, with storage organs underground, which flower in early spring), tall herbaceous plants, liverworts, hornworts, mosses, and shrubs such as currants, spindles, honeysuckles, dogwoods and elders. River flooding cycles also drive weaker trees to die back. As they decompose, they create habitats for many species of invertebrates and vertebrates. The entire ecosystems in river valleys are highly dependent on floods – they are a natural factor limiting growth and therefore helping maintain high biodiversity. When floods become less frequent, species with a greater competitive advantage (requiring less light) are able to flourish and replace those adapted to regular disruption, contributing to the unique landscape of major river valleys. This is why river regulation, which prevents annual flooding, poses a serious threat to these valuable ecosystems. Additionally, the majority of riparian forests in Poland have been converted to farmlands and pastures, which increases the risk of flooding by eliminating natural floodplains.

Swamp forests

Swamp forests are inundated with fresh water, either permanently or seasonally. Depending on the soil, they can be very poor in nutrients (bogs) or highly fertile (carrs). Swamp forests grow on soils created by the accumulation of dead organic matter under waterlogged conditions. Occurring over hundreds or thousands of years, this results in the formation of peat – an important element of the organic carbon retention cycle. Peatlands grow very slowly, at a rate of approx. 1 mm per year; however, peat levels can reach a depth of over ten meters below ground. The extreme conditions of peatlands are perfect ecosystems for species adapted to high moisture levels, low levels of nutrients and acidic soils. Any pines found in such regions grow very slowly, frequently taking thirty to forty years to reach just two meters in height. The ground is covered by highly adapted mosses which contribute to the formation of peat. Their decomposing rhizoids form part of the peat, while their stems and leaves continue growing to create moist cushions. Patches of mosses are interspersed with low shrubs such as heather, bog-rosemary, bog bilberry, bog cranberry and wild rosemary. More fertile peatlands are dominated by black alders which form clumps of root systems growing from waterlogged areas. Carrs are covered by an undergrowth of species typical of swamps: rushes, sedges, common reeds, irises, thistles, bittersweet nightshades and gypsyworts.

In Poland, we also find woodlands transitional between riparian and swamp forests, featuring moor birches and understory similar to that found in bogs. Swamp forests and alder carrs are preserved in just a few locations, mainly where converting them to farmlands would incur high costs (mainly in Pomerania and the valleys of the Biebrza and Narew rivers in northeast Poland). This makes them sanctuaries of biodiversity, especially for species sensitive to changes in environmental conditions. Due to their high water capacity, forests are an important element in water retention systems on regional and global scales. Their soils have a high organic carbon content; this makes them effective accumulators of this element and a potential source of its emission. As such, all swamp forests and carrs in Poland are important allies in our struggle to reduce the levels of carbon dioxide in the atmosphere, retain water and maintain biodiversity. This requires them to be cared for and protected.

MARCIN K. DYDERSKI

A fertile swamp forest habitat: an alder carr in the Biebrza National Park

Further reading:

Czortek P., Dyderski M.K., Jagodziński A.M., River regulation drives shifts in urban riparian vegetation over three decades. *Urban Forestry & Urban Greening* 2020, 47: 126524.

Dyderski M.K., Czapiewska N., Zajdler M., Tyborski J., Jagodziński A.M., Functional diversity, succession, and human-mediated disturbances in raised bog vegetation. *Science of the Total Environment* 2016, 562: 648–657.

Dyderski M.K., Paź S., Frelich L.E., Jagodziński A.M., How much does climate change threaten European forest tree species distributions? *Global Change Biology* 2018, 24: 1150–1163.

Jagodziński A.M., Horodecki P., Rawlik K., Dyderski M.K., Do understory or overstory traits drive tree encroachment on a drained raised bog? *Plant Biology* 2017, 19 (4): 571–583.