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Geographical forest zonation: Perspectives, history and use

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Abstract: The rate of climate change advancement and its predicted impact are valid reasons for intense discourse on the topic of choosing the most suitable silvicultural and adaptation measures for the longevity and sustainability of forest communities. Changes in growth conditions of plants can be expected in both vertical (altitudinal) and horizontal (geographical) directions. The anticipated occurrence rate of these changes should, according to climate models, be higher than the natural adaptability rate of longevous tree species. This study focuses on the possibility of utilising regional geographical units of the Czech Republic (Central Europe) – Natural Forest Areas (NFAs) – for introducing the principles of assisted forest migration to national silviculture policies in order to find solutions for the predicted climate change scenarios. The primary objectives are (*i*) to review the history of the NFA concept, (*ii*) to discuss the perspectives of NFAs with regard to climate change, and (*iii*) to propose possible solutions for further development in comparison with alternative approaches to horizontal classification of the Czech Republic. This study is the first of its kind that provides a complete textual and graphic overview of the NFAs' history from 1959 to 2018, highlighting the purpose of NFAs as both frameworks for the maintenance of the genetic potential of forest tree species' populations and frameworks for long-term strategic management planning. Further development of the concept is discussed in connection with the main principles of assisted forest migration and the possibility of employing geospatial modellation analyses for a more precise definition of current NFA borders. An assessment of the areas' potential is also debated, mainly with an emphasis on the zonality of forest sites.

Keywords: assisted migration; climate change; Czech Forest Ecosystem Classification; geographical/horizontal classification; natural forest areas

Climate around the world has experienced a significant change in the past decades. Since the 1970s in Central Europe, there has been a gradual increase of 0.2 °C in temperature each decade (climate data of the Czech Republic have shown an even higher increase – ca 0.4 °C per decade, see Crhová et al. 2023), and mean annual temperatures in 2015–2021 were evaluated as the highest since the onset of instrumental measurements (EEA 2023). The effects of climate change raise questions in choosing suitable adaptation measures regarding forest ecosystems and the sustainability of their production potential. Central European climate change manifests itself on the abiotic level by irregular precipitation distribution throughout the year and by an increased risk of drought (Hari et al. 2020; Dukat et al. 2023), wildfires (Miller, Ager 2013; Heisig et al. 2022), or flash floods (Kundzewicz, Schellnhuber 2004; Kundzewicz et al. 2005). In reaction to these risks, there are more and more common forms of negative biotic response, impacting the health of forest ecosystems (Holuša et al. 2018). The combination of biotic and abiotic factors increases the need for a long-term, sustainable silvicultural strategy and utilising specific tree species (Grondin et al. 2023).

The impacts of climate change and its predicted momentum for the future decades, in cases both optimistic and pessimistic for Europe in particular (EEA 2023), highlight the need for unified adaptation strategies (Millar et al. 2007) as well as effective sil-

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vicultural and technical measures (ME 2015, 2021). In combination with various anthropogenic barriers, the progress rate of climate change limits not only the ability of plants to migrate, both geographically (horizontally) and vertically, in a natural manner (Grondin et al. 2023) but also the adaptability of tree species for the new living conditions (Dumroese et al. 2015). Such natural shift of a species from one place to another for survival or maintenance is called a 'species migration' (Begon et al. 2006). When speaking of climate change, one can come across the term 'assisted migration' (Ste-Marie et al. 2011); and in forestry 'forestry-assisted migration', defined by Pedlar et al. (2012) as the shift of tree species populations inside their current range or in a range allowing the maintenance of the species' productivity and health.

Choosing the most suitable landscape classification system is among the most strenuous aspects of landscape planning and management (Bailey et al. 1978). An index of authors writing on the topic of multi-level landscape classification (from regions to continents) is listed e.g. in Romportl et al. (2013). Based on various principles, ecological classifications are commonly applied throughout Europe, Asia and North America (Ivanova et al. 2022; Kusbach et al. 2023).

Initial attempts to scientifically grasp the current state of landscape in the Czech Republic and its nuances stem from the constituent contributions of the following scientific fields – geology (Woldřich 1924; Stejskal, Pelíšek 1956; Svoboda 1964; Buday 1967); geomorphology (Demek 1965); climatology (Syrový 1958; Quitt 1971); and phytogeography (Dostál 1957, 1966; Skalický 1988). Maps of the reconstructed and potential natural vegetation also belong among the key sources (Mikyška et al. 1968; Neuhäuslová et al. 1997), as well as the zoogeographical (Mařan 1958) and biogeographical division (Raušer 1971; Culek et al. 2013). Current trends in landscape delineation based on ecological potential are derived from the so-called quantitative typology, which is based on mathematical and statistical methods and tools of geo-informational analysis (Romportl et al. 2008; Romportl, Chuman 2012; Divíšek et al. 2014).

Classification systems of individual and typological landscape differentiation have evolved to clarify the natural relations of spatial biotic connections in a landscape. Many of them can be used as spatial frames for assessing natural relations and landscape state during the proposal of a management strategy for forested regions (Simon et al. 2010). Czech forest ecosystem classification (ÚHÚL 2023), the foundation of any long-term management recommendations and sustainable silviculture of the Czech Republic, consists of multiple layers of individual (unique and irreproducible) units; these could be sorted respectively from the largest: natural districts (Vokoun 1999), natural forest areas and subareas (NFAs; Plíva, Průša 1969). The division into the Hercynicum and Carpaticum phytogeographical regions (Plíva, Průša 1969) also belongs to the superregional individual units and is nowadays reflected not only in some studies (Dujka, Kusbach 2023a, b) but also in legislation (Mlynář 2021). Hruban and Kusbach (2018) also differentiate between horizontal (geographical) and vertical superstructural units; the former include the NFAs, and the latter is characterised by Forest Vegetation Zones (FVZs; *sensu* Plíva 1971).

Natural Forest Areas are defined as continuous territories with similar forest growth conditions, as is declared in Forest Act No. 289/1995 Coll.; their current form is established in Annex 1 of the 298/2018 Decree regarding regional plans of forest development and the definition of management units (management series). NFAs are traditionally used as frameworks for applying long-term silvicultural strategies, adaptation measures and seed material transfer (Plíva, Žlábek 1986). Since their creation, NFAs have been considered spatial units stable enough for long-term forestry planning; however, their 'inflexibility' has been criticised as more data and knowledge collected over time (Vokoun 1999; Matějka 2003).

The concept of NFAs is, after more than 60 years, facing more and more new challenges. This article's main objectives are (*i*) to review the history of NFAs, (*ii*) to discuss the suitability of the NFAs being a geographical paradigm for applying forestry-assisted migration principles from various perspectives concerning the effects of climate change, and (*iii*) to propose further development in comparison with alternative approaches towards geographic (horizontal) division of the Czech Republic.

STUDY AREA

The territory of the Czech Republic (48°33'–51°03'N, 12°05'–18°51'E) is the study area of our analyses (Figure 1). The area is situated in Central Europe, where climate conditions are dependent on temperate latitudinal climate with prevailing oceanic and partially continental climate influence in the east (Tolasz 2007; Beck et al. 2018).

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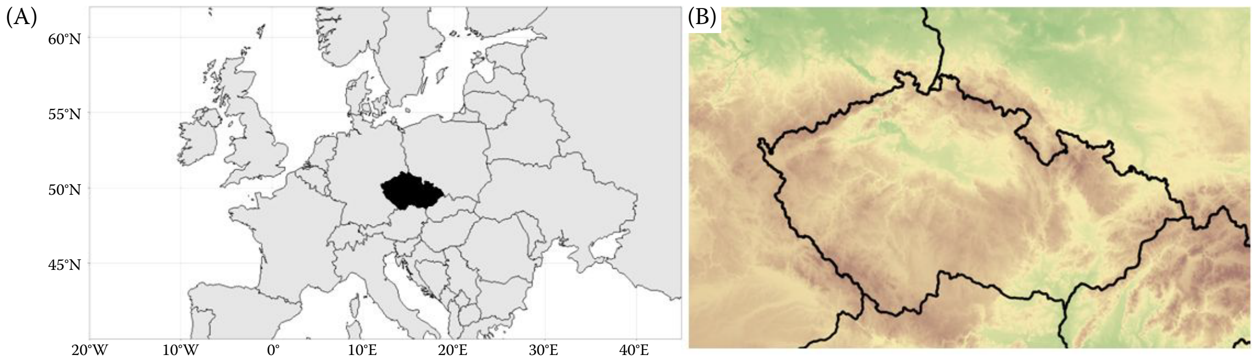

Figure 1. (A) Geographical position of the study area in the context of Central Europe, (B) elevation characteristics (EEA 2016)
Green colour – lowlands; brown colour – foothills and mountains

HISTORY OF THE NFA CONCEPT

Natural Forest Areas have been gradually developing from the Growth Areas as the result of site surveys of the Lesprojekt state enterprise initiative (present Forest Management Institute, FMI) in 1949 (Plíva, Průša 1969; Průša 2001). The definition of Growth Areas (Figure 2) was preceded by a design proposed by Hanz Sigmond in 1932 (Viewegh 1997), and Frič (1934) had al-

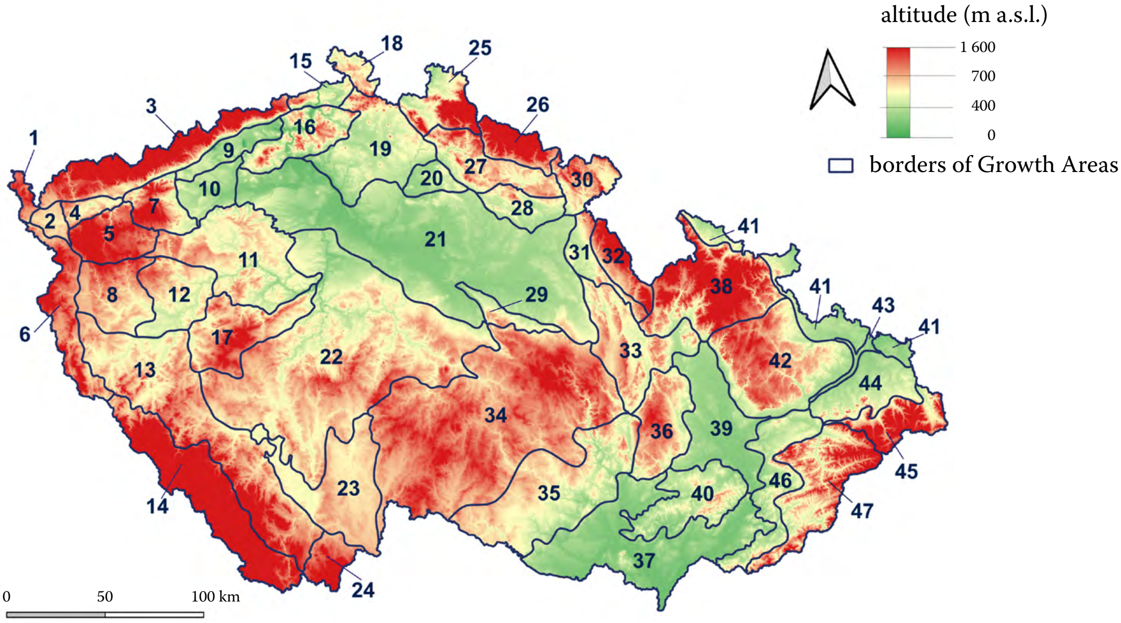

Figure 2. Growth Areas (ÚHÚL 1959)

1 – Fichtel Mts; 2 – Cheb Basin; 3 – Krušné Mts; 4 – Sokolov-Carlsbad Basin; 5 – Tepelské Hills and Císařský les Mts; 6 – Bohemian Forest; 7 – Doupov Hills; 8 – Stříbrská Basin; 9 – North Bohemian Coal Basin; 10 – Žatec region; 11 – Kladno Plateau and Křivoklát Forests; 12 – Plzeň Basin; 13 – Bohemian Forest Foothills; 14 – Bohemian Forest Mts; 15 – Bohemian Switzerland; 16 – Central Bohemian Massif; 17 – Brdy Highlands; 18 – Rumburk Hills; 19 – Northern Bohemian Sandstone Tableland; 20 – Prachov and Žehrov Rocks; 21 – Polabí and Lower Poohří (Labe and Ohře River Lowlands); 22 – Central Bohemian Highlands; 23 – South Bohemian Basin; 24 – Novohradské Mts and Slepičí Mts; 25 – Jizerské and Ještěd Mts; 26 – Giant Mts; 27 – Giant and Jizera Mts Foothills; 28 – Hořice Marlstones and Cretaceous Sandstones; 29 – Železné Mts; 30 – Broumov Promontory; 31 – Orlické Mts Foothills; 32 – Orlické Mts; 33 – Hřensko; 34 – Bohemian-Moravian Highlands; 35 – Czech-Moravian Highlands Foothills; 36 – Drahany Highlands and Moravian Karst; 37 – South Moravian Valley; 38 – Hrubý Jeseník Mts; 39 – Haná; 40 – Mars Mts and Ždánice Forest; 41 – Silesian Lowlands; 42 – Nízký Jeseník Mts and Odra Hills; 43 – Odra Alluvial Plains; 44 – Beskid Mts Foothills; 45 – Beskid Mts; 46 – White Carpathian Mts Foothills; 47 – White Carpathian Mts

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ready mentioned the idea of creating spatial frames similar to NFAs for Czechoslovakia in the 1930s.

Growth Areas had become the foundation for more detailed typological surveys performed in 1952–1968; from the results of these surveys, the borders of Growth Areas were to be corrected (Plíva, Průša 1969); see Figure 3. The division differed widely from the NFAs we know today (Mikeska 2012). Growth Areas aside, the first NFA design was developed using the orthographical knowledge of that time (Hromádka 1956), along with the prior knowledge in the fields of geomorphology (Demek 1965), regional geology (Stejskal, Pelíšek 1956), phytogeography (Dostál 1960) and climatology (Syrový 1958). Borders of the areas have also been perfected considering the species composition and range of forest communities, especially where the geological, geomorphological, climatic and phytogeographical sources diverged or were not suitable for use (Plíva, Průša 1969). These newly delineated units were labelled as Native (Natural) Forest Areas. The term was not coined for the first time; a similar procedure had been used by Zlatník (1959) in the delineation of NFAs in Slovakia.

The area of the contemporary Czech Republic was divided into the two spatially most significant units – the Hercynic (Hercynicum) and Carpathian regions (Carpaticum, also West Carpathian region – Carpaticum occidentale); these further include 40 areas and 73 subareas (Plíva, Průša 1969; Figure 3). Natural Forest Areas have been incorporated into the methodological manual for developing forest management plans (ÚHÚL 1973) due to being considered the most suitable framework for more detailed analyses of growth conditions and their practical assessment (Friedl 2012). They have virtually replaced the formerly used and or-

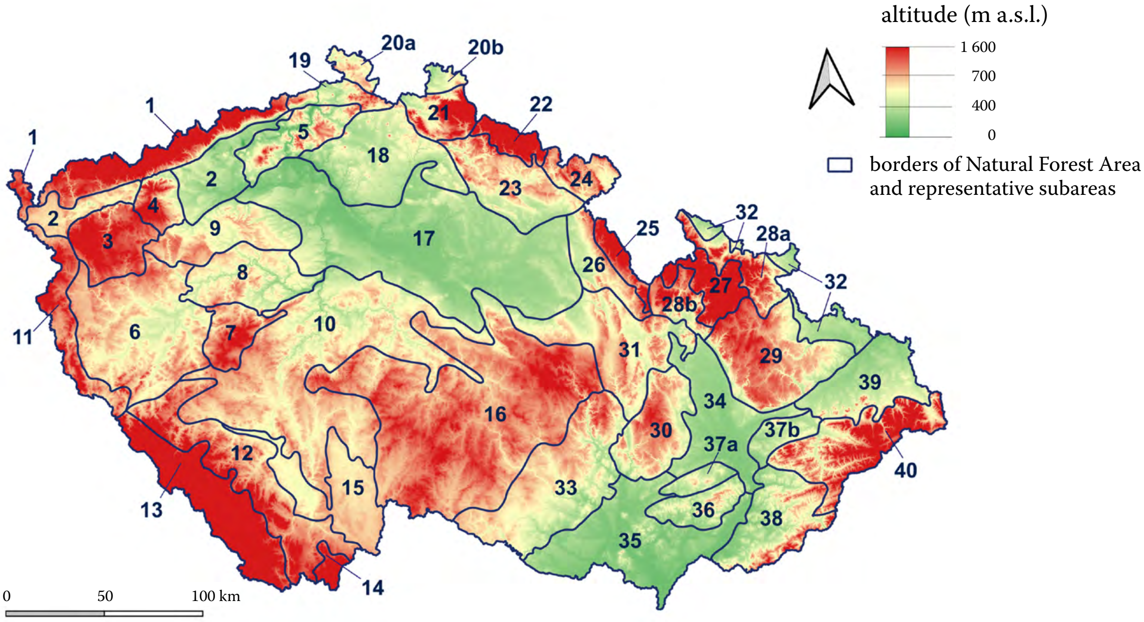

Figure 3. Natural Forest Areas (Plíva, Průša 1969)

1 – Krušné Mts; 2 – Sub-Krušné Mts Foothills Basin; 3 – Carlsbad Basin; 4 – Doupov Mts; 5 – Central Bohemian Massif; 6 – West Bohemian Highlands; 7 – Brdy Highlands; 8 – Křivoklát Highlands; 9 – Rakovnicko-Kladensko Highlands; 10 – Central Bohemian Highlands; 11 – Bohemian Forest; 12 – Bohemian Forest and Novohradské Mts Foothills; 13 – Bohemian Forest Mts; 14 – Novohradské Mts (incl. Slepičí Mts); 15 – South Bohemian Basins; 16 – Bohemian-Moravian Highlands; 17 – Polabí; 18 – Northern Bohemian Sandstone Tableland; 19 – Lužice Sandstone Highlands; 20 – Lužice Hills: 20a – Šluknov Promontory, 20b – Frýdlant Hills; 21 – Jizera Mts; 22 – Giant Mts; 23 –Giant Mts Foothills; 24 – Sudetic Intermountain Area; 25 – Orlické Mts; 26 – Orlické Mts Foothills; 27 – Hrubý Jeseník Mts; 28 – Hrubý Jeseník Foothills: 28a – north perimeter, 28b – south perimeter; 29 – Nízký Jeseník Mts; 30 – Drahany Highlands; 31 – Bohemian-Moravian Intermountain Area; 32 – Silesian Lowlands; 33 – Czech-Moravian Highlands Foothills; 34 – Upper Morava Valley; 35 – South Morava Valleys; 36 – Central Moravian Carpathians; 37 – Carpathian Foothills: 37a – Litenčice Hills, 37b – Keleč Hills; 38 – White Carpathian Mts and Vizovice Hills; 39 – Sub-Beskidian Highlands; 40 – Beskid Mts

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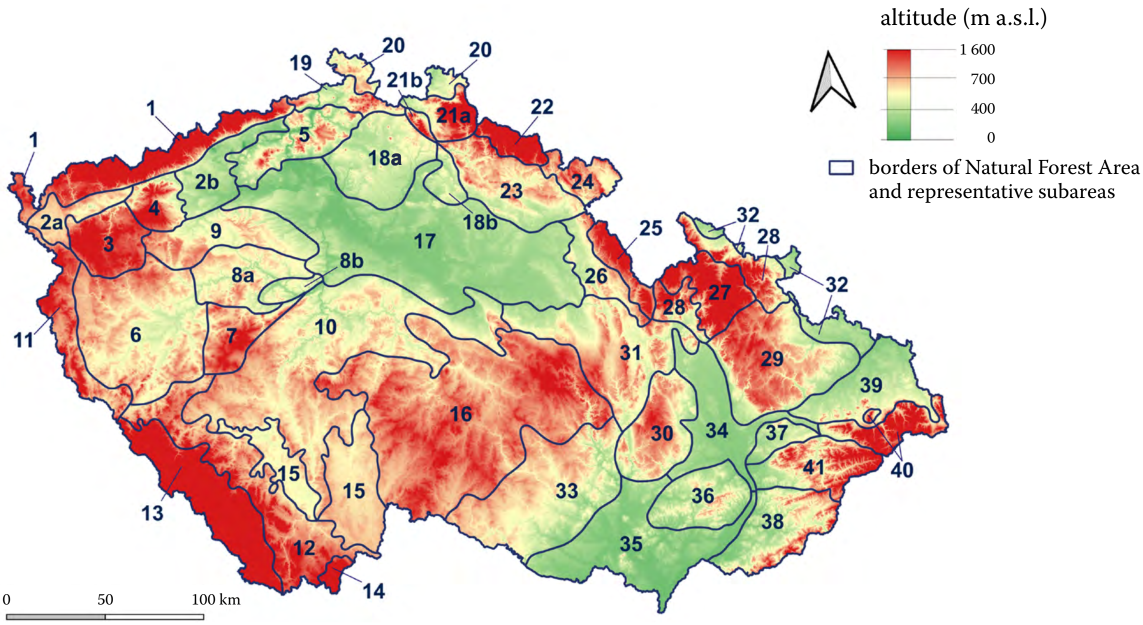

Figure 4. Natural Forest Areas (Plíva, Žlábek 1986)

1 – Krušné Mts; 2a – Cheb and Sokolov Basins, 2b – Most and Žatec Basins; 3 – Karlsbad Highland; 4 – Doupov Mts (Area borders); 5 – Central Bohemian Massif; 6 – West Bohemian Highlands; 7 – Brdy Highlands; 8a – Křivoklát Region, 8b – Bohemian Karst; 9 – Rakovnicko-Kladensko Highlands; 10 – Central Bohemian Highlands; 11 – Bohemian Forest; 12 – Bohemian Forest and Novohradské Mts Foothills; 13 – Bohemian Forest Mts; 14 – Novohradské Mts; 15 – South Bohemian Basins; 16 – Bohemian-Moravian Highlands; 17 – Polabí; 18a – Northern Bohemian Sandstone Tableland, 18b – Bohemian Paradise; 19 – Lužice Sandstone Highlands; 20 – Lužice Hills; 21a – Jizera Mts, 21b – Ještěd; 22 – Giant Mts; 23 – Giant Mts Foothills; 24 – Sudetic Intermountain Area; 25 – Orlické Mts; 26 – Orlické Mts Foothills; 27 – Hrubý Jeseník Mts; 28 – Hrubý Jeseník Foothills; 29 – Nízký Jeseník Mts; 30 – Drahany Highlands; 31 – Bohemian-Moravian Intermountain Area; 32 – Silesian Lowlands; 33 – Czech-Moravian Highland Foothills; 34 – Upper Morava Valley; 35 – South Morava Valleys; 36 – Central Moravian Carpathians; 37 – Keleč Hills; 38 – White Carpathian Mts and Vizovice Hills; 39 – Sub-Beskidian Highlands; 40 – Moravian-Silesian Beskids; 41 – Hostýn-Vsetín Hills and Javorníky Hills

ganisationally smaller Forest Management Units, which seemed insufficient (ÚHÚL 1973). In 1986, the NFA layout changed again (Figure 4) according to the results of regional typology briefs (Plíva, Žlábek 1986). The content perpetuated the 1969 publication version, and specific criteria were set for delimiting the areas. After the establishment of the Czech Republic in 1993, NFAs were legally codified in an unchanged form in Forest Act No. 289/1995 Coll. (Section 2p), their borders specified by Decree No. 83/1996 (Annex 1) regarding the processing of regional silviculture plans and the delimitation of management units, amended by the Ministry of Agriculture Decree No. 298/2018 Coll., which is still binding today. In 1997–2001, the first cycle of the Regional Plans of Forest Development (RPFD) was processed for the NFAs, and since 2018, they have been undergoing updates (Mansfeld, Hruban 2018).

DEFINITION OF NFAS AND PRIMARY PRINCIPLES OF DELIMITATION

Natural Forest Areas were defined as territories with related natural conditions in the sense of horizontal (geographical) delineation. The intent behind their delimitation was to define general management principles at the scale of smaller typological units with regard to the specific (geographical, geomorphological and other) criteria (Plíva, Žlábek 1986). The different nature of NFAs manifests in the variability of the specific tree species occurrence rate (e.g. natural spruce stands in high mountain forests) and their production potential; the presence of specific ecotypes (e.g. the Malenovice or Třeboň Scots pine varieties), their growth, quality, and the current management state of the stands. Another definition is provided in Forest Act No. 289/1995 Coll., in which NFAs are described

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Figure 5. Aerial photograph of the border of two Natural Forest Areas (NFAs): The flat terrain relief with densely populated and predominantly agricultural landscape of the Upper Morava Valley (34), and the forested, hilly area of the eastern Drahany Highlands (30)

as continuous territories with similar forest growth conditions (Figure 5).

Zlatník (1959) listed three primary principles for delimitating the Slovakian NFAs and a similar statement was also made by Plíva (1985), Plíva and Žlábek (1986), and Průša (1990): the differences in (*i*) the soil-forming and parental soil materials which condition the typological units' properties, (*ii*) terrain configuration of the unique geomorphological units, and (*iii*) the macroclimate, where the differences contribute (along with other factors) to the distribution of forest communities.

EVOLUTION AND CHANGES IN BORDER DELIMITATION

The graphical visualisation of Growth Areas was created by the Forest Management Institute Brandýs nad Labem (ÚHÚL 1959). An overview map with a 1 : 750 000 scale showed 47 Growth Areas (Figure 2) aggregated into 15 forest regions. Klika (1956) states that Growth Areas were delimitated on the grounds of a previous geobotanical survey. From today's perspective, the delineation of Growth Areas was too vague and poorly justified, as the borders did not reflect any geomorphological characteristic or an established forest unit. The first graphic form of the NFAs was a cartogram of a 1 : 1 500 000 scale (Figure 3) described in Plíva and Průša (1969). The number of NFAs was lower (40) than that of the Growth Areas (47); however, the division of the Jeseníky Mts, the Moravian-Silesian Beskids, and the Jizera Mts was more detailed. Due to the heterogeneity of the area surveyed, each NFA was further divided into 2 to 4 subsections. Despite being yet again established only vaguely, the borders of the NFA subsections did respect the landscape features more than the borders of the Growth Areas.

Changes in border lines in 1986 (Plíva, Žlábek 1986) were soon subjected to criticism, e.g. an article by Prudič (1986) presents a detailed elaboration. Most notable changes were made in Carpaticum (Figures 4 and 6). In 1969, a total of 40 NFAs were established. After revisions from 1986, the number rose to 41 due to the division of the 40th NFA (Moravian-Silesian Beskids), newly considering the Rožnov Furrow geomorphological region as a delimitation line, thus establishing the 41st NFA – Hostýn-Vsetín Hills and Javorníky Hills. NFA 37 (Carpathian Foothills) used to consist of two subsections, the Litenčice

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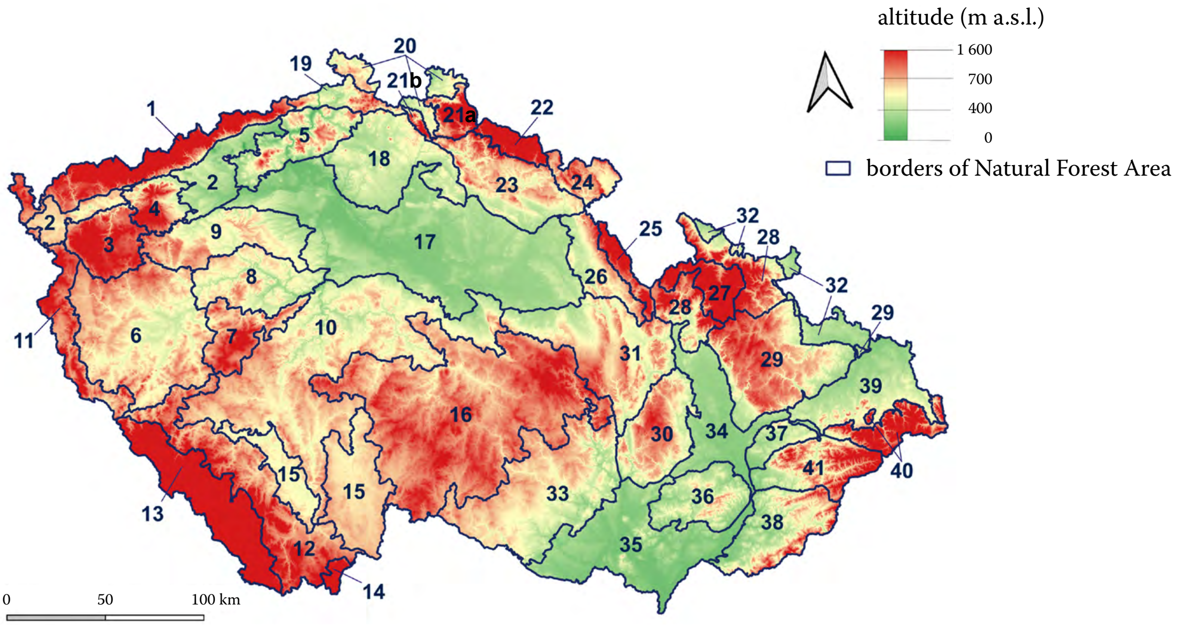

Figure 6. Natural Forest Areas (NFAs; Decree No. 298/2018 Coll.)

1 – Krušné Mts; 2 – Sub-Krušné Mts Basins; 3 – Karlsbad Highland; 4 – Doupov Mts; 5 – Central Bohemian Massif; 6 – West Bohemian Highlands; 7 – Brdy Highlands; 8 – Křivoklát Region and Bohemian Karst; 9 – Rakovnicko-Kladensko Highlands; 10 – Central Bohemian Highlands; 11 – Bohemian Forest; 12 – Bohemian Forest and Novohradské Mts Foothills; 13 – Bohemian Forest Mts; 14 – Novohradské Mts; 15 – South Bohemian Basins; 16 – Bohemian-Moravian Highlands; 17 – Polabí; 18 – Northern Bohemian Sandstone Tableland and the Bohemian Paradise; 19 – Lužice Sandstone Highlands; 20 – Lužice Hills; 21a – Jizera Mts, 21b – Ještěd; 22 – Giant Mts; 23 –Giant Mts Foothills; 24 – Sudetic Intermountain Area; 25 – Orlické Mts; 26 – Orlické Mts Foothills; 27 – Hrubý Jeseník Mts; 28 – Hrubý Jeseník Foothills; 29 – Nízký Jeseník Mts; 30 – Drahany Highlands; 31 – Bohemian-Moravian Intermountain Area; 32 – Silesian Lowlands; 33 – Czech-Moravian Highland Foothills; 34 – Upper Morava Valley; 35 – South Morava Valleys; 36 – Central Moravian Carpathians; 37 – Keleč Hills; 38 – White Carpathian Mts and Vizovice Hills; 39 – Sub-Beskidian Highlands; 40 – Moravian-Silesian Beskids; 41 – Hostýn-Vsetín Hills and Javorníky Hills

Hills (37a) and the Keleč Hills (37b). During the 1986 revision, subsection 37a had been assigned to NFA 36 (Central Moravian Carpathians), while subsection 37b became a separate area. Further objections were raised regarding the discrepancies in the visual (graphic) and textual (i.e. descriptive) tables of NFA 14 (Novohradské Mts) and NFA 21b (Ještěd), as well as in the descriptive assessments and tables for the relations between subsections (2a and 2b, 8a and 8b, 18a and 18b). The general criticism was then perpetuated by the borders' lack of definition and justification for such demarcation.

Natural Forest Areas defined by Decree No. 289/1995 Coll. did no longer elaborate with the term 'subsections'. The 83/1996 Coll. legislation in Annex 1 listed 41 NFAs. The graphic overview map attached to this legislation corresponded with the border delineation according to Plíva and Žlábek (1986). Subsections 2a and 2b, 8a and 8b, 18a and 18b (Figure 4) were then merged into NFAs 2, 8, and 18. In the text, the description of the NFAs' borders is given on the level of municipalities. NFAs with a discontinuous delimitation (e.g. NFA 32 with its four separate enclaves) contained a border description for each part of the Area.

The 298/2018 Coll. amendment of the 83/1996 legislation declared the last changes to date. The number of NFAs remained unchanged, and the graphic attachment contained a precise delineation of borders that substantially respect the sharp geomorphological boundaries (Figure 6).

PURPOSE AND USE OF THE NFAS

The use of NFAs for sustainable forest management needs can be divided into two categories: the genetic, and the planning (strategic) use. The first category views NFAs as spatial frameworks for ge-

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netic classification of tree populations and woody plant ecotypes, with the possibility of their mutual transfer with regard to the similarities of their growth conditions in the geographical ('horizontal') sense (Pařížek 2019). The second category uses NFAs for blueprint planning of sustainable silviculture principles (Mansfeld, Hruban 2018).

Natural Forest Areas were employed in the 'Directives for certifying and securing the sources of tree species' seed material and its transport from 1988' (VÚLHM 1988). Aggregation of the NFA regions gave rise to the so-called seed production areas for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), and European larch (*Larix decidua*). For example, the West-Sudetic seed production area for Norway spruce (marked by a Roman number *V*) consisted of NFAs 21, 22, 23, and 24 (Figure 4). No seed production areas were established for other tree species, plus the seed material transfer happened only when a scarcity occurred in local seed material sources. Specific rules were also set for vertical seed material transfer between FVZs in certain regions (Pařízek 2019).

By the Forest Act No. 289/1995 Coll., NFAs have become coded in law as frameworks for seed material transfer (Section 29). Regulations for seed material transfer had been specified by Decree No. 82/1996 Coll., which was content-wise very similar to the one from 1988 (seed production areas for the chief tree species had been formed analogically; only their label changed to 'areas of origin'). On the contrary, Act No. 149/2003 Coll. (Trade of Forest Tree Species Reproduction Material Act) establishes the term 'areas of provenance' for the transfer of seed material; those areas are identical to NFAs. Details regarding the transfer of tree species across NFAs have been specified in Annexes 1–5 of Decree No. 139/2004 Coll., which established the specifics of forest stands regeneration and afforestation of land lots classified as parcels designated to fulfil the functions of a forest. As of today, the last legislation regulating seed material transfer is the 456/2021 Coll. Decree, which is the amendment of the Decree mentioned (139/2004). This Decree aggregated NFAs into the Hercynicum (NFAs 1–34) and Carpaticum regions (NFAs 35–41), see Figure 4. Seed material transfer between the Hercynicum and Carpaticum regions is not possible except for a few specific cases, such as the transfer between neighbouring NFAs. For European beech (*Fagus sylvatica*), Douglas fir (*Pseudotsuga menziesii*), and Grand fir (*Abies grandis*) specifically, seed material transfer between the two spatial frames is not limited. Annex 1 (456/2021 Coll. Decree) also lists the restrictions for inter-zonal transfer for specific tree species, while Annex 2 regulates the transfer of seed material in the vertical direction (Mlynář 2021). NFAs had been the functional outline for the transfer of tree species seed material for more than 30 years.

The beginnings of utilising the NFA system as a framework for strategic silvicultural planning and the implementation of long-term national forestry policy objectives can be found in the 1980s (Plíva 1985; Plíva, Žlábek 1986). The Lesprojekt institute compiled an appendix of tables with an overview of statistical records to accompany the NFAs' graphical form (Lesprojekt 1985). The overviews contained the measurement and the percentual share of the forest site complex as well as FVZs data. In 1989, management recommendation frameworks were elaborated for each area (Plíva, Žlábek 1989). Decree No. 83/1996 Coll. of the Forest Act had defined the RPFD, which in Section 1 proposed the management principles for NFAs in the form of the so-called Framework Management Directives (ÚHÚL 2024). With a validity period of twenty years, these had become the tool for regionally differentiated application of the state forest management policy and the blueprint for processing the Forest Management Plans and the Simplified Forest Management Plans (both being in force for ten years; ÚHÚL 2024). Management principles in the Framework Management Directives contained basic management recommendations regarding social demands, stances of forest owners, managers, administrators and other subjects in the specific regions (Mansfeld, Hruban 2015). The Forest Management Institute curated the first generation of the RPFD documentation in 1997–2001 (ÚHÚL 2002; Krchov 2008); the second generation is currently being processed and its planned finish date is 2024. Macků (2018) used the NFA spatial frames to characterise zonal FVZs and to evaluate different potential scenarios of climate change effects on forests, which have been used in the second-generation documentation of RPFD (Macků, Kosová 2020).

The areas' characteristics consist of the aggregation of lower typological (or repeatable) units – forest site complexes and forest types (ÚHÚL 2023). The assessment of production parameters (poten-

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tial of the site, potential natural tree composition, actual tree composition, etc.) extends specifically to land lots classified, according to Section 3 of the Forest Act, as fulfilling the functions of a forest; however, the actual disposition of these land lots may be different, as proven by the National Forest Inventory results (Kučera, Adolt 2019; Máslo et al. 2023). A revision of the forestry-typological maps is also the subject of annual actualisations, which would explain the differences in long-term comparisons (Vokoun 1999) regardless of the system's units and their changing definitions (Zouhar 2018).

The NFA spatial frames have also been utilised outside the forest management sphere. Průša (1990) used NFAs to assess the presence of the most intact forest communities deserving the attention and care of nature protection services. NFAs also served as one of the input bases for creating the biogeographical classification (Culek et al. 1996) and the characteristics of ten specific NFAs (1, 3, 11, 13, 14, 21, 22, 25, 27, 40) became the template for montane forests' descriptions (Vacek 2003). The variety of information collected during the processing of the RPFD (e.g. the list of and the territorial measure of genetic bases, zones of hygienic water protection or forests in the Natura 2000 elements) provide valuable data for landscape management as well, such as the register of both regional and supraregional components of the Territorial System of Ecological Stability (Simon et al. 2010; Bínová et al. 2017), or close-to-nature tree species composition (Míchal et al. 1992).

PERSPECTIVES IN THE ERA OF CLIMATE CHANGE

Scenarios of climate change on both the European (Lindner et al. 2010; Hanewinkel et al. 2013) and the regional scale of the Czech Republic (Hlásny et al. 2011; Machar et al. 2017; Čermák et al. 2018) presume a geographical shift of the current climatic conditions and the related change in ecologically optimal growth conditions of forest tree species. Some studies have addressed the foreseeable shift of the FVZs in the sense of the change in climatic predictors (Macků 2015; Pokorný, Krejza 2022) by which these zones are characterised (Vahalík, Mikita 2011; Vlčková et al. 2015; Macků 2018; Čermák et al. 2018; Macků, Kosová 2020). Aside from these relatively older approaches, new concepts of modelling the optimal ecological and production condition of the dominant tree edificators arise (Hlásny et al. 2016; Mikita et al. 2016; Machar et al. 2017, 2018; Dujka, Kusbach 2023a) as the foundation for both general and concrete adaptation measures (e.g. Novák et al. 2017; Fanta, Petřík 2018; Remeš 2018; Čermák et al. 2018; Jandl et al. 2019) which should lead to sustainable forest management.

Longevous plant species, including trees, will lag behind short-lived species in the climate change-induced adaptation process moreover, some species may take decades until they develop reproduction processes in the locally adapted genotypes. Evolutionary adaptation to the new climatic conditions may, in tree species, take from hundreds to thousands of years (Lenoir et al. 2008; Vitt et al. 2010). Further complications arise with the geographical change of ecological living and productive growth conditions (Williams, Dumroese 2013; Sáenz-Romero et al. 2016).

Populations of forest tree species may react to climate change in three possible manners: (*i*) by adapting to the new climatic conditions in the existing surroundings, (*ii*) by migrating into a more suitable ecological habitat/niche, or (*iii*) by local extinction (Aitken et al. 2008).

Changes in climatic conditions force plants to migrate in the 'horizontal' direction (i.e. in latitudinal sense) from 3 km (Gömöry et al. 2020) to 5 km per year (Williams, Dumroese 2013). However, the observed migration rate of tree species in the Postglacial era was approximately ten times smaller – the ranges were 200–500 m per year for pioneer species (birch, Scots pine, alder), and even less in climax species – ca 100–400 m per year (oaks, European beech, silver fir, spruce; Feurdean et al. 2013). Gray and Hamann (2013) analysed the correlation between the change in climatic conditions in North America and the plant species' migration rate, which was determined to equal 100 latitudinal kilometres and 44 altitudinal metres. Gömöry et al. (2020) state that the isotherm vertical shift is approximately 11.5 m per year, which can pose a problem for the longevous plant species migration processes. Natural tree species' migration had been limited by the presence of natural barriers (rivers, mountain ranges) in the Postglacial epoch; contemporarily, it is also limited by various anthropogenic barriers, such as settlements, traffic, or energetic infrastructures (Klisz et al. 2023).

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The concept of assisted migration (Ste-Marie et al. 2011) appears as a perspective approach in landscape management; in connection to forest ecosystems, the term 'forest-assisted migration' (FAM) is used. FAM is defined as tree species' individual or populational shift inside their existing range or in such a range necessary for the maintenance of the trees' productivity and health (Pedlar et al. 2012). Klisz et al. (2023) differentiate three types of assisted migration (Figure 7): (*i*) assisted population migration (or assisted genetic migration, assisted gene flow), i.e. the transfer of the seed material or the whole population into locations historically already inhabited by said species; (*ii*) assisted range expansion, i.e. the transfer of seed material or a population from one area to another outside of its historical range where suitable ecological conditions are found, which allows for a more effortless potential natural movement or the simulation of the natural species' movement; and (*iii*) assisted species mi-

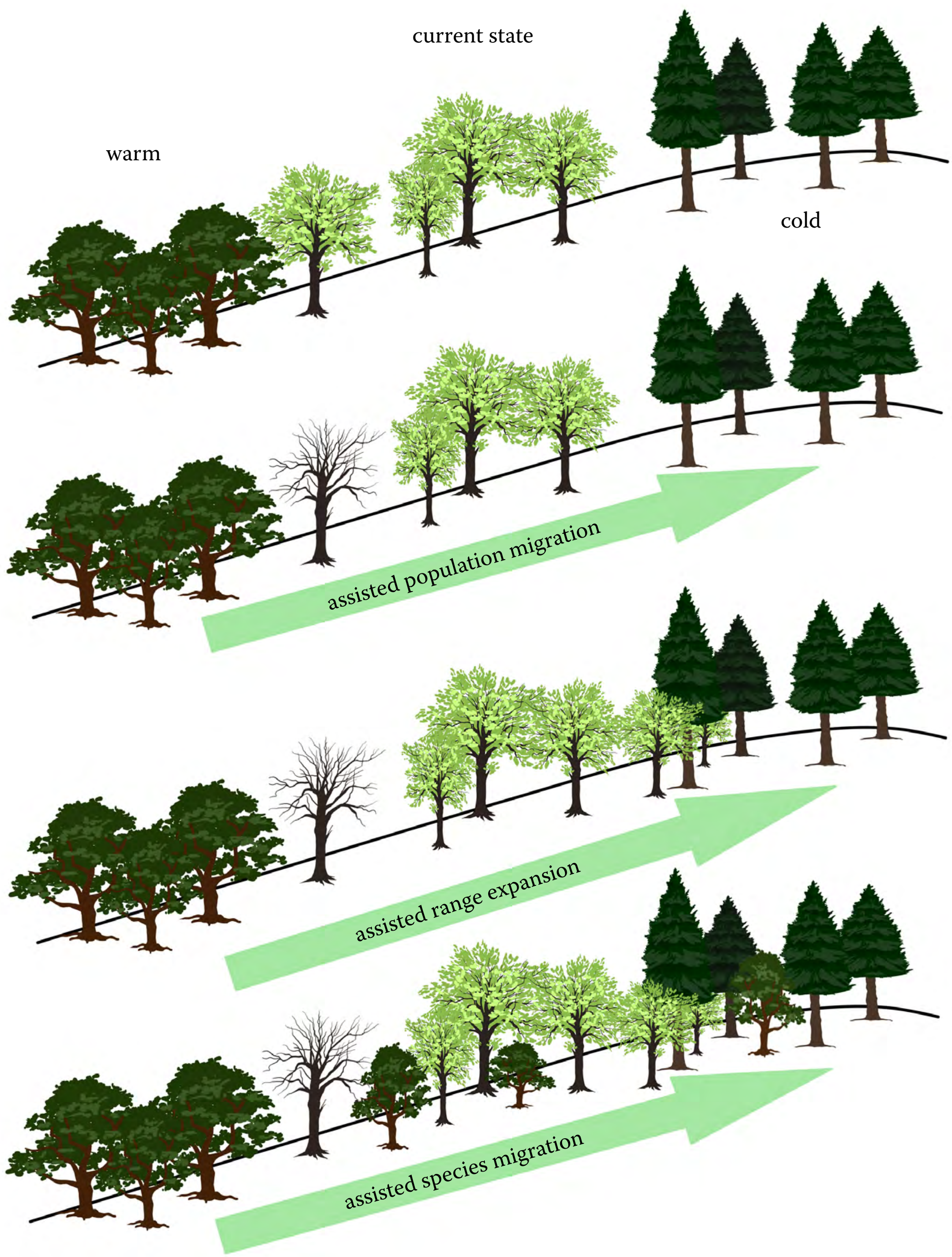

Figure 7. Three types of assisted migration (Klisz et al. 2023)

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gration (or long-distance species migration), which is the transfer of seed material of a population to distant locations outside its historical range, i.e. outside the natural occurrence area in order to overcome the natural or anthropogenic ecological barriers.

Seed material transfer is a common practice of forest management on national and international scales. In the USA, there is the Genetic Resources Management Programme (Erickson et al. 2012); in Europe, it is the Forest Genetic Strategy for Europe (EUFORGEN 2021), which gave rise to an online database and the European Information System on Forest Genetic Resources (EUFGIS). In British Columbia in the 1980s, the so-called 'seed-zones classification' came into existence (Campbell, Franklin 1981; Ying, Yanchuk 2006); at about the same time, NFAs were established in Czechoslovakia (Zlatník 1959; Plíva, Žlábek 1986). Later, in the USA, 'seed-collection zones' were established (Pike et al. 2020), as well as the 'seed transfer zones' in Hungary (Cevallos et al. 2020). Creating a database of seed material sources is the first step in seed material transfer on both national and international scales. Should the implementation of assisted migration to international and national strategies be successful and generally acceptable, it has to be built on solid foundations of classification systems based on the differentiation of climatic conditions in horizontal as well as vertical directions (McKenney et al. 2009; Kusbach et al. 2023). Directed transfer of genetic material inside the Czech Republic borders has been codified in legislation since the 1940s (Pařízek 2019). The frames utilised for vertical transfer, as based on the currently applicable legal documentation (Decree No. 139/2004 Coll.), are the 'altitudinal zones' which coincide with the FVZs of the Czech forest ecosystem classification (ÚHÚL 2023). This framework could well continue to be utilised for assisted migration under the presumption that it will be precisely defined in relation to significant climatic factors. It also has to be made into a dynamic template using sophisticated modellation processes, reflecting the changes in growth conditions. Considering the reasons presented above, NFAs appear as a perspective geographic-ecological framework for applying assisted migration on both a regional (200–2 000 km) and landscape (10–200 km) scale (Pearson, Dawson 2003).

The chief difference in the contemporary practice of assisted migration is the urgency of current and predicted climate change impacts, which should be sufficiently accounted for during transfers. While most attention has so far been given mainly to the genetic quality of the donor population when creating the rules for seed material transfer in order to ensure the best possible production and reproduction results (quality-wise), now it might be the time to seek new approaches where the principles of human-assisted migration can be applied in a broader sense (quantity-wise) to ensure the survival of the species (Pedlar et al. 2012; Klisz et al. 2023).

In connection to production, FAM refers to transferring tree species sensitive to climate change to locations with a climate suitable for their survival and maintaining a viable population (with the ability to reproduce naturally). It is due to mention that this strategy has both supporters and opponents (St-Laurent et al. 2018; McLaughlin et al. 2022). Among the oft-mentioned cons are the concerns of (*i*) potentially invasive behaviour of the transferred species (Müller, Hellmann 2008; Ricciardi, Simberloff 2009), (*ii*) the risk of unintended introduction of new pathogens into the target area, and (*iii*) the different abilities and limited adaptability of the newly introduced species (Handler et al. 2018). Newly relocated species also have the potential of crossing with native species (populations) capable of interspecific hybridisation (incl. *Picea*, *Pinus*, *Populus*, and *Quercus* genera; Aitken et al. 2008). In accord with the reasons stated, there is an ongoing discourse regarding the utilisation of FAM as an adaptational tool for e.g. nature protection management (Twardek et al. 2023).

A specific topic is the success rate of assisted migration to azonal sites, where an influence of other than climatic limiting factors is expected (e.g. the limiting factor of soils with a high percentage of rock fragments or wet soils; of competition with native species; or of the presence of specific endemic organisms; Park, Talbot 2018). It is also necessary to consider the size of the endangered population and make efforts to maintain rare and genetically limited populations which can be severely threatened by changes in climate and whose natural reproductive abilities are limited (Handler et al. 2018).

OPPORTUNITIES OF THE NFAS' DEVELOPMENT

Prudič (1986) carried out an NFA assessment from the perspective of the heterogeneity of natural conditions using the Shannon-Weiner Species Diversity Index (Magurran 2004). The result was

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a comparison of NFAs, focusing on the diversity of the represented FVZs, ecological series, forest site complexes, and the potential natural tree species composition. Besides the recommendation of using the proposed comparison method more intensively when evaluating the results of typological surveys, no other changes have been suggested. The results and conclusions of this study (Prudič 1986) have not been reflected in the further evolution of the NFA concept. Critique was also aimed at the Framework Management Directives (Plíva, Žlábek 1989) for the management of the individual NFAs. Objections were aimed mainly at the disclusion of recommendations for forests of special purpose and forests inside landscape units of nature protection (Prudič 1991).

With connections to the socio-economic changes after 1989, the need to elaborate on new legislation targeting forests arose (Poleno 1992). These thought processes included codifying NFAs in the forest legislation. General delimitation of the borders was made more accurate by the RPFD so that (*i*) border continuity is ensured and (*ii*) the borders copy easily identifiable elements marked in the land register (roads, railways, watercourses). The borders thus began to reflect environmental distinctions only partially. An example could be the 20-kilometre border strip between NFA 36 and 35, which follows the railway corridor Přerov–Břeclav (ÚHÚL 2001).

Vokoun (1999) has warned that forest typology should flexibly react to the newest research, e.g. in connection with the work of Culek et al. (1996) – in his biographical division of the Czech Republic, he saw significant progress in the evolution of phytogenetic and zoogeographical zonation. The bioregions' borders mostly overlap with the borders of NFAs, and the almost double number of regions (91) could be downsized by aggregating (large NFAs would consist of 2 or more bioregions), whereas small areas could completely correspond with small bioregions (Figure 8). Vokoun (1999) also proposes using the 14 natural circuits as superstructural units whose strength would lie in the small number and the unified ecological conditions (Figure 9). Ecologically similar conditions of the natural circuits could also be typologically char-

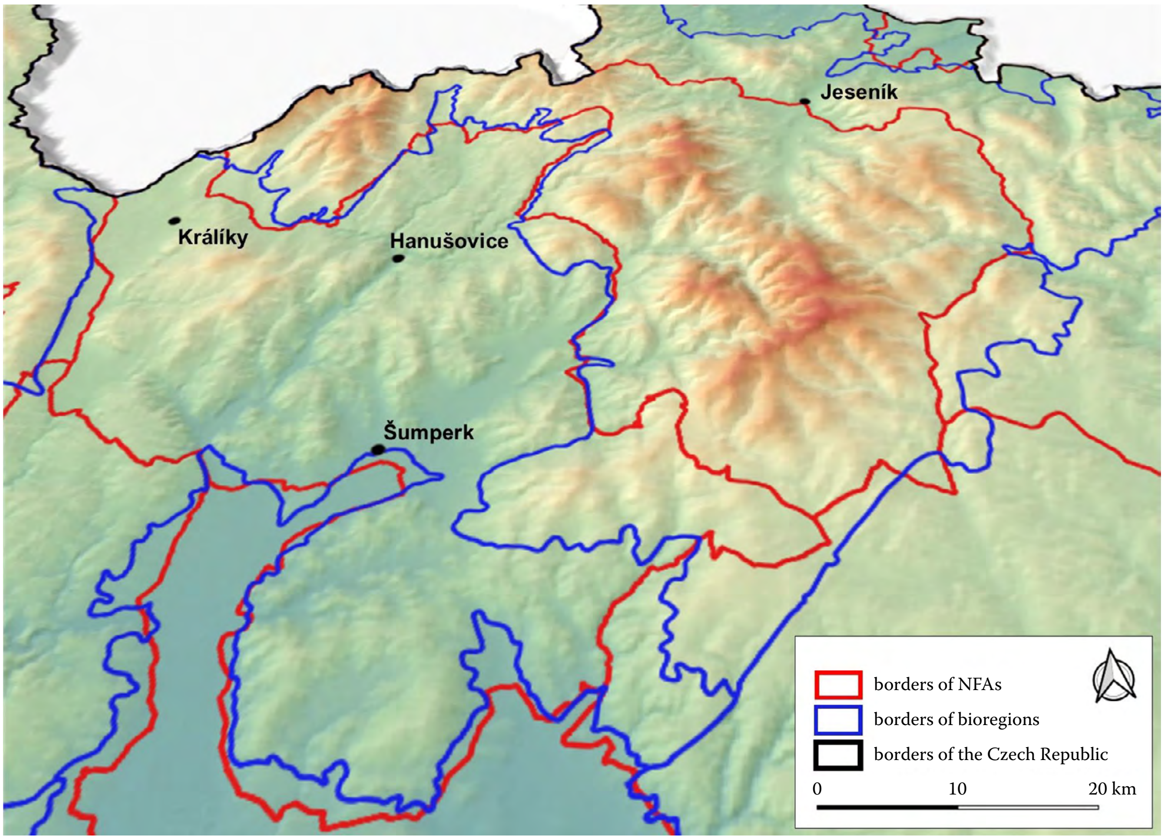

Figure 8. A graphic comparison of the Natural Forest Areas (NFAs) borders and border lines of bioregions on the base of a digital terrain model (Northern Moravia)

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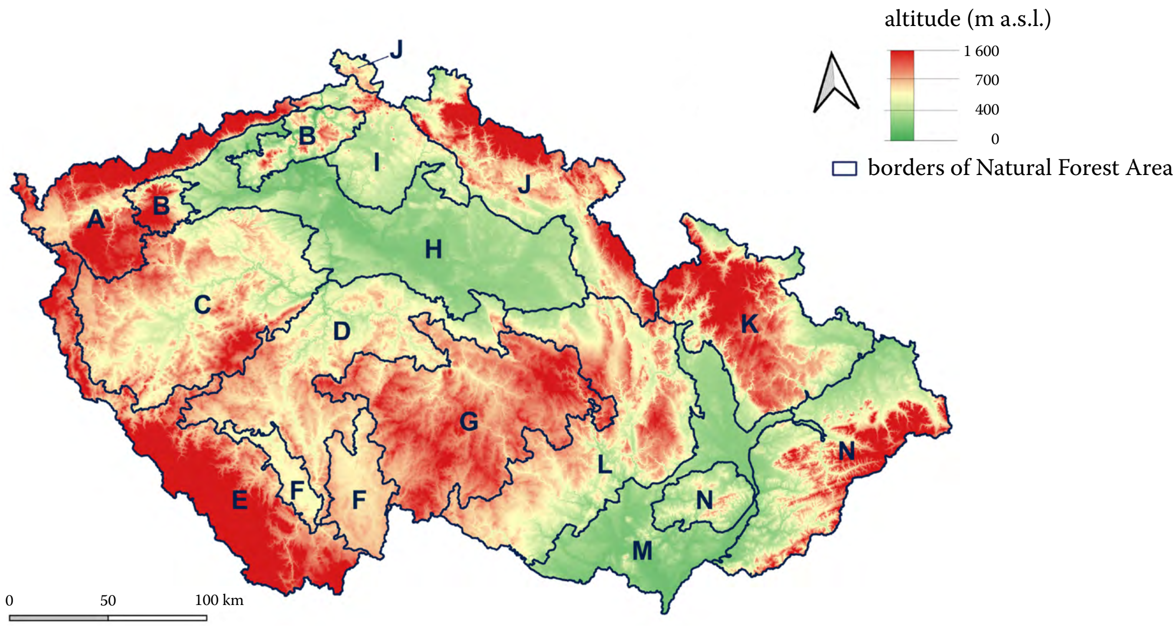

Figure 9. Natural circuits (Vokoun 1999)

A – Krušné Mts (NFA 1, 2a, 3); B – Volcanic Mts Ranges (NFA 4, 5); C – Poberounský (Berounka River Lowlands; NFA 6, 7, 8, 9); D – Central Bohemian (NFA 10); E – Bohemian Forest (NFA 11, 12, 13, 14); F – South-Bohemian Basins (NFA 15); G – Bohemian-Moravian (NFA 16); H – Polabský (Labe River Lowlands) (NFA 2b, 17); I – North-Bohemian Sandstone (NFA 18, 19); J – West-Sudetic (NFA 20, 21, 22, 23, 24, 25, 26); K – East-Sudetic (NFA 27, 28, 29, 32); L – Moravian Submountain (NFA 30, 31, 33); M – Moravian Valleys (NFA 34, 35); N – Carpathian (NFA 36, 37, 38, 39, 40, 41); NFA – Natural Forest Area (see Figure 4)

acterised more precisely and receive differentiated management measures.

To improve the quality of the current NFAs' form, it is desirable to revise the current borders to reach maximum homogeneity. To achieve this, the zonal concept could be applied (Pojar et al. 1987), with the theoretical basis and practical suggestions for the study area as created by Dujka and Kusbach (2022, 2023b). NFAs could be specified according to the prevailing potential of the sites into areas with the potential of the development of (*i*) zonal vegetation (i.e. vegetation dependent on macroclimate as the chief environmental factor) and (*ii*) azonal vegetation (i.e. vegetation primarily dependent on environmental factors different from macroclimate). The frameworks should be further divided into the two most dominant spatial units – Hercynicum and Carpaticum, as the site and climatic conditions of these two differ significantly (Dujka, Kusbach 2023a, b). In NFAs with prevalently zonal character, the application of prediction models would be viable, reflecting the possible change in climate and the accompanying change in vegetation composition in the horizontal and (predominantly) vertical direction. In the following steps, the focus should be aimed at the individual tree species (populations), and not only in the sense of their preservation (tree species ecotypes which can be found in specific locations of the individual areas; Úradníček et al. 2017) but also in the sense of their ecological potential (the so-called valuable deciduous species – genus *Acer*, *Sorbus*, *Prunus*).

Results of a study by Divíšek et al. (2014), which contained a classification of the Czech landscape based on a statistical analysis of present-day vegetation layout (natural biotopes *sensu* Chytrý et al. 2011), could also be a new opportunity for revising the current delimitation of NFAs. The study delimited seven landscape types (seven regions) characterised by altitude differences, climatic factors and the differences between the Bohemian Massif and Carpathian geological structures.

In the sense of forestry, a specific priority goal should be set regarding the future development of the Czech Republic's geographical (horizontal) zonation. Broader discussion about the purposes of spatial units of the horizontal classification offers

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contemplations to prioritise either ecological-conservational, production (silviculture) or social objectives. Ecological-conservational potential would require (*i*) a precise delimitation of the individual units with regard to the advanced opportunities offered by geospatial modelling, (*ii*) predictions of climate change scenarios, (*iii*) vegetation analyses in relation to the landscape, (*iv*) insight into rare and specific tree species/populations, as well as (*v*) insight into the adaptation capability of the current most represented tree species' individuals, their health status and genetic variability. The current forest categorisation, as stated in the forest code and RPFD, will be of great help. The silvicultural potential may be perceived as the utilisation of forests by methods currently available and for the needs of their respective owners along with demands of the society – that would require (*i*) choosing the optimal management measures for reaching a target product (e.g. the suitable management shape of high/timber forests for the cultivation of a quality timber versus a low/coppice forest for sustainable production of fuel wood), (*ii*) making the forest accessible through an infrastructure of forest roads and land rounding-off, (*iii*) choosing a type of a suitable management plan (a traditional age class forest approach versus selection forest or permanent forest/Dauerwald), and (*iv*) minimising the risk of wildfires in concentrated Central European landscape, together with (*v*) the use of forests by the wide society including recreation, tourism, sport, hunting, etc. Combining these approaches could bring about spatial units that could be effectively utilised for long-term sustainable management to fulfil environmental and economic goals as well as societal requirements.

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