

A fuel model classification approach for Central Europe: A high-resolution fire risk assessment example from the Czech Republic

Lucie Kudláčková

kudlackova.l@czechglobe.cz

Global Change Research Institute of the Czech Academy of Sciences

Jan Novotný

Global Change Research Institute of the Czech Academy of Sciences

Jana Beranová

IFER – Institute of Forest Ecosystem Research Ltd

Radka Mašková

IFER – Institute of Forest Ecosystem Research Ltd

Monika Hlavsová

Global Change Research Institute of the Czech Academy of Sciences

Emil Cienciala

Global Change Research Institute of the Czech Academy of Sciences

Jakub Dvořák

Global Change Research Institute of the Czech Academy of Sciences

Markéta Poděbradská

Global Change Research Institute of the Czech Academy of Sciences

Lucie Hasalová

Technical Institute of Fire Protection

Václav Vystrčil

Technical Institute of Fire Protection

Zander D. Opperman

Global Change Research Institute of the Czech Academy of Sciences

Miroslav Trnka

Global Change Research Institute of the Czech Academy of Sciences

Research Article

Keywords: Central Europe, Czech Republic, fire behavior, fuel model, fuel heterogeneity, wildfire modeling

Posted Date: September 14th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-8777876/v1>

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Additional Declarations: No competing interests reported.

Abstract

Background:

Central Europe is rarely considered a high-risk region for wildfire occurrence. As climate change progresses, the likelihood of fire-conducive weather is projected to increase, which could increase wildfire frequency and severity in the region. The fuel type and amount at a given location are fundamental parameters determining the potential of vegetation cover to produce a fire of a given intensity, spread rate, and duration. In assessing the risk posed by the resulting fire, this information can be considered equivalent to the fire load concept in building design. As fires in forest and nonforest ecosystems are highly complex in terms of input parameters, fuel models have been developed as simplified representations of reality that carry vegetation-cover information in terms of burning characteristics and likely fire behavior. While the 30-m resolution fuel-model classification of the US has been available for two decades, the European reality has been much less satisfactory, with openly available data accessible in at a 1-km or 100-m resolution at best.

Results:

We developed a 30-m fuel model classification system for the Czech Republic by integrating openly available national datasets and ecological habitat descriptors to map fuel models compatible with those of Scott and Burgan (2005). The resulting maps provide a fine-grained mosaic of agricultural, successional and forest fuel types typically generalized or absent in existing European products. In FlamMap simulations under identical wind and fuel-moisture settings, the Czech 30-m fuel inputs yielded substantially larger fractions with high values of the evaluated fire-behavior metrics than a 100-m European product did: the proportion of cells with a spread rate > 5 m/min increased from 5.6% to 20.9%, a flame length > 2 m increased from 5.8% to 21.5%, and a fireline intensity $> 1,000$ kW/m increased from 6.6% to 21.9%. These differences were partly explained by the contrasting treatments of agricultural fuels, with nonburnable area fractions of 15.4% in the Czech model, versus 31.3% in the pan-European product.

Conclusions:

High-resolution fuel model mapping provides a first step to valuable tool for wildfire risk assessment and management in Central Europe. After validation process it can support preventive planning, operational decision-making, and strategic measures by land managers, conservation authorities, and fire services.

1 Background

In recent years, Central Europe and the Czech Republic in particular have begun to face a new challenge, namely, an increasing risk of landscape fires, similar to other parts of the world (Duane et al. 2021, IPCC

2023). Although this region is not historically considered highly fire prone, climate change is increasing the frequency and duration of weather conditions conducive to wildfire occurrence (Trnka et al. 2020; Možný et al. 2021; Carnicer et al. 2022; El Garroussi et al. 2024). This change is reflected not only in the increasing number of reported wildfires (MI - DG FRS CR 2021) but also in their intensity and burned area (Kudláčková et al. 2023). In a fragmented landscape with a highly heterogeneous vegetation mosaic, effective wildfire prevention and operational response therefore rely on detailed wildfire risk assessments at fine spatial resolutions (Bowring et al. 2024; Pascolini-Campbell et al. 2025).

One of the key tools for both prevention and effective suppression is wildfire behavior modeling, which critically depends on adequately specified fuel models. Fuel models provide a simplified representation of the vegetation cover, thereby encoding information on the fuel load and structure, flammability, and expected type and behavior of the fire. The fuel type and amount at a given location fundamentally influence the rate of spread, fireline intensity, and burning duration. Hence, fuel models represent a primary input parameter for fire behavior simulations and can be regarded as a spatial analog of the fire load concept used in building design. However, such models constitute only one of several geospatial layers (commonly 5–8) needed to model fire behavior or predict wildfire spread (Finney 2006; Finney 1998; Finney et al. 2019).

Given the fragmented and heterogeneous land-use mosaic of the Czech Republic (Chytrý et al. 2010; Czech Statistical Office 2024; Zýka et al. 2024), detailed fuel model maps are important not only for strategic landscape and forest management but also for meeting the operational needs of the Fire Rescue Service. By translating heterogeneous vegetation patterns into standardized fuel classes, these maps provide a direct, qualitative description of the expected fire behavior and suppression conditions for different fuel types. Fires in grasslands or agricultural fields typically spread very rapidly but are relatively accessible for suppression. Early localization is therefore critical, while firefighter movement and access are generally not constrained. In contrast, forest fuel types dominated by litter and understory fuels, such as timber–litter (TL) and timber–understory (TU) models, typically support slower fire spread, but suppression is more demanding, often requiring work around standing trees, longer intervention times, increased manual firefighting efforts, and extended postfire monitoring.

When fuel model maps are subsequently combined with terrain and weather information in fire behavior models, these qualitative differences can be expressed quantitatively in terms of the expected rate of spread, flame length, or fireline intensity. Fuel model maps thus serve as both an independent source of operationally relevant information and a key spatial input for fire behavior modeling. Together, these approaches support preventive wildfire planning and informed decision-making by incident commanders, particularly with respect to tactical choices, allocation and positioning of suppression resources, and assessment of operational difficulty across the landscape.

The development of fuel models began in the United States during the second half of the 20th century, when fuel model classifications were proposed, revised and expanded over several decades (Albini 1976; Anderson 1982; Scott and Burgan 2005). While 30-m fuel model classifications have already been

available for two decades in the United States (Rollins 2009; LANDFIRE n.d.–b) and have undergone a long development process since the second half of the 20th century, such classifications remain limited in Europe in terms of the availability of detailed data. Publicly available fuel maps currently provide a spatial resolution of at most 1 km (Aragoneses et al. 2023) or 100 m (Kutchartt et al. 2024). These resolutions reflect the continental-scale objectives and spatially harmonized input data of the respective products but may generalize fine-scale fuel variability relevant to local fire behavior modeling in the fine-grained Central European landscape. In addition to a coarse spatial resolution, European fuel products often differ in conceptual design, relying primarily on land cover or spectral proxies that may involve the generalization of structurally important fuel types such as young forest stands, successional habitats (scattered and nonforest woody vegetation), or agricultural fuels. Although both pan-European products (Aragoneses et al. 2023; Kutchartt et al. 2024) use standard fuel classification systems, such as Scott and Burgan (2005), they differ from each other and from the approach developed in this study in conceptual design, input datasets, spatial resolution, and implementation. These differences complicate direct comparisons among products and the transfer of mapping approaches across regions.

Addressing these gaps requires fuel model classifications that are both spatially detailed and conceptually aligned with fire behavior processes. In view of these limitations, the aim of this study was to develop a fuel model classification methodology at a high spatial resolution of 30 m that is adapted to the specific conditions of Central European landscapes while remaining transferable to other regions. This methodology combines readily available datasets and provides a practically applicable tool that can support both preventive planning and operational decision-making in wildfire risk management.

The development of a fuel model framework, however, extends beyond the development of a fuel model classification methodology. It also requires evaluation of whether the resulting fuel model classification adequately represents local fuel-bed characteristics and, ultimately, validation of fire behavior predictions against observations from documented wildfires or experimental fires. The present study addresses only the first of these components. The subsequent stages are discussed in Section 4.4.

The objectives of this study are as follows:

1. to introduce a high-resolution fuel model classification methodology (30 m) adapted to the fragmented landscapes of Central European conditions using publicly available datasets;
2. to quantify fuel model composition differences between the proposed classification and existing European fuel mapping approaches; and
3. to assess how differences in fuel model classification and other input layers influence fire behavior predictions using fire modeling.

2 Methods

2.1 Study area

We designed a fuel model classification system (FMCS) for the geographical area of the Czech Republic (49.8°N, 15.5°E; covering 78 870 km²) as a case study of a Central European landscape. The climate of the Czech Republic is temperate with continental characteristics, encompassing hot summers and cold winters. The average annual precipitation ranges from approximately 450 mm in the driest regions to approximately 1200 mm in mountainous areas, depending on elevation (115–1602 m above sea level (a.s.l.)). These climatic and topographic gradients support a high diversity of vegetation types.

Furthermore, the Czech landscape is characterized by a fragmented and heterogeneous land-use mosaic dominated by agricultural land, including arable land and permanent grassland (approximately 53%) and forests (approximately 34%), with additional built-up areas, water bodies and succession sites (Czech Statistical Office 2024). The Czech landscape is characterized by pronounced compositional and configurational heterogeneity, expressed in substantial spatial variation in land-cover diversity, landscape structure, and fragmentation (Dušek and Popelková 2017; Sychrová et al. 2024; Zýka et al. 2024). Comparable forms of landscape heterogeneity also occur in other regions, including the Mediterranean region (Geri et al. 2010). Because the spatial distribution and heterogeneity of fuels can affect fire spread and other modeled fire behavior characteristics, capturing this fine-grained Czech land-use mosaic motivated the development of spatially consistent input layers at a 30-m resolution (Keane et al. 2001; Atchley et al. 2021).

We first evaluated the classification concept in several pilot areas that differed in terms of vegetation structure, spatial extent, and data availability. Specifically, we worked in (1) Šumava National Park in southwestern Czechia, (2) the catchments of the Vír and Švihov reservoirs (Beranová et al. 2021; Trnka et al. 2021a), and (3) select forested landscapes in the Karlovy Vary and South Bohemian regions (Trnka et al. 2026). The methodology was iteratively refined in these pilot areas before being applied at the national scale.

2.2 Fuel model classification methodology for the Czech Republic

Fuel models developed by Scott and Burgan (2005) describe surface and near-surface fuels using a set of basic characteristics: (a) fuel type (with seven basic fuel models for grass (GR), grass–shrub (GS), shrub (SH), timber–understory (TU), timber–litter (TL), slash–blowdown (SB), and nonburnable (NB)); (b) fuel load and its distinction on the basis of living (grass, herbaceous and shrub biomass) and dead biomass (litter, dead wood, etc.); (c) dimensional fuel load (with fuel loads for 1 h, 10 h, and 100 h); (d) fuel bed depth; (e) fuel surface-to-volume ratio; (f) fuel heat content; and (g) dead fuel moisture of extinction. All selected fuel models retained the original parameter values defined by Scott and Burgan (2005), including the model-specific dead fuel moisture of extinction. These values were not recalibrated for Czech fuel complexes because no region-specific calibration data are currently available.

In the FMCS, the vegetation cover of the Czech Republic is transformed into fuel models as developed by Scott and Burgan (2005). Our classification procedure is based on the analysis of geospatial data covering the entire territory of the Czech Republic.

The Habitat Catalogue of the Czech Republic (Chytrý et al. 2010) was selected as the basis for the FMCS because it provides detailed information on vegetation cover, ecosystem structure, and species composition. The catalogue classifies the Czech landscape into nine groups comprising 157 natural biotopes and one group containing 49 human-influenced or fully anthropogenic biotopes. It describes key ecosystem characteristics, including vegetation height, density, and structural attributes, allowing the identification of dominant fuel forms, vegetation structure, and potential fuel continuity. The habitat classification was subsequently integrated with the fuel models of Scott and Burgan (2005) above-ground biomass classes, and site moisture conditions (dry or wet) to define the final fuel models (Appendix, Table A1). The overall FMCS workflow is summarized in Fig. 1.

The next step included connecting the information derived from the Habitat Catalogue (enhanced by the fuel model classes) with the spatial representation of these habitats. The most detailed and comprehensive information on ecosystem spatial distribution across the Czech Republic is available in the Consolidated Layer of Ecosystems (KVES; NCA CR 2023) which already includes information on habitat from the Habitat Catalogue of the Czech Republic (available for protected areas, NATURA 2000 regions etc.), and from other spatial data sources for the Czech Republic (a detailed description of the datasets is in Appendix A.1). The KVES dataset is updated by the Administration of Nature Protection of the Czech Republic (Nature Conservation Agency of the Czech Republic n.d.) as a user and cocreator of this dataset for the Czech Republic.

The enhanced dataset on biotopes (Habitat Catalogue data paired with fuel model classes) was linked to the matching category of land cover in the KVES dataset. The spatial classification of the KVES dataset contains 41 basic ecosystem categories at four hierarchical levels and six broader ecosystem types.

The assignment of fuel models to ecosystem classification by the KVES dataset (Appendix, Table A2) indicates that most agricultural, grassland and wetland ecosystems were assigned to fuel models of the GR type (models with a predominance of herbaceous cover) or the SH type (predominance of shrubs over grasses). Among the fuel models of the TU type (forest with undergrowth), we included human-influenced biotopes such as scattered greenery, urban greenery, and parks. For agriculturally used areas, i.e., arable land and permanent grasslands, the procedure also facilitated the consideration of seasonal aspects. Most agricultural vegetation can be considered practically nonflammable for most of the growing season, except for the period of full maturity and the harvesting period of most cereals and oilseeds and forage crops. An overview of the fuel models used in Czechia, including short descriptions, is available in Table A3 of the Appendix.

The procedure follows separate classification pathways for forested and nonforested areas (Fig. 1), which are described in detail below. The forestland classification is based on datasets developed by the National Forestry Institute (NLI; NLI 2025), which in turn are derived from available satellite products, including data from the Copernicus programme (European Commission - Directorate-General for Defence Industry and Space n.d.), the programme Landsat (National Aeronautics and Space Administration 2026), PlanetScope (European Space Agency n.d.) and national aerial survey. To

determine the final fuel for forest stand classification, we considered vegetation parameters, including a) species composition, b) site, c) age group, d) leaf area index (LAI) and e) bark beetle infestation area (when applicable).

The classification process for forested areas starts with identifying bark beetle clear-cut areas. For areas containing large amounts of dead wood, we assigned the SB fuel model (either 1 or 2). The SB2 fuel model is used as a conservative option when dead wood is identified from remote sensing data. The SB1 fuel model is assigned only when supported by additional data sources, such as field surveys or local knowledge.

The next step is the determination of forest growth stages. Young stands aged 10 years represent fuel models where the predominant fuel type is a combination of herbs and shrubs (types GS and SH, respectively), while for older stands, the standard fuel type is litter or litter with undergrowth (type TL or TU, respectively).

Information on the canopy cover (LAI) was used to distinguish the GS and SH fuel models and the TU and TL fuel models. In the case of clearings, the tree regeneration stage and young stands up to 10 years old, we classified sparse stands into the GS fuel model group (the herbaceous component still prevails over the shrub layer) and close stands into the SH type (in this fuel type, shrubs already dominate). Similarly, the LAI was employed to distinguish the TU (forest with undergrowth) and TL (forest without undergrowth) fuel types in mature stands older than 10 years. Open canopies were classified as the TU fuel type, while closed canopies where insufficient light reached the ground to support vegetation were classified as the TL fuel type.

For the TU and TL fuel types, the form of the litter layer (leaves, pine needles and litter of other coniferous trees) is a key determinant of the potential fire behavior. Therefore, for these two groups, the classification was further refined on the basis of tree species characteristics, resulting in four basic categories: pine forests, coniferous forests younger than 30 years, other coniferous forests, and deciduous forests. In the case of the TL type, whether the area was located in a nonintervention zone was also assessed. If so, the area was assigned to the TL7 fuel model, reflecting an expected higher biomass load. For the remaining fuel types, including GS, SH, and TU, specific fuel models were assigned on the basis of the site productivity potential layer (based on the forestry typological system of the Czech Republic; more details are given in A.2 including Tables A4 and A5), which provides information on biomass availability (classes A, B, and C).

Without tree species information, the nonforest branch of the workflow should be applied. The classification of nonforested areas is based on the KVES dataset (NCA CR 2023), the Geographic Digital Landscape Model of the Czech Republic (ZABAGED; State Administration of Land Surveying and Cadastre 2024) and the Land Parcel Identification System (LPIS, Ministry of Agriculture of the Czech Republic 2024), which are detailed in Appendix A.1 and Fig. 1. In the case of the ZABAGED or LPIS datasets, areas classified as permanent grassland and cereal crop areas (respectively) were assigned to the GR4 fuel model.

On the basis of the workflow described above (Fig. 1), we defined 30 out of the 45 fuel models defined by Scott and Burgan (2005) for Czechia. On the basis of consultations with fire-behavior specialists from the Missoula Fire Sciences Laboratory (pers. comm.), we did not employ humid fuel model types, i.e., fuel complexes that can sustain flaming combustion even at relatively high dead fuel moisture contents, owing to their specific structure and/or chemical composition. The classification was intended primarily to represent fuel conditions during periods of elevated fire danger rather than the full range of fuel moisture conditions occurring throughout the year. Such fuel beds are not expected to represent the dominant conditions during high-fire-danger periods under the moist-temperate fire regime of Central Europe and were therefore not included in the classification of Czech fuel conditions. These findings are supported by a national analysis of fire danger conditions for the 2018–2022 period. The results revealed that the dead fuel moisture content (DFMC) in 10-h fuels was primarily low, with only short periods of critical drying (Kudláčková et al. 2025), confirming that wildfires in Czechia occur mainly under dry-fuel conditions rather than persistently humid conditions. The remaining set of 30 dry fuel model classes is therefore considered sufficient to represent the structural and management-driven heterogeneity of Czech vegetation under the conditions targeted by the classification.

We implemented the abovementioned workflow as a script in the Python programming language. Technically, the FMCS workflow starts with a definition of a regular grid. The following steps were then performed for each grid cell (30 × 30 m) independently. The FMCS was implemented using national datasets available for the Czech Republic.

2.3 Comparison of European approaches

We compared three existing fuel model products: the FMCS map developed in this study (hereafter referred to as CZE), the fuel model map described by Aragoneses et al. (2023) (hereafter referred to as ARAG), and the classification presented by Kutchartt et al. (2024) (hereafter referred to as KUTCH). For national-scale comparison, we clipped all three rasters to the territory of Czechia. The datasets from Aragoneses et al. (2023) and Kutchartt et al. (2024) were sampled at the central points of the 30-m CZE grid cells to obtain three harmonized datasets. The fuel model grid codes from Aragoneses et al. (2023) were translated to those of Scott and Burgan (2005) following the crosswalk provided in that study, whereas the dataset from Kutchartt et al. (2024) already provided fuel model classes directly compatible with Scott and Burgan (2005). For each dataset, we recoded the individual fuel models into seven fuel model types (NB, GR, GS, SH, TU, TL, and SB), counted the number of grid cells in each type and divided them by the total number of grid cells to obtain the proportional area covered by each type. The same procedure was repeated separately for each administrative region of Czechia (14 NUTS-3 regions) by aggregating the cell counts within regional boundaries to obtain the proportional area covered by each fuel model type at the regional scale.

2.4 Fire behavior modeling to assess the influence of alternative classification inputs

To demonstrate the use of high-resolution fire behavior modeling, we applied the FlamMap program (Finney 2006; Finney et al. 2019) to the Lázeňské lesy Karlovy Vary (LLKV) pilot area, a heterogeneous forest-agricultural landscape located near Karlovy Vary in western Czechia. Two complete landscape input frameworks were compared: one based on the methodology proposed in this study described above (CZE) and one based on the methodology of Kutchartt et al. (2024). Each framework included its corresponding fuel-model map and associated landscape layers required by FlamMap. The approach of Aragoneses et al. (2023) was not used because only a single input layer (fuel map) was available. All other input layers required by FlamMap (digital elevation model, slope, aspect, canopy cover and canopy structure) were derived from the input stack described by Kutchartt et al. (2024) for this scenario, and from geospatial input layers developed at the Global Change Research Institute of the Czech Academy of Sciences (CzechGlobe 2025) for fire behavior modeling in the Czech Republic, which were chosen for the CZE scenario. Each framework retained its corresponding fuel-model and canopy layers to preserve internal consistency among surface fuels, vegetation structure, and the associated landscape variables. The analysis therefore compared two complete landscape input frameworks rather than isolating the effect of the fuel model map alone.

We used the basic fire behavior module of FlamMap, which computes the potential fire behavior for each grid cell independently under spatially uniform environmental conditions. All inputs were resampled or aggregated to a common grid with a 30-m spatial resolution to match the Czech fuel model map. Fuel moisture setting followed the D2L2 scenario (Scott and Burgan 2005). The wind speed was set to 21 km/h, corresponding to the 99th percentile of hourly values derived from the Copernicus European Regional Reanalysis (CERRA) dataset for the April–September period from 1991–2020. The wind direction was set to 270°, corresponding to the prevailing westerly winds near the Karlovy Vary meteorological station. The foliage moisture content was set to 100%, and the crown fire calculation method followed the Scott/Reinhardt method. These environmental and fire behavior model settings were held constant between the CZE and KUTCH simulations.

Fire behavior was evaluated using four key indicators, namely, the rate of spread (ROS), flame length (FL), fireline intensity (FI), and crown fire activity (CFA). For each indicator, we extracted cellwise FlamMap outputs and summarized them as frequency distributions and area fractions in predefined classes.

3 Results

3.1 Fuel model classification for the Czech Republic

Within the Czech Republic, we identified a total of 23 fuel models currently represented at the national scale, out of 30 fuel models defined for Czech conditions and the 45 possible fuel models according to the classification of Scott and Burgan (2005) (Fig. 2). As described in Section 2.2, only dry fuel model types were used, and all 30 mapped classes belong to this subset. When the FMCS workflow (described in Section 2.2) was applied within the state borders of the Czech Republic, nearly 87.6 million grid cells

(with a regular step of 30 m) were populated with a fuel model estimation. The spatial representation of individual fuel model classes (Scott and Burgan 2005) is shown in Fig. 3, indicating a high diversity of fuel conditions captured by the classification.

The mapped fuel model patterns followed the major land-use and vegetation gradients in Czechia. The TL and TU fuel models dominated in the closed forest landscapes of the uplands and mountain regions, whereas the GR and GS fuel models prevailed in agricultural lowlands, permanent grasslands and successional habitats. SH fuel models occurred mainly in young forest stands and natural or seminatural shrublands, while NB fuel models were concentrated in urban areas, transport infrastructure, and open water bodies. SB fuel models were restricted to areas affected by recent disturbances, including bark beetle outbreaks and logging.

The use of a wide range of fuel models made it possible to represent the otherwise very diverse vegetation of the Czech Republic in sufficient detail with respect to fuel combustion and potential fire spread. This wide range of fuel models captured both vegetation structure and management effects, while the FMCS applied an explicit expert-based decision framework suitable for reproducible, fully automated, wall-to-wall implementation. Moreover, the obtained national-scale results provided a consistent fuel model input for subsequent comparisons with European approaches (Section 3.2) and dynamic fire behavior simulations (Section 3.3).

3.2 Comparison with European fuel model mapping approaches

Using the harmonized CZE, KUTCH and ARAG fuel maps described in Section 2.3, we found that the three classifications produced notably different fuel model type compositions for the Czech Republic (Fig. 4).

At the national scale, forest fuel types (TL and TU) dominated in all three products, but their shares and internal partitioning differed. In CZE, TL and TU together covered 31.8% of the territory (22.6% TL and 9.2% TU), while they jointly covered 25.0% of the territory in KUTCH (5.0% TL and 20.0% TU) and 32.8% of the territory in ARAG (8.2% TL and 24.6% TU). Thus, the overall representation of forest fuels was comparable between CZE and ARAG, whereas KUTCH assigned a slightly smaller share of the country to TL and TU. Within the forest type, the KUTCH classification favored TU (20.0% vs. 5.0% TL), whereas the CZE classification exhibited the opposite pattern, with TL (22.6%) dominating over TU (9.2%).

The greatest differences were observed for the GR, GS and NB fuel types. The GR fuel type covered 47.2% of Czechia in CZE and 62.2% in ARAG but only 5.1% in KUTCH. Conversely, NB occupied 62.7% of the area in KUTCH, compared with 10.2% in CZE and 3.2% in ARAG, indicating that the KUTCH approach classified a substantial part of agricultural land as nonburnable rather than as grass fuels. SH fuels accounted for 6.4% (CZE), 7.2% (KUTCH) and 1.8% (ARAG) of the territory. GS fuels, representing grass–shrub mixtures typical of young stands and regenerating clearcuts, occurred only in CZE (4.3%) and were absent in both KUTCH and ARAG. SB fuels were marginal (0.1%) and occurred only in CZE. Collectively,

these differences indicate that the three products converge on the overall dominance of forest fuel types but diverge in the representation of agricultural, successional and young-forest fuel types.

We subsequently compared the three fuel maps in the LLKV pilot area, where all the products overlapped (Fig. 5). In this heterogeneous forest–agriculture landscape, the CZE classification distinguished 22 individual fuel model classes according to the classification of Scott and Burgan (2005) whereas KUTCH identified 12 fuel model classes and ARAG 9 fuel model classes. The CZE map revealed a fine-scale mixture of GR, GS, SH, TU, TL and SB fuels that closely followed the topography, forestland structure and local land use. In contrast, the KUTCH maps and especially the ARAG maps represented the LLKV region as a more homogeneous forest-dominated area with limited representation of young stands, disturbed patches and agricultural fuels. Consistent with their native spatial resolutions (30 m for CZE, 100 m for KUTCH and 1 km for ARAG), the KUTCH and ARAG products provided a lower level of thematic detail and greater generalization of the land-cover structure than the CZE classification did, which resolved the finer spatial variability in fuel types within the LLKV area (Fig. 5).

Collectively, these results suggest that the existing European fuel model products provide substantially different fuel model compositions for the same territory and that these differences are amplified in structurally complex landscapes such as the LLKV area. Regional summaries of fuel model type compositions for all 14 NUTS-3 regions in Czechia, derived using the same harmonization and recoding procedure, are provided in the Appendix (Fig. A1) to complement the national-scale comparison and document the extent of regional variability.

3.3 Fire behavior modeling

Using the FlamMap setup described in Section 2.4, we compared the potential fire behavior in the LLKV pilot area under the CZE and KUTCH fuel model scenarios. Under identical wind and fuel–moisture conditions, compared with the KUTCH inputs, the CZE inputs systematically produced more extensive areas with high values of the evaluated fire behavior metrics (Fig. 6).

With respect to the ROS, the CZE scenario generated larger contiguous patches with an ROS exceeding 5 m/min (20.9% of the area), whereas the KUTCH scenario mostly yielded grid cells concentrated in lower ROS classes. For KUTCH, only 5.6% of the area exhibited ROS values greater than 5 m/min. A similar pattern was observed for FL values. Notably, approximately 21.5% of the area in the CZE scenario exhibited an FL value above 2 m, and locally, 3.9% of the area attained extremes above 6 m. In comparison, in the KUTCH scenario, only 5.8% of the area exhibited an FL > 2 m, and 0.8% of the area exhibited an FL > 6 m.

FI indicated an analogous pattern: most of the area in both scenarios fell into low- to moderate-intensity classes, but the CZE inputs resulted in a notably larger share of cells with FI values greater than 1 000 kW/m (21.9%) and local maxima above 10 000 kW/m (1.7%), whereas the KUTCH scenario generated 6.6% of the area with FI values > 1 000 kW/m and 0.2% of the area with FI values > 10 000 kW/m. In terms of CFA, both scenarios were dominated by surface fires, but the CZE scenario produced a higher

fraction of grid cells with passive and active crown fires, particularly in dense coniferous stands and structurally complex forest mosaics. Passive and active crown fires in the CZE simulation represented 9.5% and 1.6% of the area, respectively. In the KUTCH simulation, 1.8% of the area was covered by passive CFA, with no areas of active CFA.

With respect to the spatial distribution shown in Fig. 6 for the CZE simulation, a significant portion of highly burnable areas (as identified by FlamMap based on ROS, FL and FI) represents grasslands in the CZE fuel models, which are classified as nonburnable in the KUTCH fuel model. Notably, nonburnable regions represent 31.4% of the LLKV KUTCH fuel model and only 15.4% of the CZE version.

Overall, the results of these FlamMap experiments indicated that for the same environmental conditions, the CZE fuel model classification yielded higher predicted ROS, FL, CFA and FI values than the KUTCH classification did in the LLKV pilot area. These results demonstrate how the choice of a high-resolution, regionally informed landscape input framework can substantially affect dynamic fire-behavior outputs and, consequently, wildfire risk assessment in Central European landscapes.

4 Discussion

4.1 Proposed methodology of high-resolution fuel maps

The selection of fuel models from the system of Scott and Burgan (2005) reflects the specific fire regime and fuel conditions of Central European landscapes, where wildfire activity is largely associated with episodic periods of notable fuel dryness. The exclusion of so-called humid fuel models is consistent with national fire-danger analyses suggesting that most wildfires in Czechia occur during periods of low fine dead fuel moisture levels rather than under persistently moist conditions (Kudláčková et al. 2025).

This approach is consistent with the seasonal aridity pattern in Czechia, where summer conditions frequently reach levels of climatic dryness comparable to those observed in other temperate fire-prone regions, as documented by both global aridity indices (Zomer et al. 2022) and analyses of fire-weather and drought conditions in the Czech Republic (Trnka et al. 2021b). Even without “humid” fuel models, Czech fuel conditions can be represented in sufficient detail because the set of 30 classes captures the full range of fuel variability across stand structures, successional stages, and management practices. This approach also maintains compatibility with the standard of Scott and Burgan (2005) and preserves transferability to commonly used fire-behavior modeling tools (e.g., FlamMap).

A key feature of the methodology is the use of a high spatial resolution (30 m), which enables the representation of fine-scale fuel variability that is important for fire behavior modeling in fragmented landscapes. In contrast, European fuel maps produced at a resolution of 100 m (Kutchartt et al. 2024) or 1 km (Aragoneses et al. 2023) commonly introduce a higher degree of generalization, which can limit their applicability in fragmented Central European landscapes, for example, by underrepresenting successional habitats, encroaching clearcuts, or actively managed agricultural land, which are frequent settings of wildfire occurrence in Czechia (Možný et al. 2021; Kudláčková et al. 2025).

Moreover, the approaches of Aragoneses et al. (2023) and Kutchartt et al. (2024) represent important progress toward harmonized, pan-European fuel model products and provide a valuable baseline for international comparisons. Although our methodology currently covers a limited area (the Czech Republic), the greater spatial detail provides a more informative basis for local and regional decision-making and suggests a pathway for refining classifications in other countries with comparable landscape settings. European approaches are also evolving with recent work by Pirotti et al. (2025), further highlighting that the spatial resolution remains a key constraint for the operational and analytical use of fuel maps in heterogeneous landscapes.

Although the workflow was implemented only for the Czech Republic, its explicit decision logic, based on vegetation structure and site characteristics, may be adaptable to other Central European regions where comparable input data are available, for example from the Copernicus programme (European Commission - Directorate-General for Defence Industry and Space n.d.), the Landsat programme (National Aeronautics and Space Administration 2026), and PlanetScope data (European Space Agency n.d.). Such transferability, however, remains to be evaluated through applications outside the Czech Republic. As such, the methodology can be adapted to other regions with similar fire characteristics and can support practical wildfire risk management applications, including forecasting systems, planning preventive measures, and spatial planning in protected areas.

In contrast to European approaches that rely primarily on the normalized difference vegetation index (NDVI) and/or climatic zones (e.g., Aragoneses et al. 2023; Kutchartt et al. 2024), we adopted a structural–ecological framework. The adoption of an $LAI \geq 2.5$ as a threshold to delineate closed forests resulted in a more temporally stable basis than NDVI-based thresholding did, which can be seasonally variable and susceptible to saturation (Tian et al. 2025), particularly for dense canopies. Similarly, our treatment of the grass (GR) and shrub (SH) fuel types is grounded in habitat descriptions (e.g., NCA CR 2023) and the fuel potential rather than vegetation height or density alone. This distinction is methodologically important because the NDVI primarily reflects greenness and may lose sensitivity in dense canopies (e.g., Aklilu Tesfaye and Gessesse Awoke 2020), whereas the LAI serves as a closer proxy for canopy closure and productivity and thus for fine-fuel continuity and understory development (e.g., Parker 2020).

Another key difference among the approaches is the interpretation of agricultural land. Whereas the approach of Kutchartt et al. (2024) classified a substantial portion of agricultural cover as nonburnable (NB), in our methodology, agricultural areas are treated as potentially burnable fuels (especially GR/GS fuels) during high-risk periods because a considerable share of wildfires in Czechia occurs in agricultural land and in its immediate vicinity (Možný et al. 2021; Kudláčková et al. 2025). Crop flammability is not constant throughout the year but varies with phenology and management (particularly maturation and harvest). Therefore, the FMCS relies on a high-risk period concept, under which otherwise weakly burnable cover can temporarily behave as continuous fine fuels. This scenario-based perspective is consistent with the episodic character of wildfire activity in Central Europe and helps explain why

mapping agricultural land as NB versus GR/GS can substantially influence estimates of exposure and potential fire behavior.

The surface fire behavior fuel models reported by Scott and Burgan (2005) were developed through an iterative process of subjectively assigning fuel parameters, modeling fire behavior and review by experts. They reported the following: *“The final fuel model selection must be made by the user based on experience with fire behavior in the fuel bed under consideration”* (page 8). In a region lacking extensive fire behavior observations, validating fuel models can be difficult.

Consequently, the applicability of standardized fuel models under Central European conditions should be evaluated against local fuel bed characteristics to determine whether regional calibration of individual fuel models is required while maintaining compatibility with the Scott and Burgan (2005) framework. As discussed in Section 4.4, this subsequent field evaluation represents the next step of the proposed framework and is beyond the scope of the present study.

4.2 Comparison of fuel model classifications

Comparison of the three fuel model classifications revealed differences not only in spatial resolution but also in conceptual and methodological design, both of which directly affect the representation of fuels and consequently fire-behavior modeling. These differences are evident already at the level of fuel model types (NB, GR, GS, SH, TU, TL, SB) and become even more pronounced in the heterogeneous LLKV pilot area. The CZE classification distinguished 22 fuel models, whereas the Kutchartt et al. (2024), and Aragoneses et al. (2023) maps identified 12 and 9 models, respectively. These divergences intensify in structurally complex terrain (Fig. 5). While the Aragoneses et al. (2023) map (1 km) portrays LLKV as a largely homogeneous forest block, the Kutchartt et al. (2024) map (100 m) provides somewhat greater detail yet still generalizes transitional fuel types. In contrast, the CZE map (30 m) captures a fine-scale mosaic of GR, GS, SH, TL, TU and SB fuels that align with topography, stand structure, and local disturbances. This higher level of detail reflects the capacity of the proposed workflow to represent landscape heterogeneity (e.g., Taneja et al. 2021), enabled by the use of high-resolution input data (30 m), similar to current approaches in the United States (LANDFIRE n.d.–a).

These differences arise not only from spatial resolution but also from the conceptual framework. The methodology proposed in this study relies on structural metrics, particularly LAI, to differentiate between TL and TU fuels, whereas the Kutchartt et al. (2024) approach depends primarily on NDVI, which can saturate in dense canopies and thus overestimate closed-canopy conditions (Tian et al. 2025). The absence of GS fuels in both Kutchartt et al. (2024) and Aragoneses et al. (2023) further demonstrates that fine spatial detail is essential for detecting young stands and regenerating clearcuts - fuel complexes that have a strong influence on potential fire spread (Taneja et al. 2021). Similarly, disturbance-driven fuel patches (SB) are largely absent in the coarser European maps, limiting their applicability for operational planning.

The present classification differs from KUTCH and ARAG in that it includes only Scott and Burgan (2005) fuel models developed for dry-climate conditions. This choice was based on the represented vegetation structure and on the intended application of the classification, which focuses on wildfire conditions in Czechia. The exclusion of humid-climate fuel models should therefore not be interpreted as evidence that humid fuel conditions are absent from Central Europe, but rather as a reflection of the environmental conditions under which wildfire spread is most relevant. All original Scott and Burgan (2005) parameters, including the model-specific dead fuel moisture of extinction, were retained unchanged to preserve consistency with the standard fuel-model definitions. Because region-specific calibration data were not available, the suitability of these fuel models for Central European conditions was not independently evaluated in this study.

The comparison among the CZE, KUTCH, and ARAG products documents differences in fuel-model composition, spatial detail, and classification logic, but it does not establish their relative accuracy because none of the products represents an independent reference dataset. The coarser resolution of KUTCH and ARAG reflects their pan-European scope and does not imply that their underlying methodologies could not be applied using more detailed national data. The main contribution of the present study is therefore the integration of detailed national datasets and ecological information into an explicit 30-m workflow for the Czech Republic.

4.3 Influence of input layers on modeled fire behavior

Across all four fire behavior layers (rate of spread (ROS), flame length (FL), crown fire activity (CFA), and fireline intensity (FI)), the simulations driven by CZE inputs yielded higher values than those based on KUTCH inputs did (Fig. 6). Because the wind, fuel moisture, and crown-fire algorithms were maintained constant in both scenarios, the observed differences reflect the combined influence of the alternative landscape input frameworks. Importantly, the divergence between the CZE and Kutchartt et al. (2024) simulations is not driven by fuel models alone. Each framework used its corresponding complete set of FlamMap input layers, including canopy metrics and other structural variables, is used, as derived from different datasets (Kutchartt et al. 2024; CzechGlobe 2025). Consequently, all modeling layers, not only the fuel model map, differ between the two systems, and jointly contribute to the contrasting fire-behavior predictions. Therefore, this comparison does not isolate the independent effect of the fuel model map.

The purpose of this comparison was not to determine which input framework provides a more accurate representation of actual fire behavior, but to demonstrate the sensitivity of FlamMap outputs to the alternative input datasets available for the study area. Without independent observations of fire behavior, the relative accuracy of the two frameworks cannot be assessed. Although the finer spatial resolution of the CZE framework preserves more spatial detail, higher resolution alone does not demonstrate the quality or validity of the fuel map.

The higher values of the fire behavior metrics predicted by the CZE input layers likely reflects differences in how vegetation and fuel characteristics were parameterized compared with the methodology of

Kutchartt et al. (2024). In the CZE framework, regionally informed fuel model assignments and a more detailed stratification of forest types are incorporated, which may better capture the presence of dense coniferous stands and higher fuel loads typical of the study area. In contrast, the inputs from Kutchartt et al. (2024) are based on more generalized fuel categories, resulting in more conservative estimates of fire behavior. These methodological differences highlight the importance of region-specific fuel data and calibration when fire behavior models are applied, as input assumptions can substantially influence fire spread, intensity, and crown fire activity predictions.

These methodological differences highlight that region-specific fuel mapping and vegetation structure layers are important for representing spatial variability in fire behavior modeling, especially in fine-grained Central European landscapes. Even when atmospheric conditions are identical, divergent assumptions in the fuel model map and the associated spatial layers can substantially influence the predicted fire spread, intensity and crown-fire potential. This emphasizes the importance of regionally informed, high-resolution fuel and canopy datasets when dynamic fire-behavior models are applied in operational and landscape-risk contexts.

4.4 Next steps

As outlined in the Background, the present study is limited to the development of the fuel model classification methodology. The next phase of this work will focus on its systematic field evaluation and subsequent validation of fire behavior predictions.

To support the development of the proposed framework, preliminary field comparisons were performed to identify obvious inconsistencies and iteratively refine the classification rules. The preliminary comparisons confirmed that the proposed classification captured the major fuel type groups, but they were intended only to support methodology development. They were not collected within a systematic validation framework and should therefore not be interpreted as a systematic field evaluation.

The next step will be the development of a representative sampling design covering the major fuel model groups, stand structures, and site conditions represented in the FMCS. Representative plots will be selected using stratified random sampling. Fuel bed characteristics will be quantified using established field methods appropriate for the individual fuel components. Dead woody surface fuels will be estimated using the photoload method (Keane and Dickinson 2007) combined with double sampling (Tinkham et al. 2015). Live herbaceous and woody fuels will be quantified using vegetation cover and height measurements combined with double sampling, while herbaceous fuel loads in graminoid-dominated vegetation will be estimated using the Robel visual obstruction method (Robel et al. 1970). Additional descriptors of forest composition will be used to distinguish coniferous, deciduous, mixed, and nonforest fuel types where appropriate. The measured fuel bed characteristics will then be compared with the corresponding Scott and Burgan (2005) (pg 3) fuel model parameters to determine whether the proposed classification adequately represents local fuel conditions and to identify where regional calibration of individual fuel models is required while preserving compatibility with the standardized Scott and Burgan framework. The development of a descriptive fuel model catalogue,

including fuel-load data, representative photographs, and site descriptions, is planned as an important outcome of this work. The catalogue will provide a valuable resource for education, training, and future research on fire behavior and fuel characterization.

The final step will be the validation of fire behavior predictions against observations from documented wildfires and experimental fires. This stage evaluates the complete modeling framework rather than the fuel model classification alone, as predicted fire behavior also depends on terrain, weather, fuel moisture, and the selected fire behavior model. This work will build on the existing collaboration between the Fire Rescue Service of the Czech Republic and fire behavior researchers, ecologists, and climatologists, combining field observations, wildfire documentation, and fire behavior modeling. Building on the FlamMap application to the Bohemian Switzerland National Park wildfire (Kudláčková et al. 2023) future work will extend this approach to additional wildfire events representing a broader range of fuel types and environmental conditions.

5 Conclusions

This study presents a new methodology for applying the standard Scott and Burgan (2005) fuel classification using existing open-access national datasets and ecological characteristics of vegetation in the Czech Republic. It could serve as a basis for adaptation in other Central European regions, although its broader applicability has yet to be evaluated.

Although the methodology was developed for the Czech Republic, its general workflow may be transferable to other Central European countries. Comparable forest and land-cover datasets are increasingly available through pan-European sources, such as Copernicus products. However, the assignment of these datasets to the standard Scott and Burgan (2005) fuel models requires regional adaptation and calibration to account for local vegetation characteristics and fuel conditions. The resulting high-resolution fuel model maps and derived fire behavior characteristics provide applicable inputs for dynamic fire behavior modeling, thereby supporting assessments of potential fire development and offering a practical basis for preventive planning, operational decision-making, and conservation management purposes.

Overall, this work enhances the ability of land managers and emergency services to respond to the increasing wildfire risk under climate change and establishes a methodological foundation for further harmonized development of fuel mapping across Europe.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Clinical trial number

Not applicable.

Authors' information

ORCIDiDs

Kudláčková, Lucie. 0000-0002-3921-1601

Novotný, Jan. 0009-0004-1017-9160

Hlavsová, Monika. 0000-0003-1951-4290

Cienciala, Emil. 0000-0002-1254-4254

Dvořák, Jakub. 0000-0001-7845-7738

Poděbradská, Markéta. 0000-0002-3121-4904

Hasalová, Lucie. 0000-0002-4657-6254

Vystrčil, Václav. 0000-0001-5406-6652

Trnka, Miroslav. 0000-0003-4727-8379

Funding

The contributions of LK, JN, MH, and MT were supported by the Ministry of Education, Youth and Sports of the Czech Republic (grant AdAgriF —Advanced methods of greenhouse gases emission reduction and sequestration in agriculture and forest landscape for climate change mitigation (CZ.02.01.01/00/22_008/0004635)). The lead author's (LK&JB) work and manuscript development were also supported through OPSEC project no. VK02030092 (Increasing the Czech Republic's resilience to vegetation fires using advanced methods of modeling and wildfire weather prediction). The contributions MP was supported by Interreg Central Europe and the European Union within the framework of the

Author Contribution

All the authors contributed to the study conception and design. JN, LK and JD performed out the material preparation, data collection, and analysis. LK, JB, RM, MH and JN wrote the initial version of the manuscript, and all the authors provided feedback on the earlier version of the manuscript. All the authors have read and approved the final manuscript.

Acknowledgements

Not applicable.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available because they are owned by a third party and the terms used prevent public distribution, but they are available from the corresponding author on reasonable request.

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54. Appendix.
55. A.1. *Detailed datasets used for classification 1. Vector layer: consolidated layer of ecosystems (KVES)*, Nature Conservation Agency of the Czech Republic (AOPK).

56. <https://portal.nature.cz/w/konsolidovana-vrstva-ekosystemu-2023-kves->
57. open data.
58. last updated in. 2023; nominal mapping scale: 1:10,000.
59. a seamless land. -cover layer dividing the territory of the Czech Republic into 40 categories.
60. Used for the following.
61. identifying ecosystem types. *located outside the forest habitats classified above 2.*Raster layer: forest tree species, Czech Forestry Institute (NLI).
62. <https://geoportal.uhul.cz/mapy/MapyDpz.html>
63. nonopen data, WMS.
64. last updated in 2022; spatial resolution: 3 m.
65. tree species layer derived from remote sensing data; provides information on stand tree species composition (9 categories: spruce, pine, beech, oak, other conifers – mixed, other broadleaved species, dwarf pine, plantation, and harvest).
66. Used for the following.
67. distinguishing forest and nonforest habitats.
68. determining the dominant. tree species composition (pine – pine + dwarf pine; other conifers – spruce + other conifers; broadleaved species – beech + oak + other broadleaved species; undefined – plantation + harvest) 3.Raster layer: forest stand growth stages, Czech Forestry Institute (NLI).
69. <https://geoportal.uhul.cz/mapy/MapyDpz.html>
70. nonopen data, WMS.
71. last updated in 2022; spatial resolution: 2 m.
72. the layer was derived via the segmentation of a normalized digital surface model (nDSM. 2019/2020) and contains aggregated information on the forest stand growth stage (clearcut, plantation, regeneration, pole stage, maturing stemwood, and mature stemwood).
73. Used for the following.
74. determining stand age classes by forest stand growth. stage (clearcut, plantation, regeneration – up to 10 years; pole stage – 11–30 years; maturing stemwood – 31–60 years; mature stemwood – over 60 years) 4.Raster layer: leaf area index (LAI), Czech Forestry Institute (NLI).
75. <https://trendy.uhul.cz/index-listove-plochy>
76. open data.
77. last updated in 2023; spatial resolution 20 m.
78. the layer. represents the annual values of the leaf area index (LAI).
79. Used for the following.
80. determining canopy closure categories (open stands. $LAI \leq 2.0$; *sparse stands: $2.0 < LAI \leq 2.5$; closed stands: $LAI > 2.5$*) 5.Vector layer: forest typology, Czech Forestry Institute (NLI).
81. <https://geoportal.uhul.cz/mapy/MapyOprl.html>

82. nonopen data, WMS.
83. last updated in. 1996. 2022; *nominal mapping scale: 1:10,000 or more detailed*. Ministry of Agriculture of the Czech Republic.
84. the forest site. typology map contains information (among other attributes) on the represented forest site type groups (185 categories).
85. Used for the following.
86. determining site productivity. potential related to the fuel bed depth (A, B, and C; more details are provided in Appendix Tables A4 and A5) 6.Vector layer: zoning of large-size specially protected areas, Nature Conservation Agency of the Czech Republic (AOPK).
87. https://gis-aopkcr.opendata.arcgis.com/datasets/1f82e49b9bf5418a82f076e5f1f7e9cc_1/explore
88. open data.
89. last updated in. 2023; nominal mapping scale: 1:25,000.
90. contains information on the. *boundaries of conservation zones within large-scale protected areas, including national parks (NP) and protected landscape areas (CHKO)*.
91. Used for the following.
92. identifying nonintervention zones (Zone A in NPs and Zone I in CHKO) 7.Vector layer: bark-beetle infestation map, Czech Forestry Institute (NLI).
93. <https://ga.nli.gov.cz/DsNli/Dpz/>
94. nonopen data, WMS.
95. last updated. in 9/2023; derived from PlanetScope satellite imagery with a spatial resolution of 6–8 m.
96. detection of standing dead. 2023. trees and salvage logging based on remote sensing data for multiple time horizons (September 2019–September).
97. Used for the following.
98. updating previous layers. *to account for newly formed clearcuts and determining the proportion of standing dead trees* 8.Vector layer: *permanent grassland from Fundamental Base of Geographic Data of the Czech Republic (ZABAGED)*, State Administration of Land Surveying and Cadastre (ČÚZK).
99. [https://geoportal.cuzk.cz/\(S\(mvhxpfwzu0lijls3rdy0wejm\)\)/Default.aspx?lng=CZ&mode=TextMeta&side=zabaged&metadataID=CZ-CUZK-ZABAGED-VP&mapid=8&menu=241](https://geoportal.cuzk.cz/(S(mvhxpfwzu0lijls3rdy0wejm))/Default.aspx?lng=CZ&mode=TextMeta&side=zabaged&metadataID=CZ-CUZK-ZABAGED-VP&mapid=8&menu=241)
100. open data.
101. last updated in. 2024; level of detail corresponding to the 1:10,000 Basic Map of the Czech Republic.
102. a layer. of spatial objects characterizing a given land-cover type.
103. Used for the following.
104. for delineating permanent. grasslands (PG) from the broader KVES category degraded grassland 9.Czech Land Parcel Identification System (LPIS), cereal and oilseed crop areas.

105. <https://mze.gov.cz/public/portal/mze/farmar/LPIS/export-lpis-rocn-shp>
106. open data.
107. last updated in 2024.
108. Crop. layer.
109. Used for the following.
110. delineating cereal and. oilseed crop areas from the broader KVES category arable land.
111. A.2. *Implementation of forest typology* (forest type classification).
112. On the basis of growth conditions, we distinguished three levels. of the decomposition rate of dead wood because this parameter significantly affects the amount of available fuel in litter. Decomposition is influenced by temperature, humidity, and nutrient availability. Under drier and colder conditions, which are unfavorable for decomposition, the accumulation of undecomposed organic material in various dimensions can occur, including from the perspective of the combustion of the riskiest group with a size of up to 0.6 cm (1 h of fuel). When assessing the thickness of the layer of flammable material in natural and near-natural ecosystems, it is necessary to consider the management method and the intensity of cultivation affecting decomposition and ground vegetation, which can influence the rate of fire spread under the condition of low biomass humidity.
113. The categorization of. individual forest types according to their expected potential in relation to the thickness of fuel layers A, B, and C is provided in the (Tables A4 and A5), especially for stands with a predominance of deciduous or coniferous trees.
114. Site conditions correspond. to fuel models that are characterized by a lower fuel layer and small volume. The fuel models represent different age stages of stands at the poorest and driest sites with expected low production levels.
115. The site represents a wide. range of average conditions in terms of the production potential of trees and the rate of decomposition of organic material. The conditions correspond to fuel models that are characterized by a greater thickness of the fuel layer. Sites in category B cover most of the area of the mid- and high-altitude areas of the Czech Republic; extreme sites are not included. The limiting factor for tree growth is the water regime rather than the quality and thickness of the soil.
116. In the case of stands with a predominance of deciduous trees, stands that grow under optimal conditions in terms of nutrient supply and available moisture fall into this category. These areas include enriched soils on stony stands at lower and middle altitudes and stands of deciduous trees growing in rich to lush glaciated stands.
117. Select fuel models are assigned to the corresponding forest ecosystems across the abovementioned habitat categories. These include, for example, all the involved pine stands over approximately 10 years old, which involve stands in zones left to develop spontaneously in large-scale, especially protected areas or stands with a high proportion of standing land. In this case, characteristics other than the potential of the habitat are more important for assigning the correct fuel model. 8.1Appendix Tables.

Figures

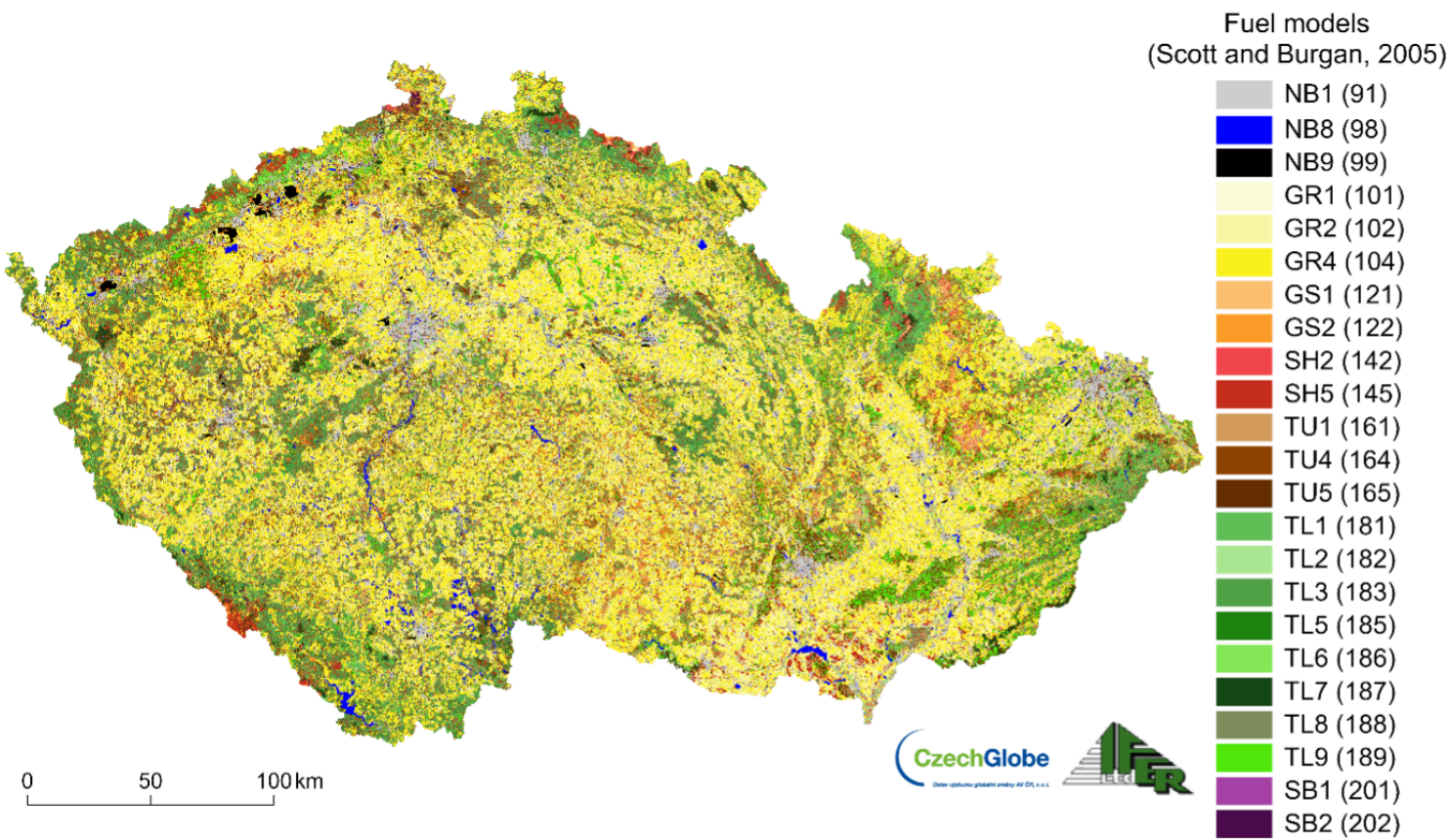


Figure 1

Schematic representation of the fuel model classification workflow based on remote sensing inputs.

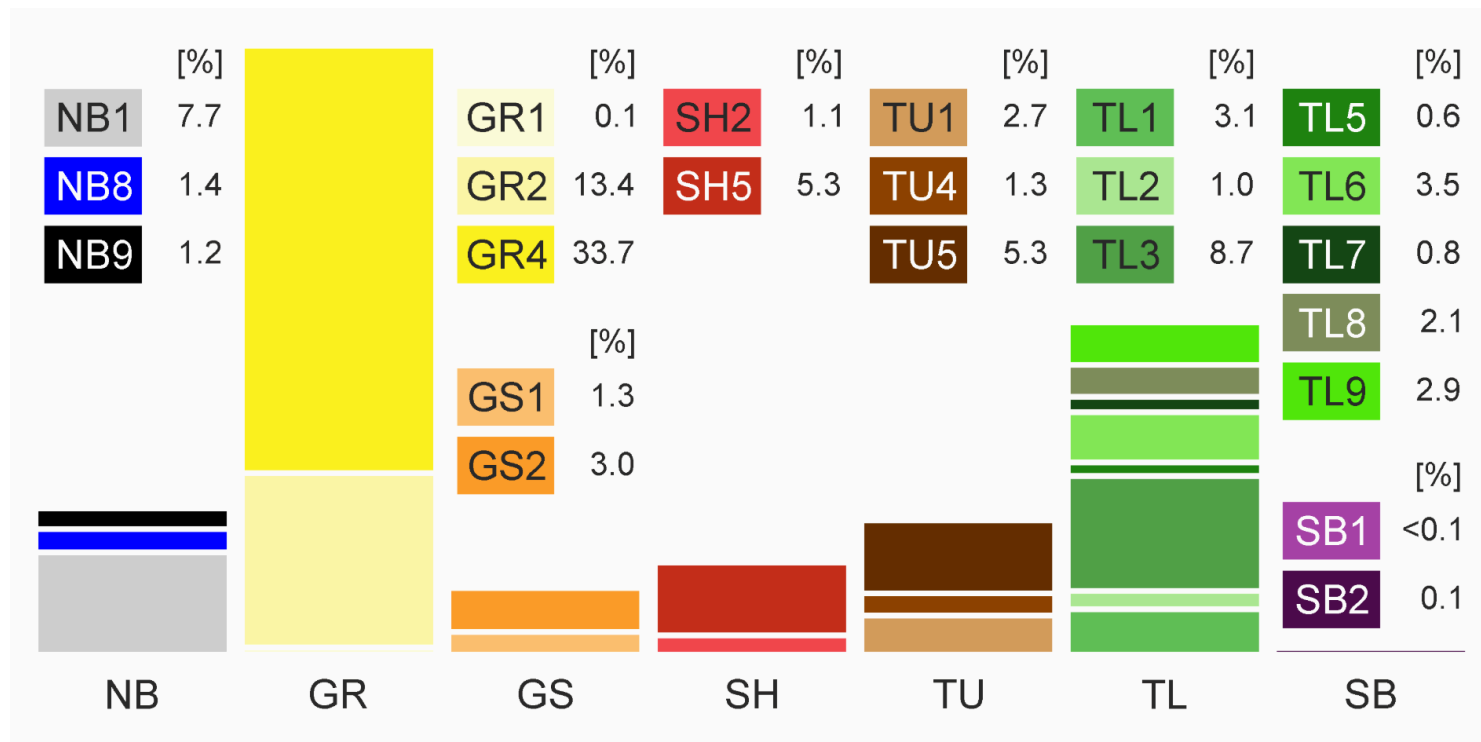


Figure 2

Fuel model classification system developed for the Czech Republic using the methodology proposed in this study

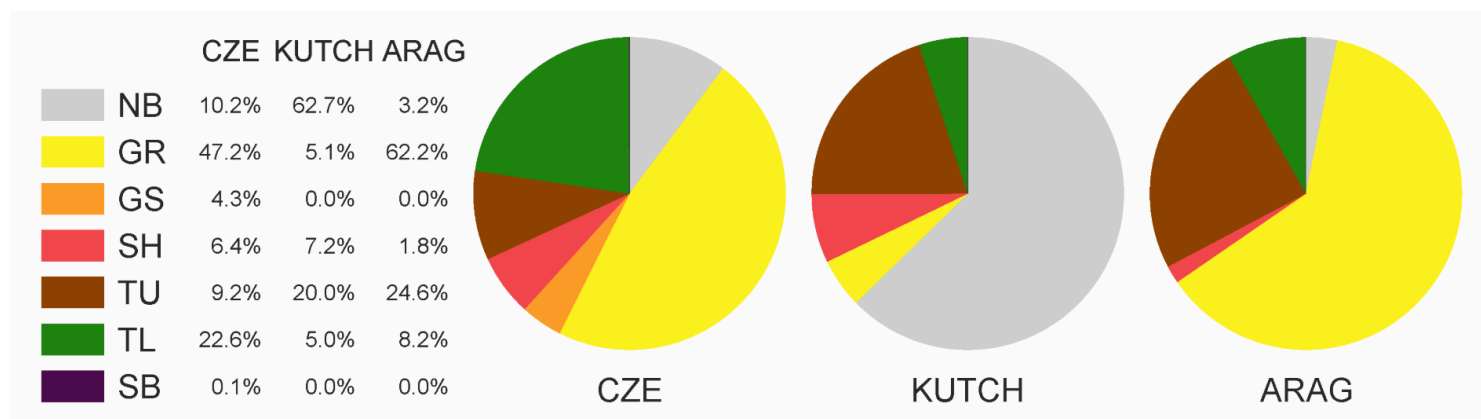


Figure 3

Percentage of the area in the Czech Republic covered by different fuel model classes (Scott and Burgan, 2005). The bar heights illustrate the relative proportions of the fuel model classes, while the corresponding percentages are shown numerically using the same corresponding color coding. Fuel model categories are abbreviated as follows: nonburnable (NB), grass (GR), grass–shrub (GS), shrub (SH), timber–understory (TU), timber–litter (TL), and slash–blowdown (SB).

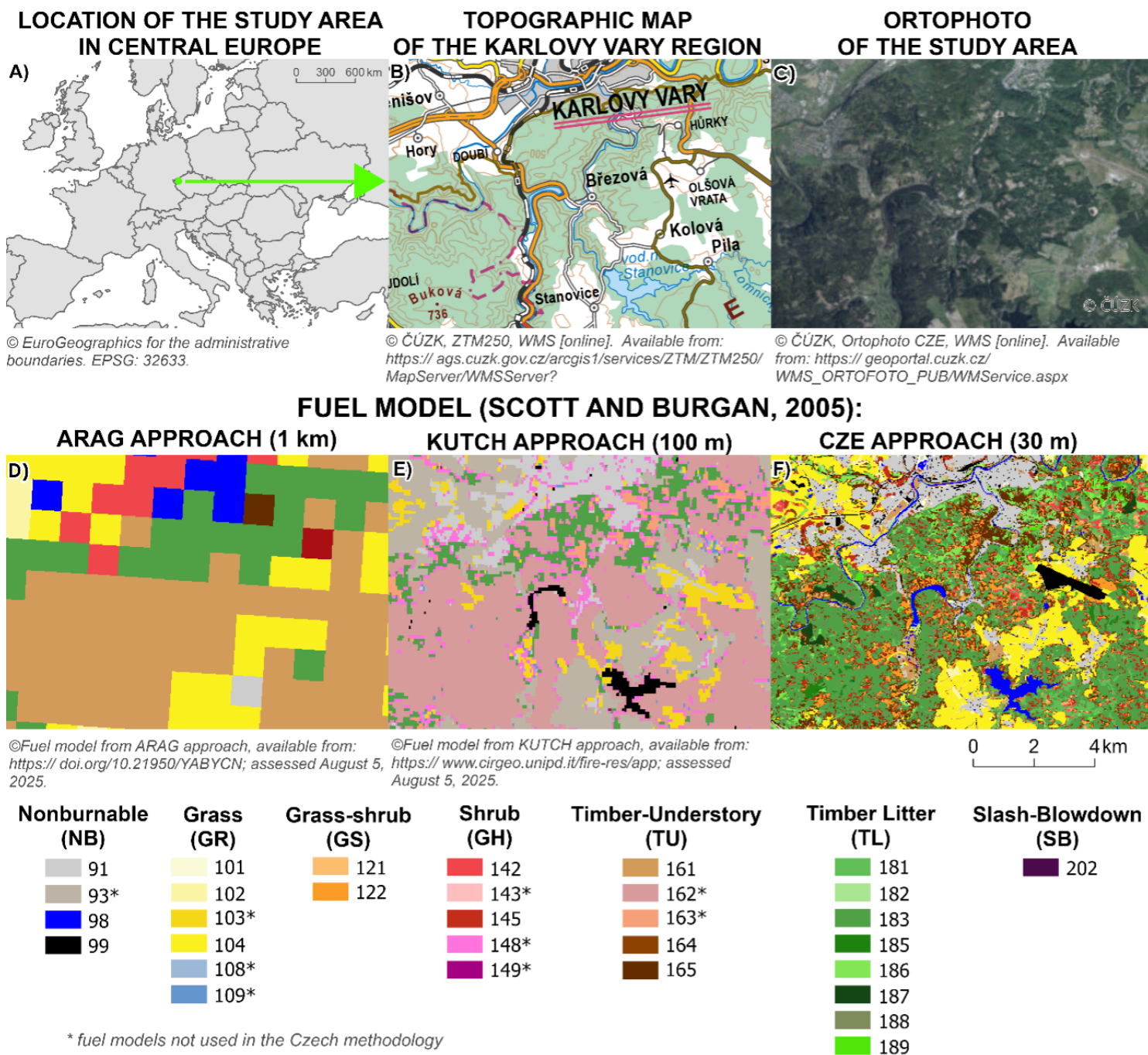


Figure 4

Percentage of the area in the Czech Republic covered by different fuel model classes (Scott and Burgan, 2005). The bar heights illustrate the relative proportions of the fuel model classes, while the corresponding percentages are shown numerically using the same corresponding color coding. Fuel model categories are abbreviated as follows: nonburnable (NB), grass (GR), grass–shrub (GS), shrub (SH), timber–understory (TU), timber–litter (TL), and slash–blowdown (SB).

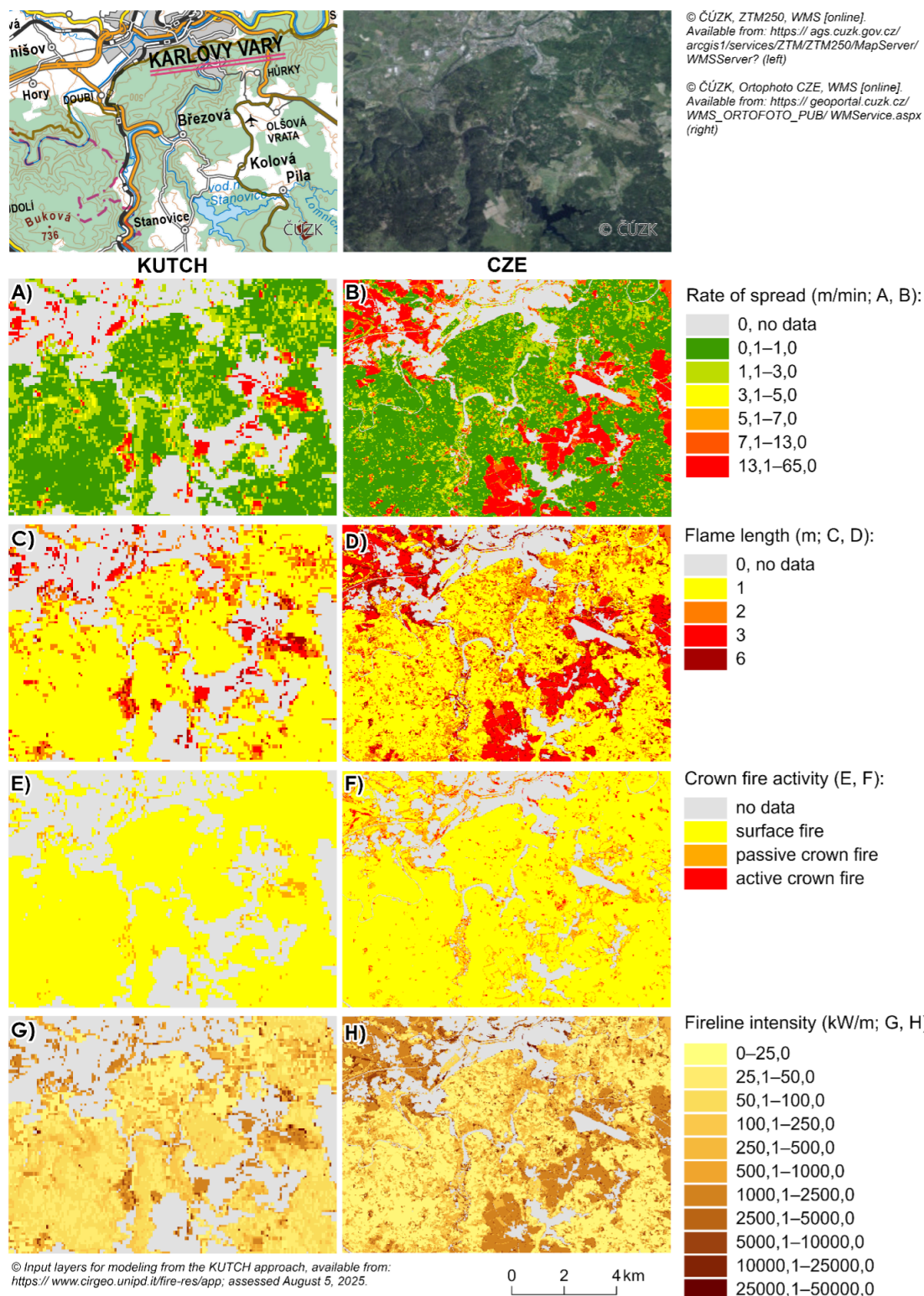


Figure 5

Location and characteristics of the study area. Top row: (A) location of the Czech Republic in Central Europe, (B) topographic map of the Karlovy Vary region, and (C) orthophoto of the selected area. Bottom row: Differences in fuel model classification based on available European maps: (D) Aragoneses et al. (2023; ARAG) approach at a 1-km resolution, (E) Kutchartt et al. (2024; KUTCH) approach at a 100-m resolution, and (F) approach proposed in this study at a 30-m resolution (CZE).

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