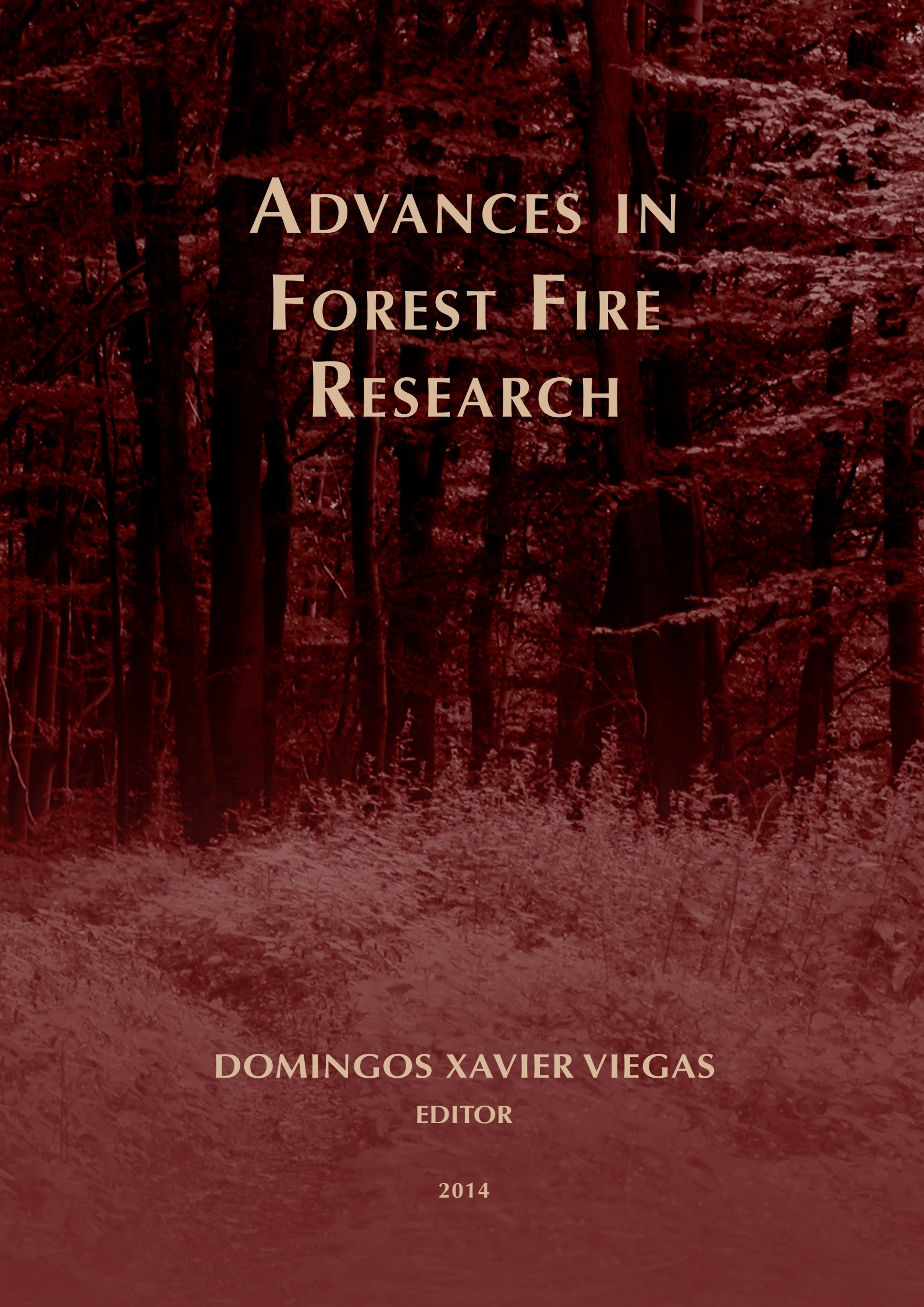

Advances in Forest Fire Research

DOMINGOS XAVIER VIEGAS

EDITOR

2014

Mapping of forest habitats vulnerable to fires using Corine Land Cover database and digital terrain model

Edyta Woźniak[a], Mirosław Kwiatkowski[b], Bartłomiej Kołakowski[c]

[a] *Space Research Center, Bartycka 18A, 00-716 Warszawa, e-mail: ewozniak@cbk.waw.pl*
[b,c] *Forest Research Institute, Sękocin Stary, Braci Leśnej 3, 05-090 Raszyn, m.kwiatkowski@ibles.waw.pl, b.kolakowski@ibles.waw.pl*

Abstract
An appropriate system of fire detection and proper preparation of the forested areas for emergency and fire extinguishing activities have a significant impact on the magnitude of losses caused by forest fires. The basis of the forest fire protection planning is the forest categorisation in the context of fire risk, which is performed on the basis of the percentage of area covered by the most vulnerable habitats: dry coniferous, fresh coniferous, fresh mixed coniferous, wet coniferous, wet mixed coniferous and riparian forest. Maps of forest habitat are available for the State Forests however for private forests this information does not exist, so the proper categorisation of fire risk in these forests is very difficult and costly. The object of the study is to develop a method for the estimation of the area cover of the above-mentioned forest habitats using open source data Corine Land Cover (CLC) database and SRTM - Digital Terrain Model in order to fill the information gaps for the private forests. Employing GIS environment the analysis of the correlation between CLC land cover classes and specific forest habitat was performed. Then, the terrain characteristics such as curvature and slope were correlated with habitat humidity. Also, the shape analysis of units was carried out. On the basis of these three parameters was estimated the areas covered by fire vulnerable habitats for forest inspectorates in central and north-west Poland where the state forests constitute 98% of the area so the ground verification data was accessible for almost the entire terrain. The overall agreement between obtained and reference maps is 89%, and the error of the estimation of the specific fire vulnerable habitats is lower than 20%. The proposed method is relatively fast and low-cost and may be used for fire risk categorisation of the forested areas where the ground verification information is not available.

Keywords*: fire detection, Corine Land Cover (CLC), forest habitat*

1. Introduction

The appropriate organisation of the fire detection system and preparation of forest areas to conduct prevention-extinguishing activities has a significant influence on the size of losses caused by forest fire. The basis for planning activities in the extent of forest fire protection is the forest fire risk category (KZPL). It is determined according to the requirements specified in the Ordinance of the Minister of the Environment of the 22nd of March 2006 concerning detailed principles of forest fire protection of forests (Journal of Laws No. 58 entry 405 with subsequent amendments). It concerns forests of a similar level of susceptibility to fire, established on the basis of frequency of fire occurrence, stand and climatic conditions and anthropogenic factors. This category is established on the basis of the sum of points resulting from calculations for four, following parameters:

a) average annual number of forest fires in the period of the last 10 years per thousand hectares of afforested area,
b) sums of percentage participation of stands growing in habitats: dry forest, fresh forest, moist forest, moist mixed forest and riparian forest,
c) average relative air humidity at height of 0.5 m and percentage of days with air humidity less than 15% at the hour of 9.00,
d) average number of inhabitants per hectare of forest area.

The range of forest habitat types (STL) considered in the establishment of KZPL results from analysis of flammability of forests presented in the study "Categorisation of fire risk of Polish forests" (Szczygieł *et al*. 2009, in which to categorise flammability is used the flammability indicator, being the quotient of the share of the number of fires of given stands to the areas of these stands. As flammable habitats, the share of which is influences KZPL, those are recognised, for which this indicator is greater than the units. They are: dry coniferous forest (Bs)-4.39, moist coniferous (Bw)-1.81, fresh coniferous forest (Bśw)-1.66, fresh mixed broadleaved forest (BMśw)-1.30, moist mixed coniferous forest (BMw)-1.18 and riparian forest (Lł)-1.03.
Insofar as for forests managed by State Forests National Forest Holding the decisions of KZPL do not give rise to greater difficulties and are updated each time while drawing up forest management plans, to that extent for remaining forests, principally private, its decisions cause significant difficulties. This is connected primarily with the lack of detailed information, concerning the proportion of surface area covered by particular forest habitat types. In individual provinces these forests consist of from 2.9 to 54.2 per cent of the afforested area. Equally the density of occurrence of fires in particular years in the period 2003-2012, as also the average area of one fire are clearly greater for forests in other forms of ownership, in comparison to forests managed by State Forests (Figure 1).

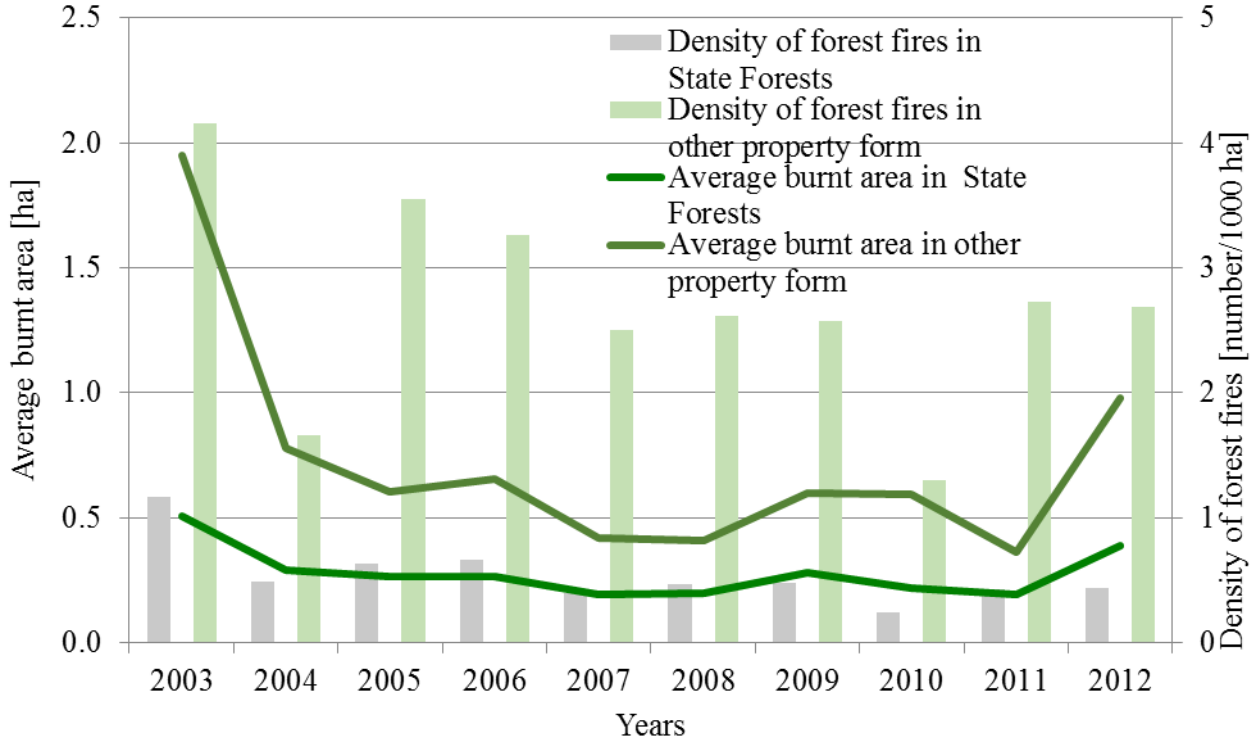

Figure 1. The occurrence of forest fires in the years 2003-2012

Density of occurrence of fires in State Forests is fivefold less in comparison to forests in other forms of ownership, fluctuating in particular years between 3.4 and 6.4. Equally the average area of a single forest fire in forests in other forms of ownership is significantly greater (from 1.9 to 3.8) than in State Forests. In this situation it is essential to seek a method determining the proportion of surface area taken by habitats Bs, Bw, Bśw, BMśw, BMw, Lł, enabling appropriate determination of KZPL for these forests, and in consequence appropriate preparation of forest areas for the conduct of prevention-extinguishing activities. This problem is diligently solved by drawing up a modelling method for proportion of selected forest habitat types on the basis of the Corine Land Cover land-use map and numerical terrain models.

Comparative works to the CORINE maps and models exist in the databases of national forest maps and for defining its suitability in forest cartography on regional scales (Waser, Schwarz, 2006). Because of the great generalisation of information, direct interpolation of data is not possible, especially in mountainous areas typified by great heterogeneity. In such a situation it is essential to use various auxiliary materials in order to increase the spatial resolution of CORINE. Such assumptions were accepted by Pekkarinen *et al*. (2009) in the cartography of afforested areas. It is simultaneously supported by Landsat ETM+ satellite photographs. In the work presented below the increase of CORINE spatial resolution is obtained by use of numerical terrain model.

2. Area of research

For the purpose of drawing up the habitat designation method two research areas were chosen. The first research area served as a research area, the second as a testing area. For the research area was chosen the territory of the following Forest Districts: Dobieszyn, Kozienice, Marcule, Radom and Zwoleń of a combined area of approximately 500 000 ha, among which almost 63 000 ha is covered by forest, managed by these forest districts. The combined area of forests on the territory of these forest districts according to CORINE amounts to 101 816 ha. The basic characteristic of the stands of these forest districts in comparison to conditions for the area of all Poland is shown in figures 2-4. These forest districts are typified by proportions of high flammability class habitats: dry coniferous forest, fresh coniferous forest, moist coniferous forest, fresh mixed broadleaved forest, moist mixed broadleaved forest and riparian forest that are close to the national average. Equally the distribution of forests in specified age group is similar to the national average. In relation to Polish forests as a whole, in these forest districts there is an approximately 20% greater proportion of pine stands.

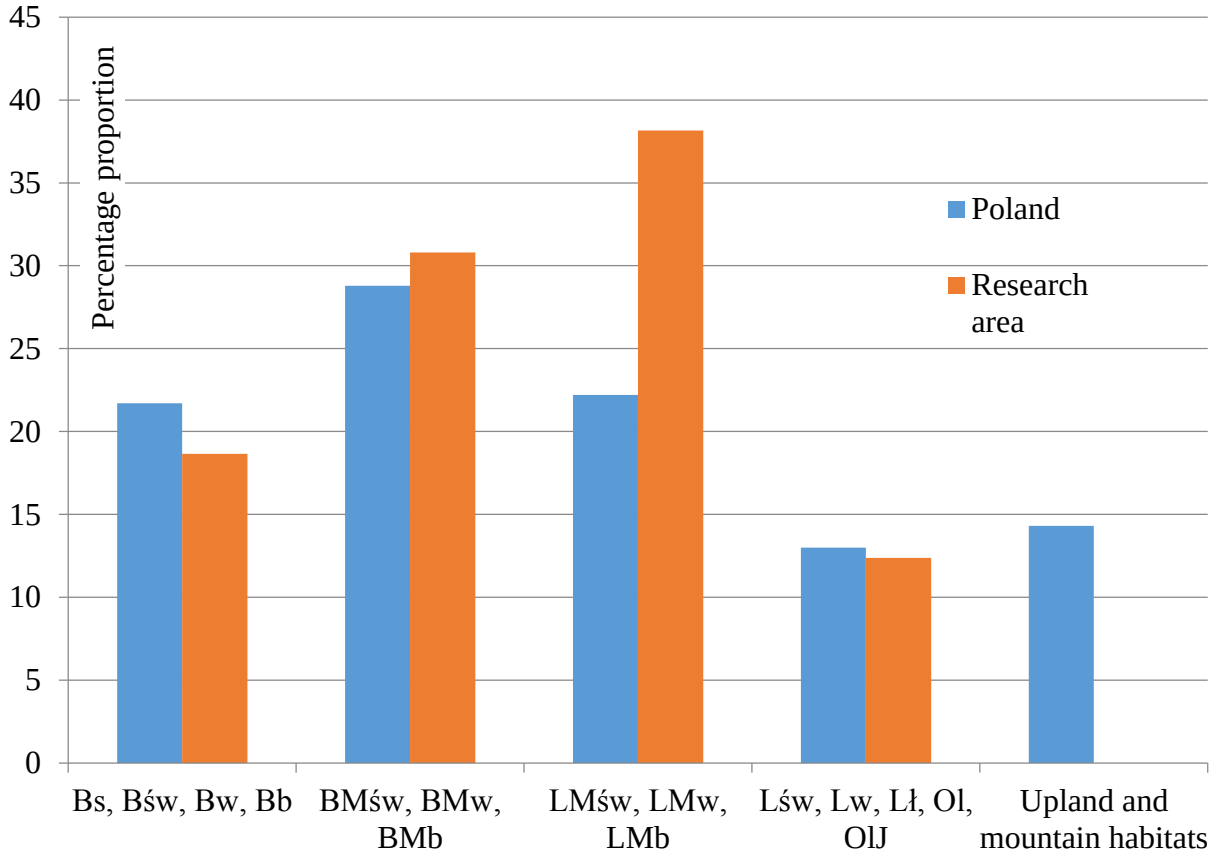

Figure 2. Percentage proportion of stands according to forest habitat types

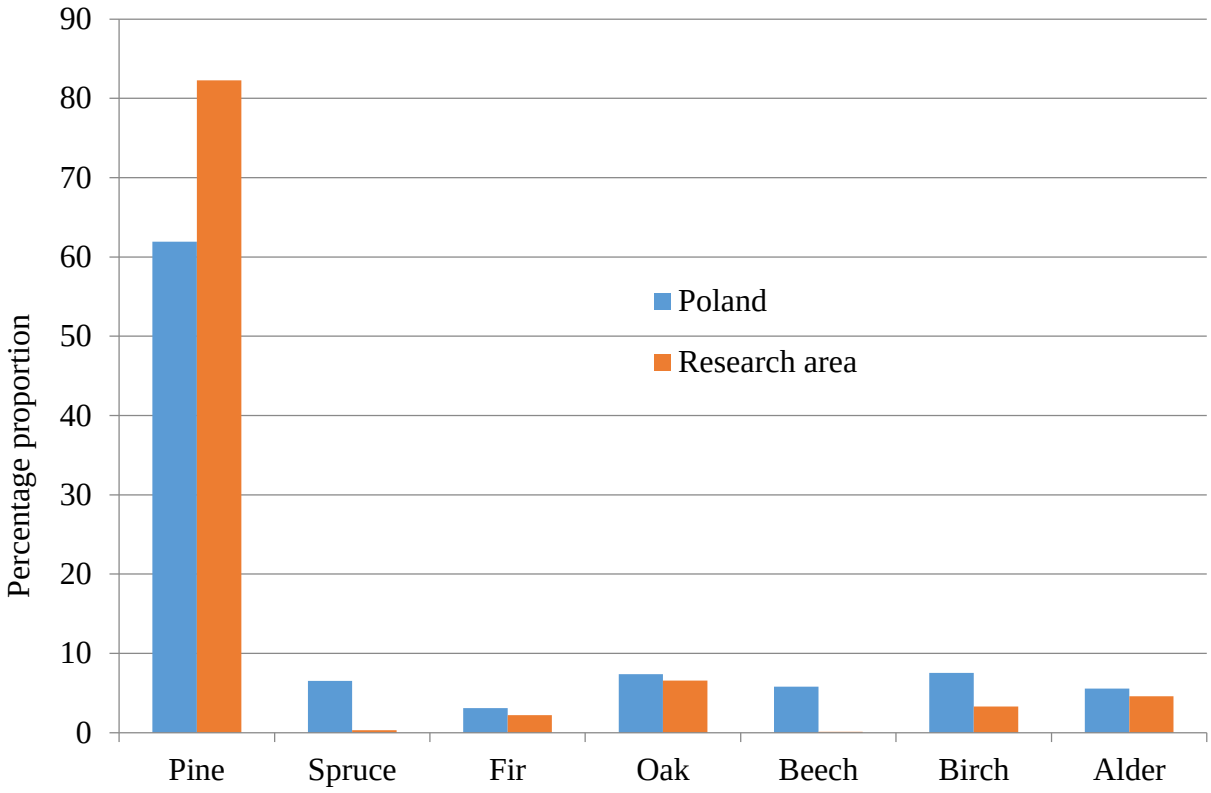

Figure 3. Percentage proportion of stands according to prevailing species

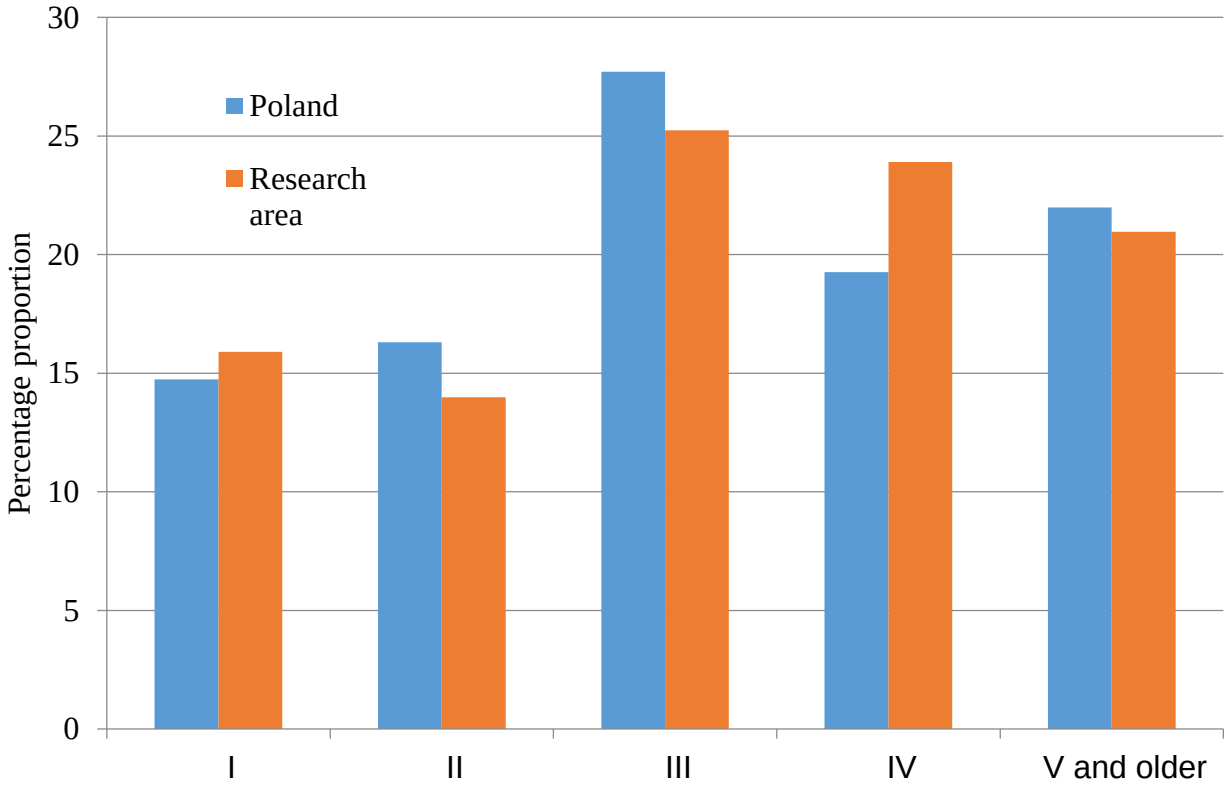

Figure 4. Percentage proportion of stands according to stands age

In the verification of the drawn up method it was applied to the area of forest districts within the whole or part of the province of Western Pomerania (57 forest districts). This area was chosen with regard to the virtually 98% share of state forests in the ownership structure of forests in the given province.

3. Source data

In the study, data generally available with the aid of Internet services was used. The basis for the performance of the work was the terrain use data CORINE Land Cover – CLC2000 and also data of the numerical terrain model SRTM (Shuttle Radar Topography Mission). For reference material the Forest Numerical Map supplied from the State Forests database was used.

3.1. CORINE Land Cover 2000 Database

The CLC2000 database is constructed in three hierarchical levels. The first level (European) differentiates 5 basic groups of terrain cover, agricultural, forest and semi natural ecosystems, boggy terrains and water. The second level (regional) separates 15 classes and the third (national) distinguishes 44 classes, of which 31 occur within Poland. In the study only three classes are used from the third group - forests and semi natural ecosystems: 3.1.1 deciduous (broadleaved) forests, 3.1.2 coniferous forests, 3.1.3 mixed forests. Their definitions are placed below.

Deciduous forest - code 3.1.1. - This class includes botanical communities consisting primarily of trees, with regard to the undergrowth layer, where deciduous species are dominant. The crowns of the trees should cover over 30% of the surface and deciduous trees should represent over 75% of the stand. The height of trees of this class should exceed 5 m in normal climatic conditions.
Coniferous forest - code 3.1.2. - Flora classified as coniferous forest should consist primarily of trees, with regard to the undergrowth layer, where coniferous species are dominant. Similarly to the deciduous forests the height of the trees in this class should exceed 5 m. Coniferous trees should represent over 75% of the stand.
Mixed forest - code 3.1.3. - General class definition is similar to the preceding cases i.e. flora should consist primarily of trees, with regard to the undergrowth layer and height of trees in this class should exceed 5 m. Nonetheless however percentage participation of deciduous or coniferous may not be dominant.

CORINE Land Cover map sheets covering the study terrain were taken from the website of the European Environment Agency (European Environment Agency) http://www.eea.europa.eu/themes/landuse/interactive/clc-download in .shp. format. Subsequently the reproduction of the maps obtained was changed to UTM zone 34, reference system WSG84.

3.2. Numerical Terrain Model

Numerical Terrain Model (NMT) SRTM was obtained for Polish terrain from the website http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp in format GeoTiff. This model has spatial definition of 80 m. For the needs of the work the terrain definition of the model was increased to 30 m. The sheets taken were joined in one layer and the reproduction was changed to UTM zone 34, reference system WGS84. Then two types of errors occurring in the model were located: height value anomaly, above 2600 m above sea level and lacking pixels and designated as no data. Corrected anomalous pixel values and supplementation of lacking pixels through interpolation with nearest surroundings.

3.3. Numerical forest map

Reference data are obtained from Numerical Forest Map, which contained basic data concerning all designated forest areas lying within the boundaries of the research polygon. These areas are designated

during the drawing up of forest management plans for piece of land constituting a part of uniform forest section with regard to biotope and biotic forest community. For each of these data is available relating to:

- forest habitat type,
- layered vertical zones structure,
- area,
- layer structure,
- species composition,
- age of stand
- height of stand
- density.

4. Methodology and results of studies

4.1. Analysis of occurrence of CLC terrain cover class and types of forest habitats.

In order to verify the comparability of data of particular habitat types they were pre-classified according to CORINE nomenclature, those in which percentage share of coniferous trees in the stand exceeded 80% were classified as class 3.1.2, those in which percentage share of deciduous trees in the stand exceeded 80% were classified as class 3.1.1 and the remainder as mixed 3.1.3. Percentage proportional quantities of particular CLC classes in succeeding habitat types being the object of interest are shown in table 1. From the table it is seen that with a very high probability it may be stated, that CLC classes of coniferous and mixed forests shall correspond to forest classes on forest map. Riparian forest habitat type completely fulfils the criterion of CLC deciduous forest. Remaining types in an exceptional majority correspond to CLC criterion for deciduous or mixed forest degree.

Table 1. Percentage share of quantity allocation of specific classes of Corine Land Cover in analysed habitat types.

Habitat type	CLC 3.1.1	CLC 3.1.2	CLC 3.1.3
Dry coniferous forest	2%	89%	9%
Moist coniferous forest	4%	74%	22%
Fresh coniferous forest	4%	67%	29%
Fresh mixed coniferous forest	4%	52%	44%
Moist mixed broadleaved forest	10%	36%	54%
Riparian forest	98%	0%	2%
Other forests	65%	15%	20%

4.2. Study of profile indicators on the basis of numerical terrain model to achieve a more detailed localisation of habitats

Each habitat is associated with a specific genetic soil type, which in turn is associated with the sediment deposit type, from which it is created. Depending on the origin and mechanical composition of deposit subjected to various types of geomorphologic processes and differing intensities, it is reflected in the shape of the terrain. The predominant part of Poland is covered with Quarternary formations of glacial, water, river, lake and aeolian origin. Various types of loose sands, clay sands, clays, dusts or silts dominate. Bearing in mind equally: origin, manner of settlement, resistance to processes occurring on the surface, as also age of deposit it may with considerable generalisation be stated, that terrains constructed of older substrates are flatter, and those in areas with a sandy substrate have a less varied terrain topography. Together with increase of the values of silts in surface formations, reaching the level of heavy clay, the morphological sculpting is ever more varied. Areas formed from silts are typified by a large quantity of deep cut ravines. Areas formed from silts are normally flat. This is the result of sedimentation processes, which lead to the creation of geological formations.

On the basis of the numerical terrain model the degree of terrain topography variation may be defined through definition of two parameters: terrain inclination and its curvature (Zeverbergen, Thorne, 1987, Moore *et al*. 1991). Variable terrain inclination is generally known and does not require further comment, if however it concerns curvature of terrain this defines three basic situations: flat terrains, concave terrains and convex terrains.
In table 2 are shown an average dimensions of standard deviation values, and also span of extent of terrain curvature and inclination of slopes for particular types of forests, with the exception of dry coniferous forest, the rare appearance of which in the studied terrain prevented taking the appropriate samples. From the table it is shown that terrain curvature enables separation of fresh and moist habitats. Fresh habitats are typified by an average terrain curvature exceeding 0, corresponding to areas with "curvature" dominance, moist habitats though are typified by values less than 0.006, corresponding to "concave". Mixed forest habitats are characterised by greater deviation of standard terrain inclination.

Table 2. Values of terrain shaping indicators for forest habitats

	Incline of slopes			**Curvature**		
STL forest types	Variation extent	Average	Standard deviation	Variation extent	Average	Standard deviation
Fresh coniferous	5.5874	1.2071	**0.8887**	0.6719	**0.0071**	0.0644
Fresh mixed forest	7.2093	1.1821	**0.9588**	0.6563	**0.0070**	0.0600
Moist mixed forest	6.0675	1.2246	**0.9511**	0.4688	**-0.0022**	0.0581
Moist coniferous	3.4723	1.0994	**0.8445**	0.3438	**-0.0048**	0.0590

4.3. **Study of terrain shape indicators to achieve very detailed habitat localisation.**

Shaping indicators may provide information on circularity, extension and degree of complication of polygons. In the case of definition of types of forest habitats, shape parameters have great significance in the emergence of riparian forests among all deciduous forests. The PARA shape indicator being the relationship of the polygon circumference to its surface area describes the degree of elongation of polygons or their shape complication. Poligony, for which the PARA indicator is less than 0.007, does not correspond to riparian forest shape criteria. Polygons described in PARA with greater value than given threshold value may be riparian forests, but additional criteria are necessary in order to separate them from other forests with an elongated shape.

4.4. **Developing method of habitats designation on the basis of CLC and previously enumerated indicators.**

With regard to excessive numbers of polygons for showing on CLC maps (minimal area 25 ha) additional terrain division was made. Utilising the numerical terrain model, areas were designated every 30 m of height, and then CLC polygons were "fragmented" with the use of the designated areas. Thus was segmentation achieved of terrain surface polygons, which enabled the obtaining of more precise statistics for smaller polygons. For particular habitats of high flammability groups a procedure was drawn up leading to the imaging of the given habitat on map. Dry coniferous forest constitutes an exception, because of the very small statistical size of the classification. Basic layers used to designate these habitats are: CORINE Land Cover (CLC) map and also those received from numerical terrain model of declines and curvatures. In some instances other variables were also used, which were described together with the necessitating case.

Moist coniferous forest was designated on the basis of the following routine:

1. polygons coded as coniferous forest were selected from the CLC map (3.1.2),
2. average terrain curvature and standard deviation from terrain inclination values were calculated for the selected polygons,
3. polygons of curvature less than 0.006 and standard deviation of terrain inclination less than 0.9 were reclassified as moist coniferous forest. Fresh coniferous forest was designated on the basis of the following routine:
4. polygons coded as coniferous forest were selected from the CLC map (3.1.2),
5. average values of terrain curvature and standard deviation of terrain inclination were calculated for the selected polygons,
6. polygons of curvature greater than 0.006 and standard deviation of terrain inclination less than 0.9 were reclassified as fresh coniferous forest. Fresh mixed coniferous forest was designated on the basis of the following routine:
7. polygons coded as coniferous forests were selected from the CLC map (3.1.2),
8. average values of terrain curvature and standard deviation of terrain inclination were calculated for the selected polygons,
9. polygons of curvature greater than 0.006 and less than 0.02 and standard deviation of terrain inclination greater than 0.9 were reclassified as fresh coniferous forest,
10. polygons coded as mixed coniferous forest were selected from the CLC map (3.1.3),
11. polygons of curvature less than 0.007. Moist mixed forest was designated on the basis of the following routine:
12. polygons coded as coniferous forest (3.1.2), were selected from the CLC map
13. average values of terrain curvature and standard deviation of terrain inclination were calculated for the selected polygons,
14. polygons of curvature less than 0.006 and standard deviation of terrain inclination greater than 0.9 were reclassified as fresh coniferous forest. Riparian forest was designated on the basis is the following routine:
15. polygons coded as deciduous forest (3.1.1) were selected from the CLC map
16. PARA indicator values were calculated for selected polygons,
17. selected polygons of PARA indicator greater than 0.007,
18. water flows system was generated from the numerical terrain model,
19. only those deciduous forests were classified as riparian forests, which fulfilled the condition of elongated shape and at least partially covered with water flows and having a surface area less than 500 ha.

4.5. **Method validation**

Habitat maps received with the aid of described procedures were compared with the Digital Forest Map. Analysis was conducted of the percentage surface share taken by particular habitats (figure 5). A large conformity of results is visible, though an increased share of riparian forest habitats should be noted. Perhaps is a result of fact that they are mainly outside the area of State Forests.

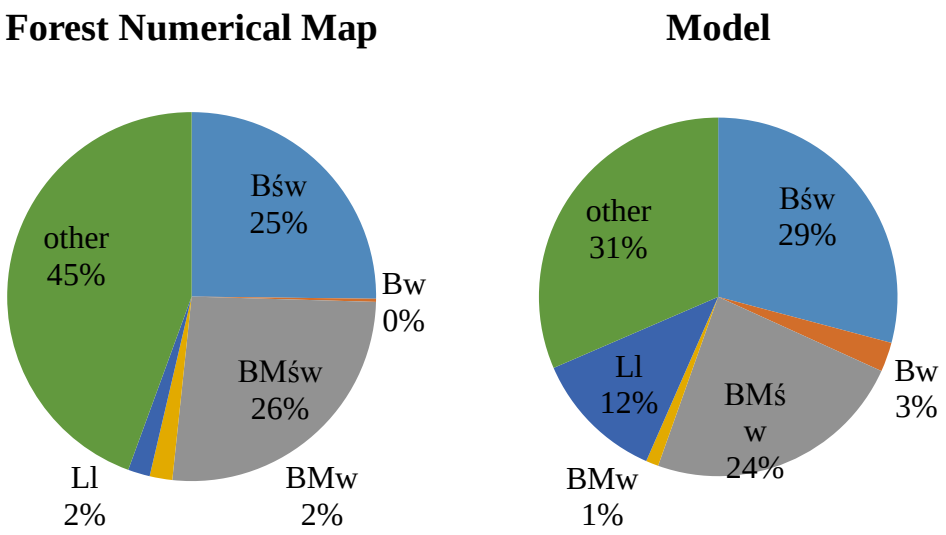

Figure 5. Percentage share of habitats according to numerical forest map and model

5. Application of method for the Western Pomerania province

On the terrain of forest districts being at least partially within the Western Pomerania province there are 1 130 918 ha of forest according to Corine CLC and 1 006 647 according to forest reports. As a whole the difference of forest areas between the two sources of information amounts to 124 270 ha, which constitutes 12% of the total area.
Habitat modelling results are shown in figure 6. The greatest percentage participation of habitats with a high flammability indicator is found in forest districts located in the southern and eastern parts of the province. The least percentage of these habitats may be noted in the central part of the province.

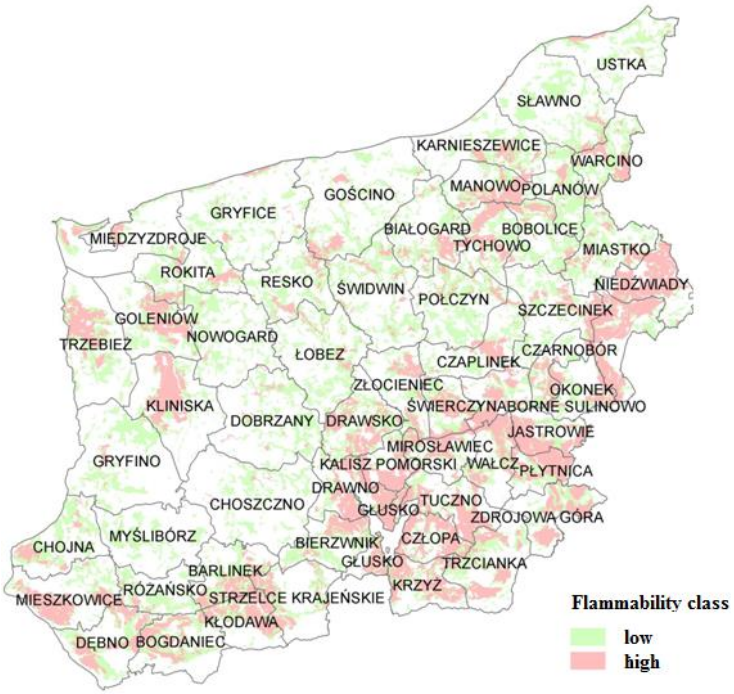

Figure 6. Habitat map according to flammability class indicator in forest districts of Western Pomerania province

At the provincial level 89% conformity was received, relating to surface area of groups of habitats of high flammability. In 39 out of 57 cases the error of designation of percentage of habitats of high flammability class did not exceed 20%. In 4 cases, where this error was greater than 20% it might equally be noted that the total forest surface difference according to Numerical Forest Maps and Corine Land Cover is greater than 21%. One may therefore accept that the difference in percentage participation of flammable habitats may arise from differences of types of habitats of forests contained in the digital forest map and those charted in the CORINE database. From this it results that 76% of forest districts estimated percentage participation of flammable habitats with an error not exceeding 20%. In 44 cases follows the estimation that may equally result from a greater forest area charted in comparison with the CORINE database. Considerable non-estimation, exceeding 30%, was noted only in two forest districts: Barlinek and Kłodawa. Perhaps this results from generalisation of the CORINE database, where small single patches of forest other of mixed and coniferous forest interlaced with each became jointly classified as mixed.

6. Summary

The method presented above enables the definition of percentage participation of habitats of a high flammability in forests on the basis of generally available low resolution data.
The difference of proportion of flammable habitats in the study area is established according to Forest Numerical Map and the study model is connected with the significant difference in forest area of forests being managed by forest districts being part of this area and areas of forests charted on the basis of Corine data.
Differences in the precision of methods for the study area (Forestry Districts: Dobieszyn, Kozienice, Marcule, Radom and Zwoleń) and the control check area (forestry districts being at least partially in the Western Pomerania province) may suggest that it requires local calibration of thresholds accepted in the method. This may be associated with a different geological substrate and type of terrain shape in both areas, which have an influence on values of indications.

Abbreviation:

BMśw – *fresh mixed coniferous forest*
Bs – *dry coniferous forest*
Bśw – *fresh coniferous forest*
Bw – *moist coniferous forest*
BMw – *moist mixed coniferous forest*
Bb – *bog coniferous forest*
BMb – *bog mixed coniferous forest*
Ł – *riparian forest*
Ol – *alder forest*
OlJ – *alder-ash forest*
Lw – *moist broadleaved forest*
LMśw – *fresh mixed broadleaved forest*
LMw – *moist mixed broadleaved forest*
LMb – *bog mixed broadleaved forest*
Lśw – *fresh broadleaved forest*

7. References

Moore, I.D., Grayson, R.B., Landson, A.R. Digital. 1991. Terrain Modelling: A Review of Hydrological, Geomorphological, and Biological Applications. Hydrological Processes 5: 3–30.

Pekkarinen, A., Reithmaier, L., Strobl, P. 2009. Pan-European forest/non-forest mapping with LandsatETM+ and CORINE Land Cover 2000 data. ISPRS Journal of Photogrammetry and Remote Sensing 64, 171-183

Szczygieł, R., Ubysz, B., Kwiatkowski, M., Piwnicki, J. 2009. Klasyfikacja zagrożenia pożarowego lasów Polski. Leśne Prace Badawcze 70 (2): 131-141.

Waser, L.T, Schwarz, M. 2006. Comparison of large-area land cover products with national forest inventories and CORINE land cover in the European Alps. International Journal of Applied Earth Observation and Geoinformation 8 (3), 196-207

Zeverbergen, L. W., R. Thorne. 1987. Quantitative Analysis of Land Surface Topography. Earth Surface Processes and Landforms 12: 47–56.