https://doi.org/10.17221/59/2020-JFS

Automated construction of ground access routes for the management of regional forest fires

Ekaterina Podolskaia, Dmitriy Ershov, Konstantin Kovganko*

Laboratory of Forest Ecosystems Monitoring, Center for Forest Ecology and Productivity, Russian Academy of Sciences (CEPF RAS), Moscow, Russia

**Corresponding author: ekaterina.podolskaia@gmail.com*

Citation: Podolskaia E., Ershov D., Kovganko K. (2020): Automated construction of ground access routes for the management of regional forest fires. J. For. Sci., 66: 329–338.

Abstract: Modern geospatial technologies and permanently updated wildfire monitoring datasets are the basis of improving forest firefighting on different administrative scales. One of the tasks is to use the spatial representation of forest fire locations during the fire season and offer timely suitable technical options for accessing them. We developed a GIS technology to create forest fire ground access routes for special firefighting vehicles moving from a ground firefighting base (fire-chemical station) to the place of the forest fire detection; the technology includes a statistical and geospatial accessibility analysis of the routes. The key data are a transport model consisting of public roads and forest glades on the regional scale. We described the main principles of the transport model construction and usage, and their implementation for the Russian Federal Districts. An access routes database for the 2002–2019 fire seasons, a central part of the Siberian Federal District, was produced and analysed. By using a hot spot analysis, we confirmed that forest fires are poorly accessible away from the centre of the Siberian District. The created road accessibility maps show "a proposed ground access zone" within the key area to fight forest fires for the fire seasons to come.

Keywords: access route; GIS; forest fire; fire-chemical station; forest management

Transport modelling is currently a fairly well-developed research domain. New challenges to this topic are related to the trend of sustainable territories development, which is determined by the transport accessibility (Liu, Zhu 2004), the development of decision support systems and a forest road network model (Akay et al. 2012; Akay et al. 2015), and the optimisation of the transportation costs as shown by Akay (2019). It is noted (Loidl et al. 2016) that the research should be continued in the areas of using geospatial data for transport models, studying spatially disaggregated transport models, and geovisualisation. Transport models are created and maintained on city, regional, and federal scales for different applications. In transport Geographic Information System (GIS) developments for regional coverage data, the problem of creating and developing a system of transport thematic models is still relevant, for example, the construction of optimal routes in a web GIS environment (Alazab et al. 2011). In recent decades, scientific and industrial communities have expressed the need to develop and to improve transport models in the regions (Kotelnikov et al. 2017).

Forest sustainable management is characterised by a set of complex activities of cultivation, con-

Supported by the State Funding Contract "Development of methodological approaches to the remote monitoring of resource potential and ecological state of forest ecosystems" (topic N AAAA-A18-118052400130-7).

https://doi.org/10.17221/59/2020-JFS

servation and restoration. They should be in line with the World Climate Treaty and be based on pragmatic and scientific solutions, as mentioned in the paper (Goldammer et al. 2017). Researchers have addressed a variety of aspects related to climate change, natural and human-related disturbances in the forest domain, for instance, the creation of forest road networks undertaken by Krumov (2019, 2020), transportation planning (Malladi, Sowlati 2017) and a fire management paradigm (Dunn et al. 2017). GIS is actively being used in forest fires management issues (Oleynikov, Markov 2014). Long-term field and space (aerial and satellite) observations are the main actual data sources to analyse the forest firefighting situation (Loupian et al. 2006).

At the conjunction of regional transport modelling and forest sustainable management, both terms are widely used and covered, yet there is still some niche for some interdisciplinary research like the ground accessibility to forest fires. This topic is of particular interest and meaning for the Russian Federation where there is still some certain room for improvement in the data analysis of forest fires and the development of adequate technical solutions to keep control of the forest firefighting situation on the regional scale of the Federal District (FD), which was firstly established in Russia in 2000 and nowadays considered as a new type of administrative-territorial unit (Decree of the President of the Russian Federation 2000, https://base.garant.ru/12119586/). The value and necessity of the monitoring of regional forest fires and the related road accessibility have already been discussed in some papers, for instance, (Loupian et al. 2006; Podolskaia et al. 2019b, c).

OBJECTIVES

The objectives of this work were:

(*i*) to develop a technology to construct access routes from a fire-chemical station to the place of the forest fire's detection for operational firefighting activities on a regional scale in Russia,

(*ii*) to perform a technology test on the example of one Russian FD (Siberian, or Sibirsky federalny okrug) in order to produce an example of the database for the 2002–2019 archived fire seasons and then

(*iii*) to perform a statistical and geospatial analysis of the access routes within the zones of the fire-chemical stations responsibility.

MATERIAL AND METHODS

The following vector datasets in geographical coordinates, WGS (World Geodetic System) 84 were used in the present research:

– data on the public roads and forest glades from the former Soviet road maps of 1:200 000;
– dataset with fire-chemical stations as the main asset of the forest firefighting technical forces concentration in Russia, a point feature class covering the central part of the Siberian FD;
– data on the forest fires detected by the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite system, extracted from the Russian information system of forest fire monitoring, or ISRM-Rosleskhoz (Kotelnikov et al. 2019).

The technology to automate the construction of ground access routes for the forest firefighting management in the Russian FDs includes three stages (Figure 1). Firstly, a transport model consisting of public roads and forest glades on the extent of the Russian FD is being created, at the second stage, we presented a methodological and technological solution for the automated construction of ground access routes on the scale of Russian FDs. The third stage includes the analysis of the roads/glades' accessibility to forest fires by statistical and geospatial tools. The described stages were implemented in the geoinformation software ArcGIS from ESRI (ESRI, Redlands, USA).

The preparation of the transport model for the FD consists of several consecutive stages, namely: merging layers of public roads and forest glades into a one linear feature class of a geodatabase file; the creation and verification of the topology; adding a speed attribute for the public road and forest glade; calculating the length and access time of the road/forest glade segment; the creation of a road and forest glade network by the tools of the Network Analyst ArcGIS. The values of the special transport speed vary within the 0–60 km per hour range depending on the road class, in our research, they can be of two types: without taking the elevation of the start point relative to the elevation of the end point of the road segment or glade into account, "flat" values (2D), or the speed values can be "corrected" by the elevation values (3D). For the present research, we used the 3D-variant. The method of constructing the transport model in 2D and 3D was taken from the paper (Podolskaia et al. 2019a). The resulting transport models for all the Russian

https://doi.org/10.17221/59/2020-JFS

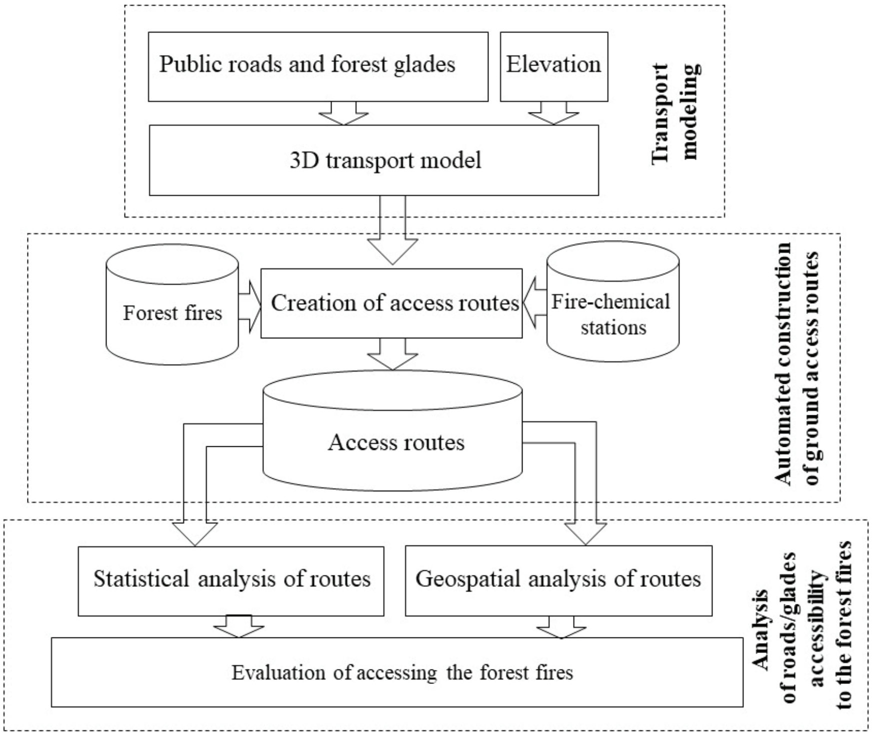

Figure 1. General scheme of the technology

FDs are stored in the ESRI geodatabase data format which is convenient for the subsequent construction of access routes. Thanks to the unified data organisational structure and the topology verification at the stage of combining the road layers, the geodatabase files of the Russian FDs can be merged into one common database across the country without any geometric or attribute duplication.

RESULTS

We have developed a Python-based set of programs that uses the data transport network for a specified FD to create a route shapefile, to construct a map displaying routes and to export the routes to a geodatabase. Calling the program for the selected FD opens a list of workflows (Figure 2), there are two ways to run the technology: (1) creating routes in the range of the dates of the fire season (time interval can be limited by months or year) and (2) creating routes for a given date.

Technology's tests were carried out for the data of the Siberian FD. To organise the data, we created a system of directories such as "Models" (Model Builder files), "Output" (shapefiles with routes), "Projects" (ArcGIS MXDs (map exchange documents), and "Scripts" (Python script files). The "Models" directory includes Model Builder programming blocks exported to Python format ("Scripts" directory). The script to create the access routes (shown schematically on Figure 3) uses the road network, the data on the forest fires and the set of fire-chemical stations as the input variables.

Statistical analysis

The retrospective statistics of the created forest fires access routes for the Siberian FD are shown in Table 1 for the 2002–2019 fire seasons. This database, from the archive of 18 years with about 200 000 records, helped in the estimation of next fire season's data volume for the Siberian FD and confirmed that geodatabase file can handle such a number of records. The historical data about the fire season's number of days (days when forest fires occur) were of help to estimate the volume of such a database too.

Resident Automation module
Siberian FD: D:\MapResident\QSql.exe

Loading and Processing Data Module
Check/clean old records: D:\MapResident\DeleteOld.ptn
Load data for Siberian FD: D:\MapResident\GetHS.ptn
Create routes shp-files: D:\MapResident\CreateShps.ptn
Create map, load to database: D:\MapResident\CreateMaps.ptn
Search and delete duplicates: D:\MapResident\DeleteIdentical.ptn

Figure 2. Workflows to create the forest fires access routes (example for the Siberian Federal District)

https://doi.org/10.17221/59/2020-JFS

Table 1. Length, time and speed of the forest fires access routes in 2002–2019 for the Siberian Federal District

Year of fire season	Number of forest fires	Number of access routes	Length of access routes (km)	Mean length (km)	Mean time (hours)	Mean speed (km per hour)	SD length (km)	SD time (hours)	SD speed (km per hour)	Median length (km)	Median time (hours)	Median speed (km per hour)
2002	9 308	8 812	763 637.28	86.70	2.79	38.92	57.61	2.24	7.39	57.73	1.52	40.52
2003	19 836	18 436	1 651 260.07	89.60	2.73	39.01	61.08	2.14	7.18	58.90	1.50	40.32
2004	12 197	11 536	890 322.53	77.21	1.94	40.64	51.38	1.32	5.99	52.32	1.34	41.24
2005	12 257	11 670	867 763.89	74.39	1.92	41.04	49.49	1.34	5.97	50.42	1.25	41.53
2006	13 952	12 819	902 527.03	70.44	2.36	39.32	46.01	2.04	6.66	48.44	1.23	40.31
2007	11 952	10 891	951 083.36	87.34	2.36	40.67	61.78	1.80	6.52	54.31	1.42	41.80
2008	17 339	15 395	1 104 758.16	71.80	1.97	40.16	47.38	1.42	6.13	49.05	1.21	40.83
2009	10 522	9 984	625 695.34	62.73	1.76	40.11	38.08	1.23	6.35	46.13	1.11	40.74
2010	12 342	11 877	773 450.72	65.18	1.73	40.78	39.46	1.14	5.82	47.71	1.17	41.12
2011	12 074	11 257	777 632.81	69.19	2.18	39.59	46.57	1.82	7.06	46.40	1.15	40.65
2012	14 130	12 187	900 927.63	74.03	2.60	38.58	49.45	2.33	7.55	50.28	1.26	39.93
2013	5 103	4 513	293 137.10	65.08	2.44	38.65	44.35	2.37	7.77	43.96	1.08	40.10
2014	14 665	13 424	1 008 948.67	75.24	2.60	39.23	52.52	2.38	7.29	40.52	1.22	40.52
2015	6 101	5 712	405 046.52	70.97	2.67	38.90	48.71	2.60	8.05	46.97	1.16	40.60
2016	7 035	6 018	560 463.16	93.22	3.78	37.76	68.99	3.80	8.68	55.35	1.37	39.72
2017	9 537	8 560	703 221.88	82.29	3.04	38.99	61.57	3.02	7.57	49.70	1.24	40.43
2018	11 314	9 691	768 484.60	79.37	2.86	39.05	58.07	2.77	7.53	49.77	1.22	40.59
2019	20 817	19 186	1 586 281.94	82.54	2.56	40.19	58.91	2.21	6.75	52.76	1.29	41.27
Average	12 249	11 220	863 035.70	75.06	2.46	39.60	52.30	2.11	7.01	50.04	1.26	40.68

SD – standard deviation

The statistical data from Table 1 on the three parameters (length, time and speed) shows that 2016 is characterised by the highest variety of the access time values (till almost 4 hours), the longest routes were created in 2003, 2007 and 2016 (the fire seasons with the most remotely located forest fires relative to the fire-chemical stations), and the mean and median speed (40 km per hour) are very homogeneous.

The average number of created routes is 11 220 (or about 91 % of the total number of forest fires in the studied archive), or about 200 000 routes to access 220 500 forest fires, which obviously means that majority of the forest fires that occurred in 2002–2019 were accessible by ground transport. The average access time lies within 2 and 4 hours, the average length is within 63–93 km, and the average route speed varies from 38 to 41 km per hour. The median length, time and speed are 50.04 km, 1.26 hours and 40.68 km per hour, respectively.

Geospatial analysis

We converted the routes' polylines into points, considering the last vertex of the route as the final destination of the route or place of the forest fire and keeping the attributes of time, length and speed associated to the forest fire point, every point is the centre of the forest fire accessible from the nearest fire-chemical station.

A thematical map of road accessibility to the forest fires for the Siberian FD was produced in several possible ways of rasterisation: access time (in hours), route length (in kilometres), and route average speed (in kilometres per hour). For the access time map, we used the Russian forest legislation document's (Recommendations on the use of forces and technical means to extinguishing forest fires 2014, http://legalacts.ru/doc/metodicheskie-rekomendatsii-po-primeneniiu-sil-i-sredstv-dlja-tushenija/) accessing limit of three hours from the forest fire's detection moment for the ground pro-

https://doi.org/10.17221/59/2020-JFS

```
#Loading of Toolboxes
Arcpy.ImportToolbox ("D:\FireNetProject\Model\FRTTools.tbx")

# Declaration of Variables
Transport_ND = "D:\\FireNetProject\\Data\\SibirskiyFD\\SibFD_wgs84.gdb\\Transport\\Transport_ND"
GetHS_shp = "D:\\MapResident\\Shape\\GetHS.shp"
PHS6_shp = "D:\\FireNetProject\\Data\\SibirskiyFD\\PHS6.shp"
FireRoutes_shp = "D:\\FireNetProject\\Output\\Shape\\FireRoutes.shp"
frt_cDate_shp = "D:\\FireNetProject\\Output\\ShapeArch\\frt%cDate%.shp"

# Creation of Access Routes
Arcpy.gp.toolbox= "D:/FireNetProject/Model/FRTTools.tbx";
Arcpy.gp.FindRoutes (FireRoutes_shp, Transport_ND, GetHS_shp, frt_cDate_shp, "20170717", PHS6_shp_)
```

Figure 3. Python script to create the access routes (example for the certain date of the fire season, Siberian Federal District)

tection zone and made two maps: forest fires classified with differentiation (A) in less than 3 hours, 3–6, 6–9 and more than 9 hours of access and (B) in less than 1 hour, 1–2, 2–3 and more than 3 hours (Figure 4). Only the data on the central part of the Siberian FD are shown and analysed in

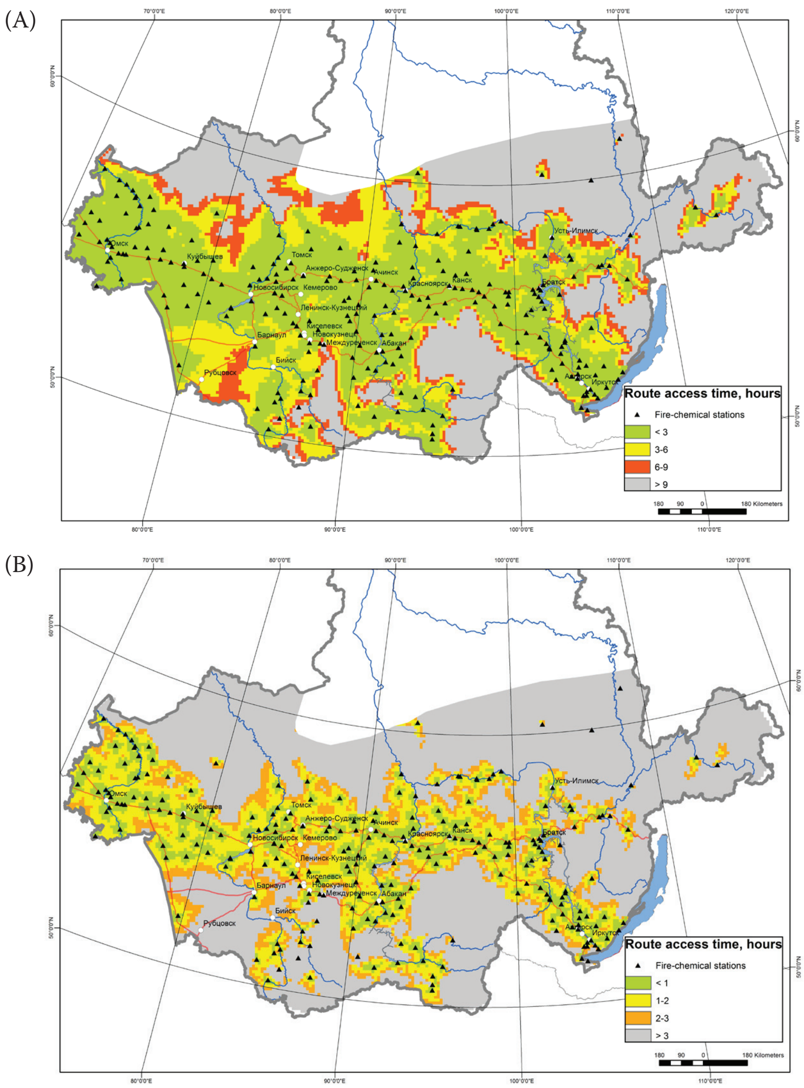

Figure 4. Road accessibility to the forest fires by access time: (A) grouped by 3 hours, (B) grouped by 1 hour

https://doi.org/10.17221/59/2020-JFS

(A)

(B)

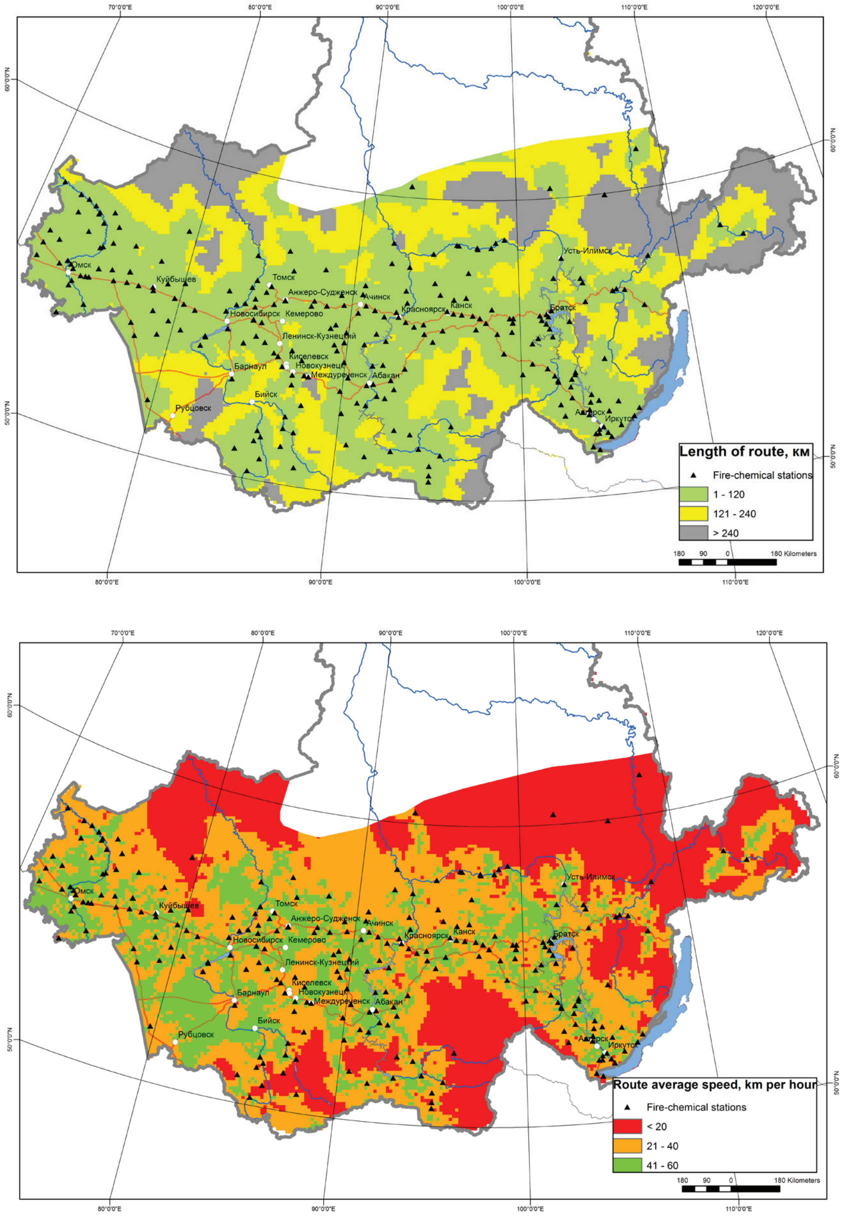

Figure 5. Road accessibility to the forest fires by (A) length and (B) average route speed

Figure 4–7, the uncoloured territory (white colour) has no data, the data on the fire-chemical stations are shown on the maps of Figure 4–5 for reference.

The road accessibility to the forest fires was differentiated by (A) the route length and (B) the average route speed (Figure 5). Figure 5A logically refers to the map of Figure 4A by using the same time interval. As we can see from Table 1, the mean and median speed of travelling along the access routes are about 40 km per hour, so this value was the multiplier for the "3-6-9" hour time set to create the map (Figure 5A). The average route speed map (Figure 5B) indirectly shows the development of the road network and how fast the firefighting vehicles can move to reach the forest fire.

For the regional evaluation of the road accessibility from the fire-chemical stations to the wildfires, we have used the hot spot analysis described by Mitchell (2005). A set of Thiessen polygons was created and considered as the area of the fire-chemical station's responsibility, for simplification, we agreed that the stations have the same value and technical resources.

The calculation of the transport fire access (TFA) ratio (the number of accessed forest fires to the total

https://doi.org/10.17221/59/2020-JFS

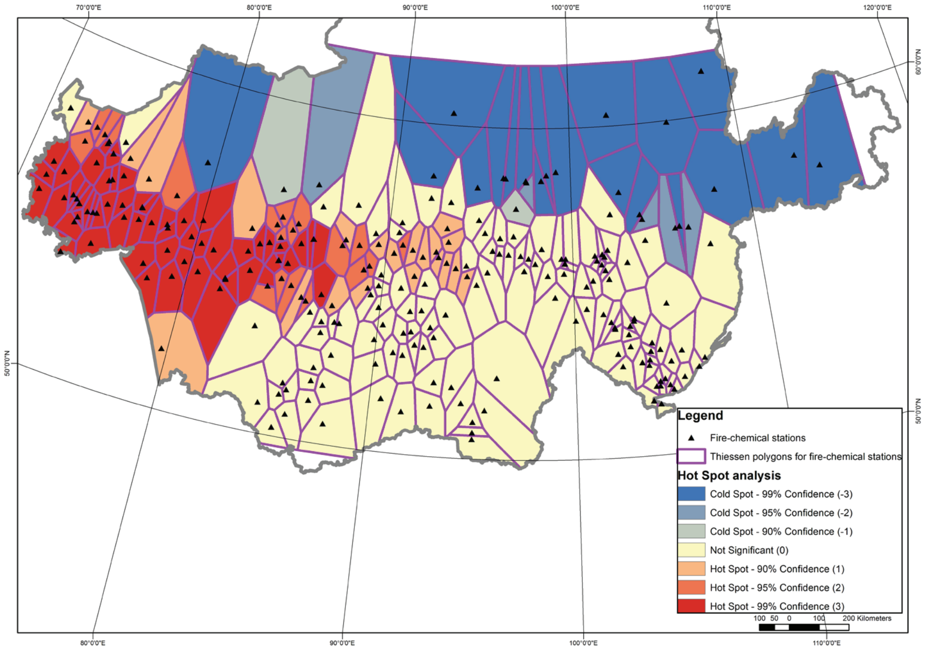

Figure 6. Hot Spot analysis of the fire-chemical stations road accessibility

number of the fires that occurred in 2002–2019) was performed and the final evaluation map (Figure 6, with the legend and notions of a hot spot analysis) was produced. We have used the TFA ratio as incident values and have analysed them within the areas of the fire-chemical stations areas of responsibility. The hot spot groups are presented with values –3, –2, –1, 0, 1, 2, and 3 (the legend of Figure 6). As we can see from Figure 6, there are two clusters distinguished by their homogeneity. The "red" zone has high values (hot spots) and 99% confidence, the "blue" ones are low ones (cold spots) with the same confidence. We tried to explain these anomalies by using two parameters: the road network density (number and length within the polygon) and the forest cover around the stations. A cold spot indicates high forest cover values, an area covered by forests to the area of the fire-chemical areas of responsibility, measured from the MODIS 230 m vegetation map (Bartalev et al. 2015), and a low density of the road and glades network. A hot spot cluster is characterised by a small amount of forests and a developed road/glade network, thus, has a good transport fire access ratio.

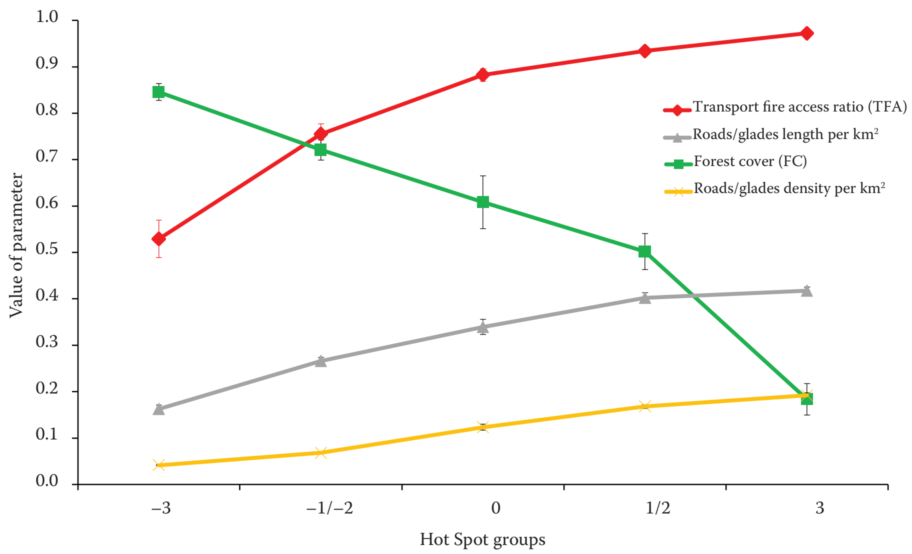

Figure 7. Transport accessibility vs Forest cover by Thiessen polygon groups

https://doi.org/10.17221/59/2020-JFS

The calculated values of four parameters (forest cover, transport accessibility ratio, roads/glades density by number and length) were shown relative to the area of Thiessen polygon (Figure 7). The larger the forest cover area is, the less accessible the forest fires are. The roads/glades in terms of their length and number within the Thiessen polygons also look have a logical function: from minimum in group "–3" (underdeveloped network in the north and north-eastern part of the key area) to the maximum in group "3" (well-developed network in the west).

DISCUSSION

The results of the present study are based on archived data and are aimed at helping the decision-making ability in the daily activities of regional forest firefighting management units. The time, length and speed of the access routes have been calculated and analysed statistically and cartographically. The statistical analysis of the obtained results (Table 1, Figure 4–5) gave some understanding of the road data, the spatial location of the fire-chemical stations and the natural distribution of the forest fires through the years. As we can see from Table 1, the biggest differences in the values "routes/fires" belong to 2006, 2008, 2012 and 2018, and could be related to the accessibility to the forest fires in principle. In terms of access routes' length, only the year 2008 is characterised by one of the biggest values for the selected data period. Thus, a certain number of forest fires were detected relatively close to the existing fire-chemical stations, but they were still not accessible, probably because of the road/forest glade's absence nearby. The speed of the firefighting vehicle did not change much and varies within 5–10 km per hour only (that could be an indicator of quite homogeneous conditions of the road/forest glade along the created route), but access routes could be 40–70 km long (a little less than 2 times different), and the access time's variety lies within 1–3.8 hours (almost 4 times different). The median values show that half of the routes have an access time less than 1–1.5 hours, and half of the routes are shorter than 40–60 km.

The statistic and cartographic interpretation led to an optimisation analysis where we evaluated the spatial correctness and locations of the existing firefighting activity centres, namely the forest fires stations. Statistically speaking, we got a picture of good accessibility to the forest fires from the existing stations. By using the sets of time intervals "3-6-9" and "1-2-3" hours, we made reference to the forest firefighting Russian rules and, at the same time, gave a reasonable travelled by special vehicle time estimation.

There are two reasons of forming the zones in Figure 6. Firstly, the roads/glades network within the key area has some certain irregularity due to its history, economic development and other reasons. Secondly, the forest cover is inhomogeneous by the area. The western part of the key area has a good enough roads/glades density to create access routes for the archived data. The "blue" zone with limited access logically neighbours the aviation protection zone to the north.

The ground protection access zones within the central part of the Siberian FD could be extended for the upcoming fire seasons taking the existing locations of fire-chemical stations and the hot spot analysis of the road accessibility into account. We can call the territory covered by the "red" zone (Figure 6) as "the proposed ground access zone within the Siberian FD" which has to be analysed in future research. It should be noted that fire-chemical stations location was evaluated by the Thiessen polygons, however, according to the recommendations from the Russian forest legislation, it could be undertaken by the forest unit (forestry).

CONCLUSION

The created transport models are cartographic products with attributes of traffic speed on public roads and forest glades. They can be used in a variety of thematic tasks, examples in the forest industry include the assessment of travelled by fire brigade time and distance, forest protection and biodiversity conservation, as well as a new road network's design. Additionally, the use of transport models can expand and enrich research activities of different interdisciplinary groups. As a direction for further studies, there is a need to develop some methods and techniques to update the road network data.

GIS-technology was used to construct and create the ground access routes based on the use of forest fires data, data on the fire-chemical stations and transport models on the scale of Russian FD. The technology has been tested for the retrospective dataset of forest fires of the Siberian FD. The

https://doi.org/10.17221/59/2020-JFS

data structure is shown, the interface and workflows of the access routes construction is presented. The route construction is shown in the form of a diagram describing how the script works. The technology could be of interest for management units of various responsibility levels and can be used in logistic operations to deliver technical forces and means to the forest fires and, thus, to solve the transport problem of ground access by public roads and forest glades.

We received a database with access routes from the 2002–2019 archive data. Maps of the roads/glades' accessibility to the forest fires in time, length and average speed for the central part of the Siberian FD were produced. The main value of the road accessibility maps and the fire-chemical station's location estimation created from the archive data with the technology described is that the information plays a reference role in evaluating the current geometry of the ground forest protection zone. The information could be included in the regional Forest Plans during the preparation of the upcoming fire seasons and then, consequently, influence the wildfire management optimisation.

REFERENCES

Akay A.E., Wing G.M., Sivrikaya F., Sakar D. (2012): A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean Region of Turkey. Environmental Monitoring and Assessment, 184: 1391–1407.

Akay A.E., Aziz B. (2015): GIS-Based forest road network model for forest protection. In: 38th Annual COFE Meeting, Engineering solutions for non-industrial private forest operations, Lexington, Kentucky, USA, July 19–22, 2015: 266–281.

Akay A.E. (2019): Analyzing the effects of logging truck sizes on transportation costs of forest products, V. In: Science Technology and Innovation Congress, Alanya, April 17–21, 2019: 29–36.

Alazab A., Venkatraman S., Abawajy J., Alazab M. (2011): An optimal transportation routing approach using GIS-based dynamic traffic flows. In: 3rd International Conference on Information and Financial Engineering IPEDR, Shanghai, China, Aug 19–21, 2011: 172–178.

Bartalev S.A., Egorov V.A., Zharko V.O., Loupian E.A., Plotnikov D.E., Khvostikov S.A. (2015): Current state and development prospects of satellite mapping methods of Russia's vegetation cover. Current problems in remote sensing of the Earth from space, 12: 203–221. (in Russian)

Dunn Ch.J., Thompson M.P., Calkin D.E. (2017): A framework for developing safe and effective large-fire response in a new fire management paradigm. Forest Ecology and Management, 404: 184–196.

Goldammer J.G., Eritsov A.M., Kisilyakhov E.K. (2017): The need for development of pragmatic and science-based solutions for forest management and fire management for the Russian Federation. Siberian Forest Magazine, 5: 114–124.

Kotelnikov R.V., Korshunov N.A., Giryaev N.M. (2017): Objectives of decision making in protecting forests from fires. Priorities on development of informational support. Siberian Forest Journal, 5: 18–24. (in Russian)

Kotelnikov R.V., Loupian E.A., Bartalev S.A., Ershov D.V. (2019): Space monitoring of forest fires: the history of creation and development of ISRM-Rosleskhoz. Russian Journal of Forest Science, 5: 399–409. (in Russian)

Krumov T. (2019): Determination of the optimal density of the forest road network. Journal of Forest Science, 65: 1–8.

Krumov T. (2020): Construction link between agricultural and forestry road networks. Mechanics. Transport. Communications, 18: VIII-1–7.

Liu S., Zhu X. (2004): Accessibility Analyst: an integrated GIS tool for accessibility analysis in urban transportation planning. Environment and Planning B. Planning and Design, 31: 105–124.

Loidl M., Wallentin G., Cyganski R., Graser A., Scholz J., Haslauer E. (2016): GIS and transport modeling – strengthening the spatial perspective. ISPRS International Journal of Geo-Information, 5: 1–23.

Loupian E.A., Mazurov A.A., Flitman E.V., Ershov D.V., Korovin G.N., Novik V.P., Abushenko N.A., Altyntsev D.A., Koshelev V.V., Tashchilin S.A., Tatarnikov A.V., Csiszar I., Sukhinin A.I., Ponomarev E.I., Afonin S.V., Belov, V.V., Matvienko G.G., Loboda T. (2006): Satellite monitoring of forest fires in Russia at federal and regional levels. Mitigation and Adaptation Strategies for Global Change, 11: 113–145.

Malladi T., Sowlati T. (2017): Optimization of operational level transportation planning in forestry: a review. International Journal of Forest Engineering, 28: 198–210.

Mitchell A. (2005): The ESRI Guide to GIS Analysis, Volume 2: Spatial Measurements and Statistics. Redlands, ESRI Press: 252.

Oleynikov V.T., Markov A.G. (2014): Problems of development and use of geoinformation systems in divisions of Emercom of Russia. Fire and Explosion Safety, 8: 32–35. (in Russian)

Podolskaia E.S., Kovganko K.A., Ershov D.V., Shulyak P.P., Suchkov A.I. (2019a): Using of transport network model to estimate travelling time and distance for ground access a forest fire. Forest Science Issues, 2: 1–24.

https://doi.org/10.17221/59/2020-JFS

Podolskaia E.S., Kovganko K.A., Ershov D.V. (2019b): Regional Geoinformation Modeling of Ground Access to the Forest Fires in Russia. In: Popovich V., Thill J.C., Schrenk M., Claramunt C. (eds): Information Fusion and Intelligent Geographic Information Systems. Advances in Geographic Information Science. Cham, Springer: 155–165.

Podolskaia E., Ershov D., Kovganko K. (2019c): GIS-analysis of ground transport accessibility of fire stations at regional scale. Abstracts of the ICA, 1: 301.

Received: April 24, 2020
Accepted: July 27, 2020