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Spatial patterns of crops in Russia

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Abstract. Information about spatial distribution of agricultural crops in Russia exists only in the form of statistical data aggregated at the level of regions or farms, which does not make it possible to obtain data about the actual distribution of crops. Attempts to use satellite data for mapping of individual crops have not yet been successful either. We have attempted to disaggregate statistical data on crop areas using map of ploughed soils in Russia, information on crop rotations, and assessment of suitability of land for cultivation of specific crops. An analysis was conducted for the 28 most common crops in Russia. Maps of the distribution of these crops in the country were constructed. The maps give an idea of the geography of crops in Russia and can be used to improve approaches to satellite mapping and monitoring of crop areas in the country.
Keywords: croplands, crop mask, cropped area, statistical data disaggregation, Russia

Conflicts of Interest. The authors declare no conflict of interest.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Introduction

Information about crop location is important for planning and forecasting agricultural production and regulating agricultural markets. It is widely used in shaping overall agricultural land use policies [1], in crop insurance [2, 3], in planning production and sales of seeds, fertilizers and crop protection products [4] and in planning humanitarian assistance to food insecure countries [5, 6].

In many countries around the world, where there is a well-developed statistical service, information on crop area is collected as part of the statistical reporting of agricultural enterprises and farmers. It is very time-consuming to collect this information, and in most cases, the specific field's location where the crop is grown is not included.

In many countries of the world, information on cropped area is not regularly collected at all. The only source of data on the areas of cultivation of individual crops for these countries is the expert estimates of FAO experts [7].

In recent decades, there has been active research in developing methods for satellite monitoring of crops [8—11]. The main goal of such research was to develop rapid, accurate, and low-cost methods for crop condition assessment and yield prediction. Most of the currently available approaches are based on the analysis of seasonal and multi-year dynamics of crop vegetation index values [12]. In order to aggregate vegetation index values for all pixels with crops of a particular crop and exclude from the analysis pixels where the crop in question is not cultivated, accurate individual crop masks are needed. Therefore, methods are being developed to detect individual crops from satellite data to create their masks [13]. But, due to insufficient data at the appropriate scale, these methods are still little used in operational satellite monitoring systems. The values of vegetation indices are at best aggregated for the entire arable land area of the analyzed region [8, 10].

In Russia during the Soviet era, there was a well-functioning system of agricultural statistical data collection. In addition, agricultural enterprises used to strictly adhere to directives about sown areas, which made the advance knowledge of production fairly accurate [14]. After the collapse of the Soviet Union agricultural producers became increasingly oriented to the needs of the market when choosing crops to cultivate, which significantly and unpredictably changed the geography of individual crop sowing. Climate change has also had an impact. Some crops can now be grown in previously unsuitable areas. As a result, there has been a strong change in the sowing area of crops. In many regions of Russia, it is especially noticeable for such crops as soybean, rape, sunflower, maize [15].

The goal of our research was to create maps of the location of the main crops in Russia for 2020, which would provide accurate information about the geography of crops in the country, and would also serve as a basis for refining the approaches of satellite monitoring of crops.

Materials and Methods

To construct the map, we used statistical data on the areas of crops sown in 2020, collected by the State Statistics Committee of Russia for all administrative districts of the country (a total of 1868 administrative districts) [16]. Data for the following crops were analyzed: winter and spring wheat, winter and spring barley, winter and spring rye, winter and spring rape, winter and spring triticale, oats, maize for grain, sunflowers for seed, sorghum, rice, sugar beets, potatoes, millet, buckwheat, peas, soybeans, flax for oil, flax for fiber, mustard, redeye (*Camelina saliva Czantz.*), annual and perennial grasses, and maize for silage. Data are presented in hectares.

Only annual crops were analyzed. This is due to the fact that perennial crops are less important for Russia and their areas are insignificant. In addition, the existing satellite agricultural monitoring systems in the world also do not include perennial crops in the analysis.

We used a vector map of administrative boundaries of Russia (analogue of the GAUL database level 3 (The Global Administrative Unit Layers dataset, implemented by FAO within the CountrySTAT and Agricultural Market Information System (AMIS) projects), which were digitized from topographic maps of scale 1:50000 [17].

A vector map of ploughed soils in Russia was also used [18]. The geometric part of the map represents the mapping units of the vector soil map of Russia (vector map, created using original paper soil map of Russia at scale 1:2,5 mln. It is available in a form of geotiff (pixel size is 300 m) file or as a shape file) [19], to which the information about the type of prevailing and three associated soils in each soil-geographical unit is attached. Also in the attribute part of this database is the percentage of plowing of each of these soils is indicated. There are a total of 25711 map units, with attributive information attached to each unit.

The suitability of the ploughed soils for cultivation of specific crops was assessed. The assessment was done based on the FAO approaches [20], adapted to the specifics of Russian crops [21]. The evaluation was based on the analysis of soil properties, without taking into account the terrain features and specifics of the climate. All soils were assigned to 3 evaluation classes: suitable without limitations, limited suitable, and unsuitable.

Literature data on typical crop rotations used in different oblasts and agro-climatic zones of Russia were also used in the analysis [22]. It should be noted that the information on crop rotations is rather schematic and is of a recommendatory nature. There is no information on the extent to which crop rotations are maintained in a particular area.

All vector maps used for the analysis were presented in a projection with the following parameters:

- Lambert Azimuthal Equal Area;
- Datum: WGS 1984;
- Ellipsoid: WGS 84 (a=6378137.00, 1/f=298.257223563);
- False Easting: 0.0000;
- False Westing: 0.0000;

– Central meridian: 100.00 E;
– Central parallel: 45.00 N;
– Scale factor: 1.000.

In the first stage of the study, the map of ploughed soils of Russia was crossed with the map of administrative districts of Russia. After that, statistical data on the areas sown to individual crops were linked to the divisions and names of ploughed soils within each administrative district. When linking individual crops to a specific soil, the suitability of that soil for the crop was taken into account. Once the crops that statistically appear to be cultivated in a particular administrative area were associated with soils and soil-geographical divisions, the logic of the set of crops assigned to the same soil was analyzed in terms of possible crop rotations. On this basis, the association of crops with soils and the areas of specific crops assigned to specific soils were corrected.

A similar procedure was carried out by three independent experts. All cases of inconsistency in the experts' decisions on a particular soil for a particular crop were discussed collegially to make a final decision by consensus.

The statistical data on cropped area was processed on Microsoft Office Excel Professional 2020. The software used for creating the maps was ILWIS v.3.3 [23].

Results and Discussion

The maps of the spatial distribution of individual crops constructed as a result of the analysis are shown in Appendix A. The maps made it possible for the first time to assess the geography of the sowing of individual crops in Russia.

According to the data obtained, potatoes, annual and perennial grasses, and oats are the most widely sown crops in Russia. These crops are cultivated almost throughout Russia. This is due to the demand for these crops in agriculture (potatoes are the main food crop for the population in many regions of the country, and oats and sown grasses are the main fodder for farm animals), as well as to the lack of climatic restrictions on their growth in the country. The main limitations to the wider spread of these crops in Russia are related to the underdeveloped infrastructure, the country's settlements distribution or economic reasons (less profitable cultivation compared to other crops) [24].

Crops such as rice, soybeans, maize for grain, sugar beets, sorghum, and winter crops (wheat, barley, rye, triticale, rapeseed) are less common and more spatially localized. The distribution of winter crops is mostly conditioned by climate [25]. Sowing areas of winter crops are most common in the south of the European part of the country.

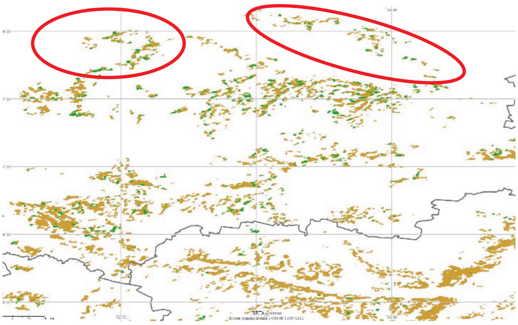
Also due to climatic conditions sowing areas of sorghum and maize are limited. In addition, in areas with a favorable climate, winter wheat, which is a priority for the country, is a big competitor to the sowing of these crops.

The prevalence of rice crops is related both to climatic conditions and to the crop cultivation traditions of the population and the availability of the necessary infrastructure (systems of water supply to the rice checks).

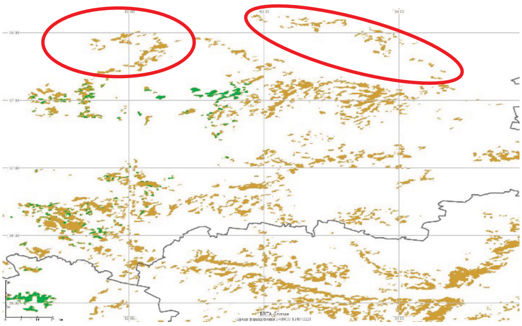
Soybean production is concentrated in two areas. The first occurs in the Chernozems (black soils) of the European part of Russia and the second in the easternmost part of the country. The concentration of crops in the Far East is largely due to the traditions of the population and the proximity to China, where this crop is very widespread. And the spread of soybean crops in the European part of Russia is due both to the ever-increasing economic demand for this crop and to trends in climate change in this territory, which is becoming increasingly favorable for soybeans.

We also consider the obtained maps as a basis for satellite detection of crops and improvement of satellite monitoring methods. To improve the quality of crop masks derived from satellite data, these masks can be combined with our crop distribution maps, and those pixels that lie outside the crop distribution ranges indicated on the map can be considered erroneous.

For example, in Russia, operational satellite-based crop monitoring is carried out only for winter crops [26]. Every year, due to crop rotations and economic reasons, crops «migrate» within the mask of arable land (Fig.). But crop sowing areas cannot spread beyond the units of the maps we have compiled, because outside these units there is no land suitable for the crops in question or there is no appropriate infrastructure. Therefore, all pixels of the winter crop mask constructed from satellite data outside of the corresponding units on our map can be considered erroneous and excluded from further analysis.



2020



2021

Satellite-based winter crop masks for 2020, and 2021: brown color — arable lands; green color — winter crop; dark grey lines — administrative boundaries; light grey color — graticule; red ovals delineate areas, where winter crops cannot be cultivated due to unfavorable soil conditions

In addition, our maps can be used for the construction of satellite monitoring technology in Russia not only for winter crops, but also for other crops.

The methods we used in our analysis require statistical data on crop area at the sub-national administrative unit level. Such information is in most cases unavailable for developing countries, which makes it impossible to use such an approach for their territories.

Similar to our approaches are used in European countries, in the United States and in China [10, 27, 28]. Attempts have been made to use similar approaches to create crop masks for individual crops for Russian territory as well. For example, crop masks for wheat, barley, maize, sunflower, and potato were created within the framework of the

EC MARS project [28]. Similar work has been carried out in China [10]. But in these cases, the crop information was entered into a regular grid of 1×1 km in size. This led to a strong generalization of information and distortions in the display of crop areas.

Attempts to directly disaggregate crop area statistics from satellite data have been done for many years [29—31]. The results of such analysis over large areas (countries, continents, global level) are rarely subject to quality assessment, or their quality is assessed in comparison with the same statistics, which is used for disaggregation. But their margin of error can be up to tens of percent [32].

One reason for this is that in all mentioned above cases, the information was not linked to the soils and their characteristics. As a result, part of crops was shown on soils that are obviously unsuitable for cultivation of the crops in question. In our case, when creating maps, the suitability of soils was taken into account, which allows to eliminate such errors.

Conclusions

A great deal of research exploring agricultural production planning, and monitoring ignores the spatial component, and this manuscript is able to identify where main crops cultivation in Russia is located. Additionally, our maps can help researchers easily conduct studies on agricultural land use planning, crop monitoring, and crop yield forecasting in specific places.

The results can be used for improvement of modern methods of satellite-based crop monitoring in Russia by fusion of our maps with remote sensing methods of crop detection and masking.

Taking into account the spatial location of specific crops can increase the accuracy of their status monitoring and crop yield forecasting. In addition, our maps can be used to organize satellite monitoring of crops, which have not yet been monitored worldwide due to the lack of data on their geography.

Appendix A

Maps of crops in Russia, ha, black lines — administrative units' boundaries (oblast)

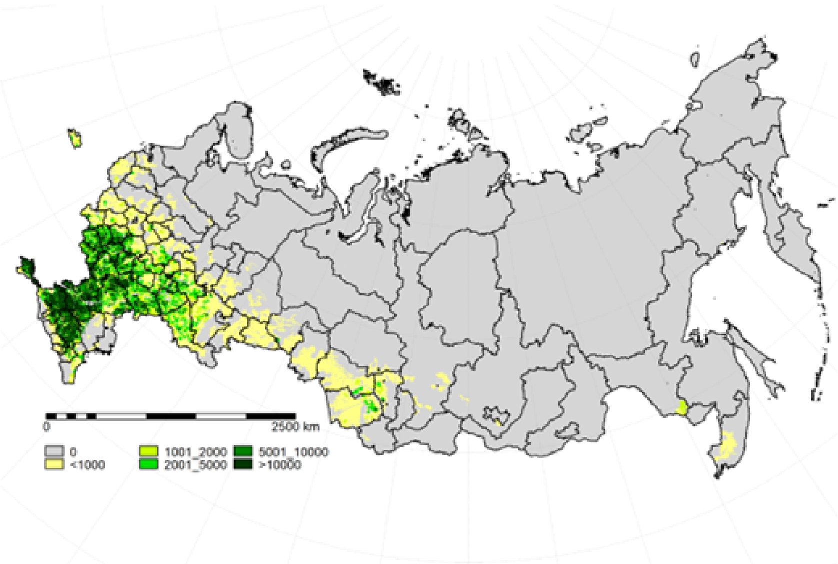


Fig. A1. Winter wheat

Fig. A2. Winter barley

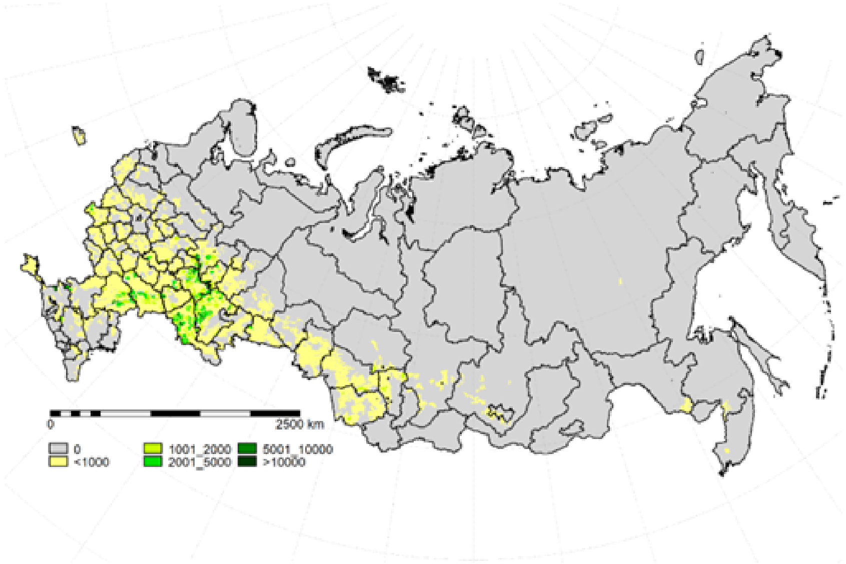


Fig. A3. Winter rye

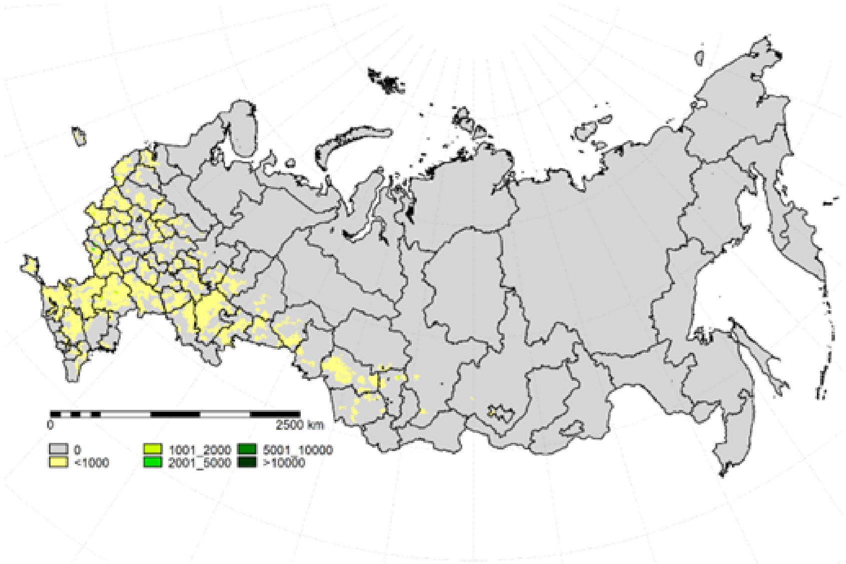


Fig. A4. Winter triticale

Fig. A5. Winter rapeseeds

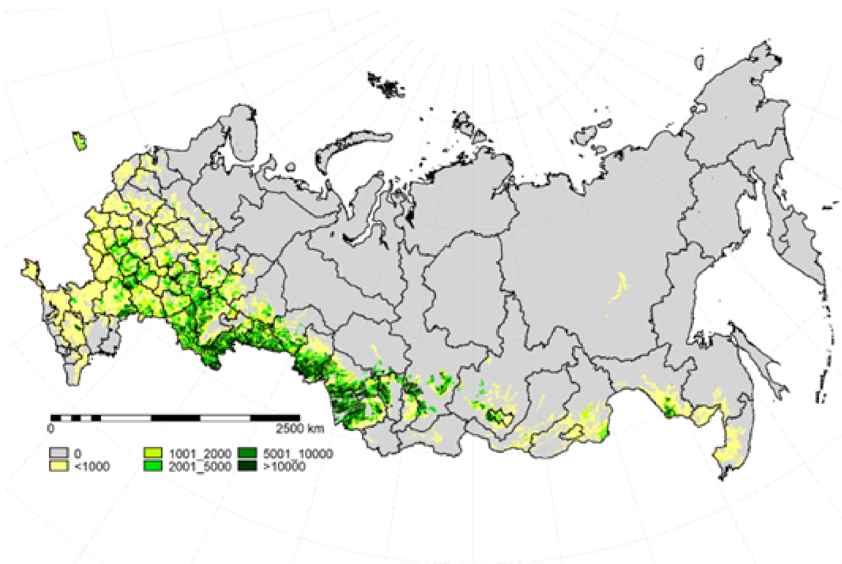


Fig. A6. Spring wheat

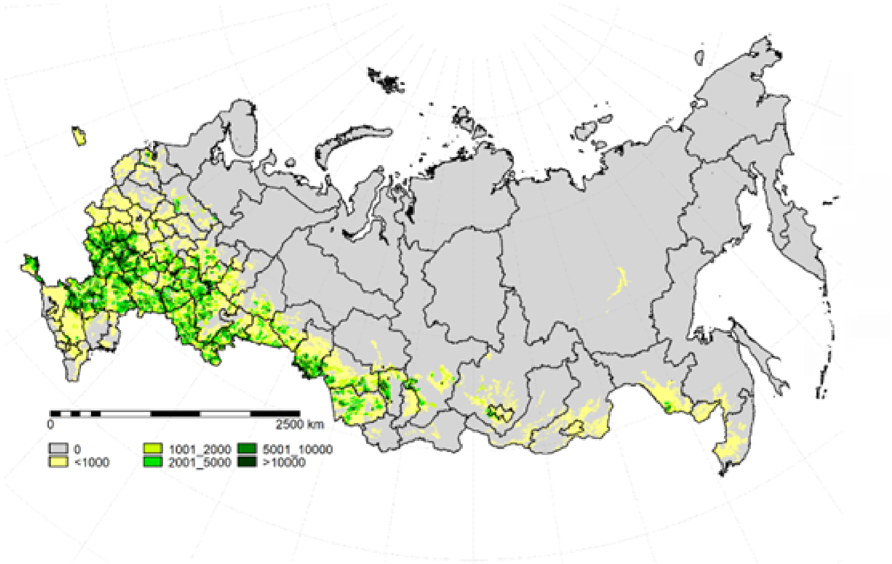


Fig. A7. Spring barley

Fig. A8. Spring rye

Fig. A9. Spring triticale

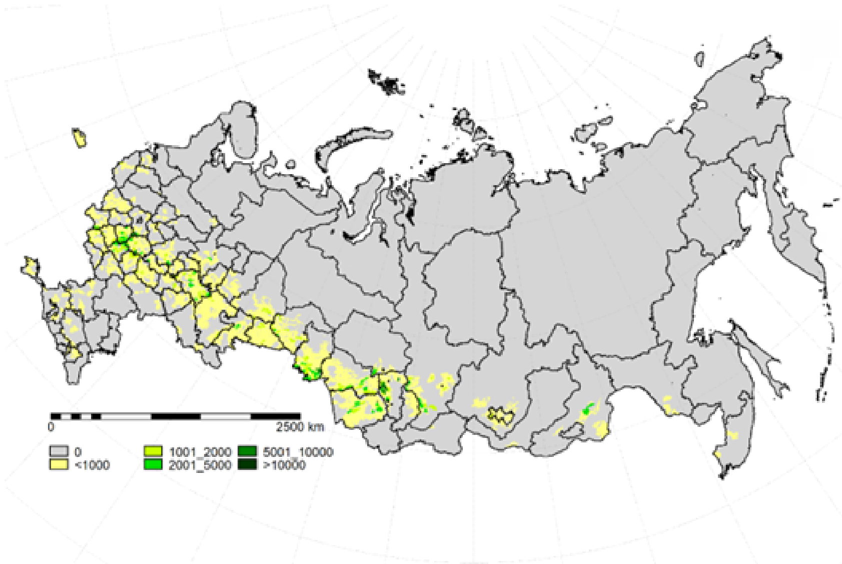


Fig. A10. Spring rapeseeds

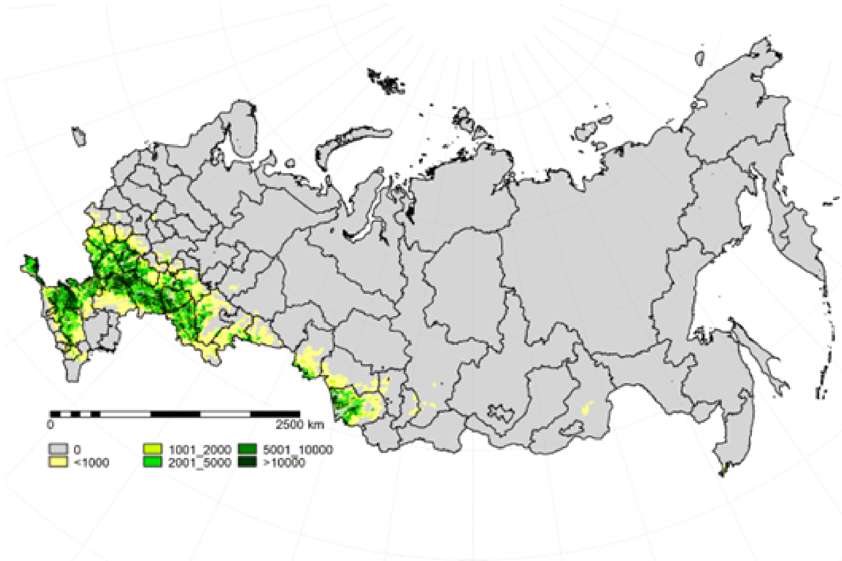


Fig. A11. Sunflower

Fig. A12. Soyabeans

Fig. A13. Sorghum

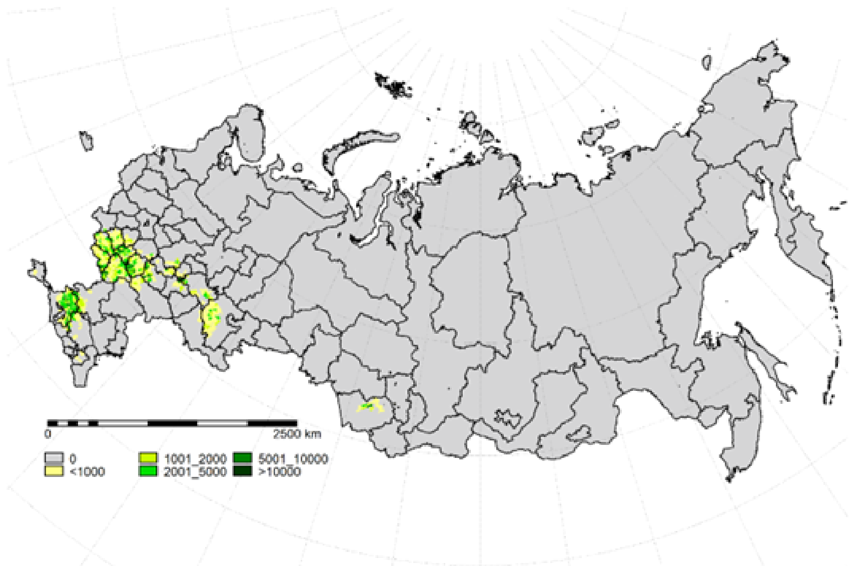


Fig. A14. Sugar beets

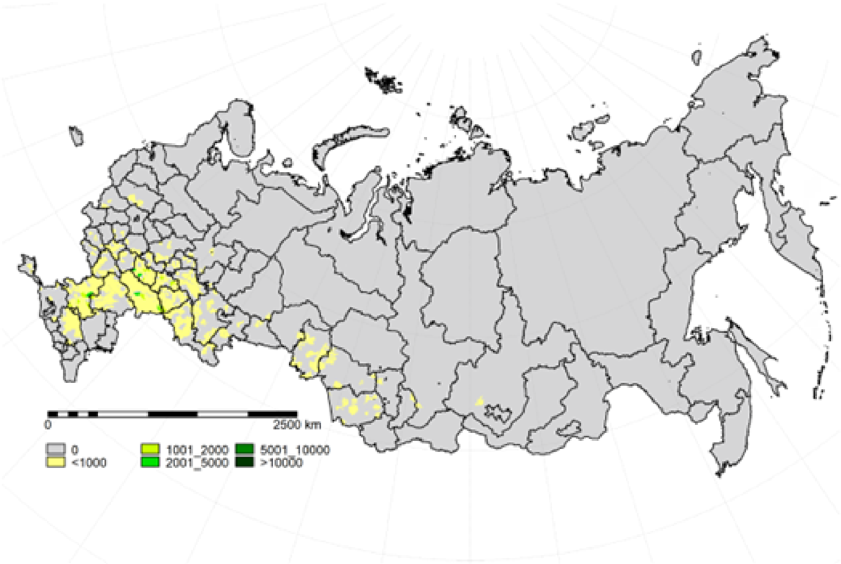


Fig. A15. Redeye (*Camelina saliva Czantz.*)

Fig. A16. Rice

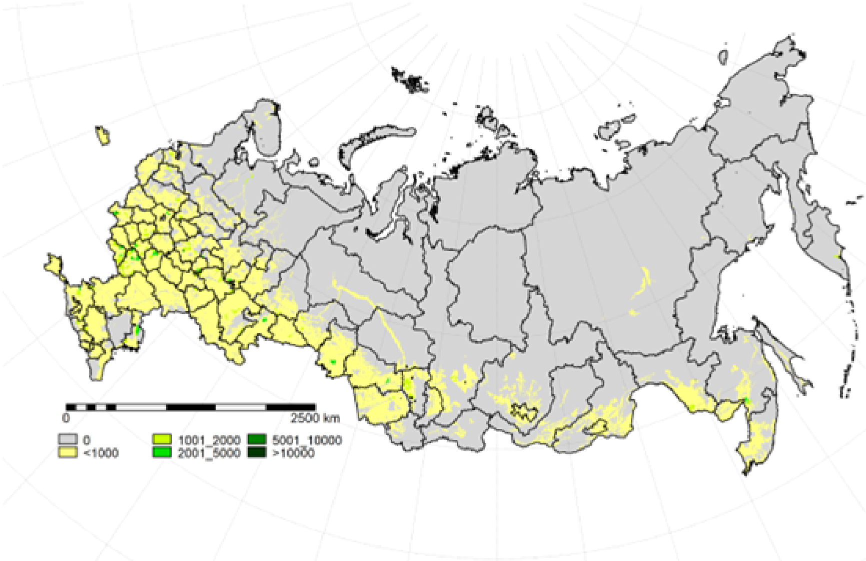


Fig. A17. Potato

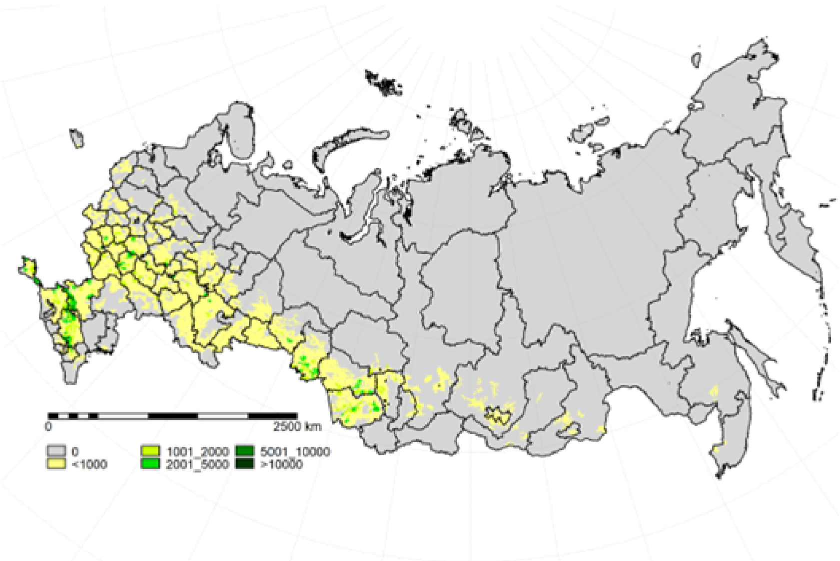


Fig. A18. Peas

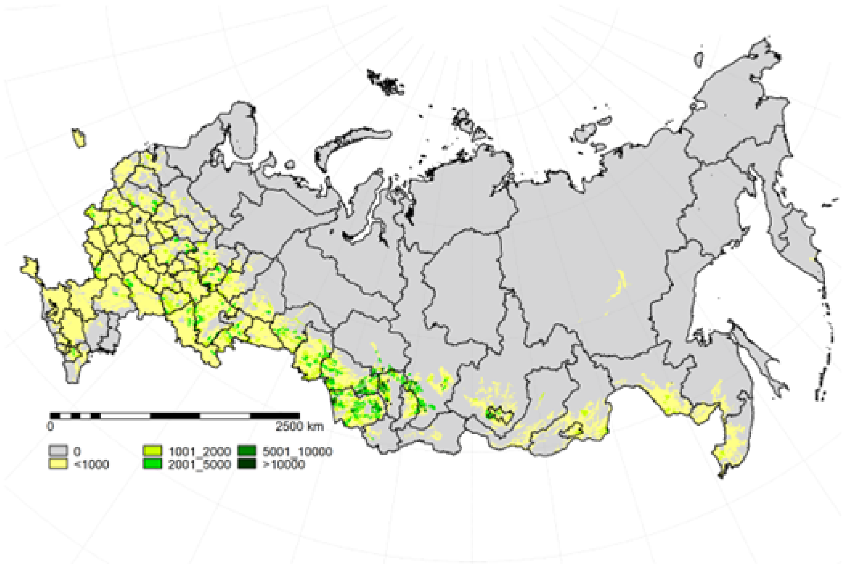


Fig. A19. Oats

Fig. A20. Millets

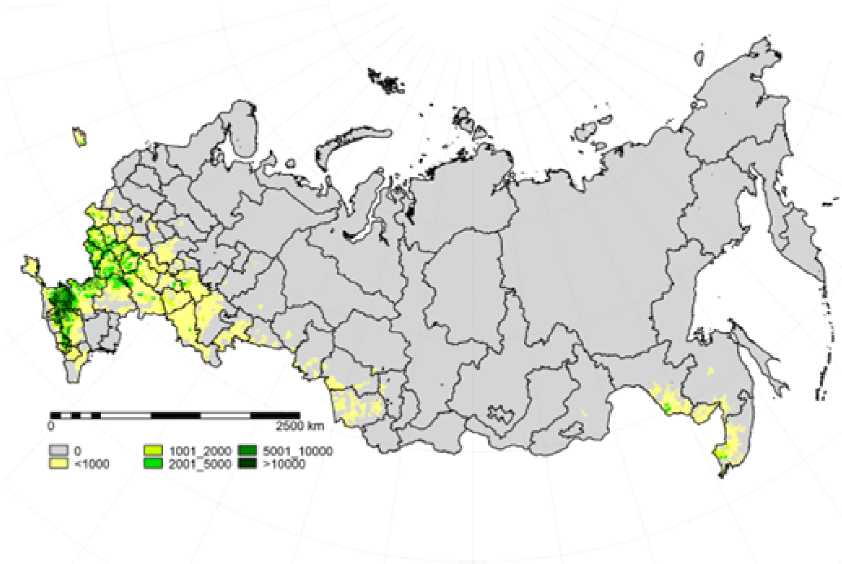


Fig. A21. Maize for grain

Fig. A22. Mustard

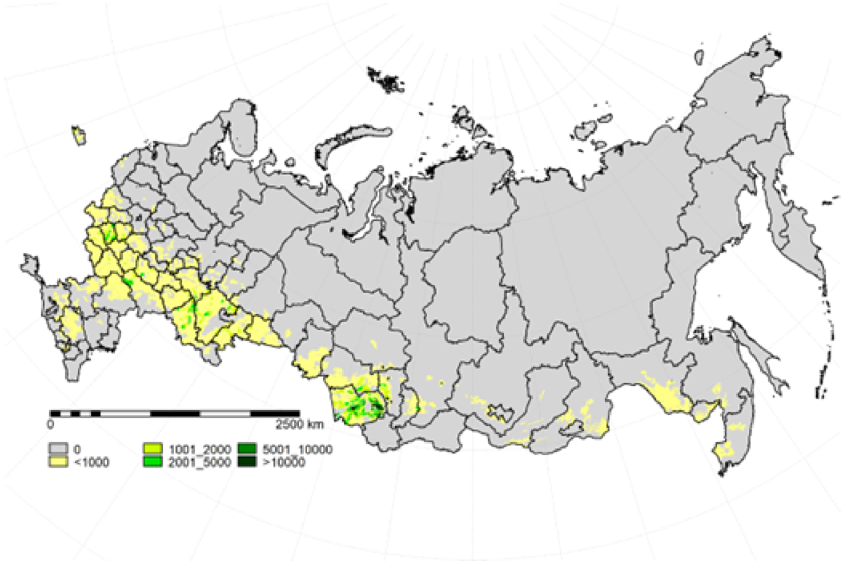


Fig. A23. Buckwheat

Fig. A24. Flax for oil

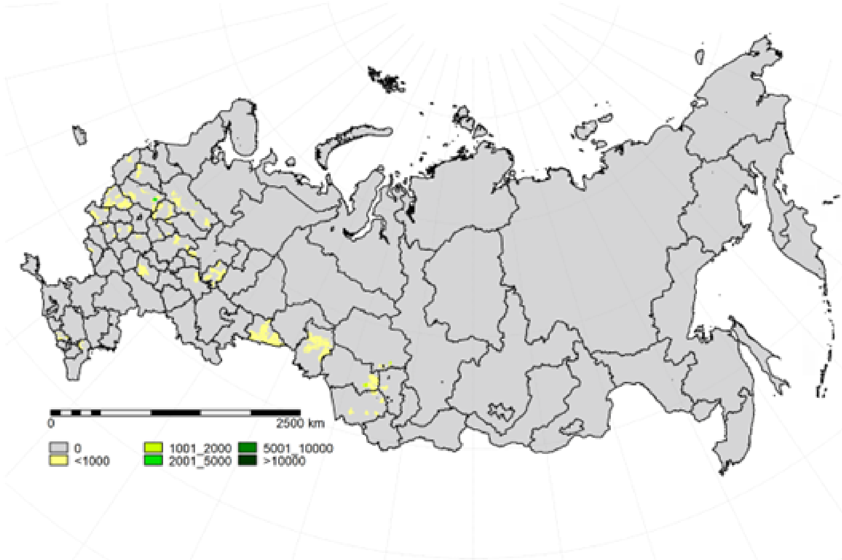


Fig. A25. Flax for fiber

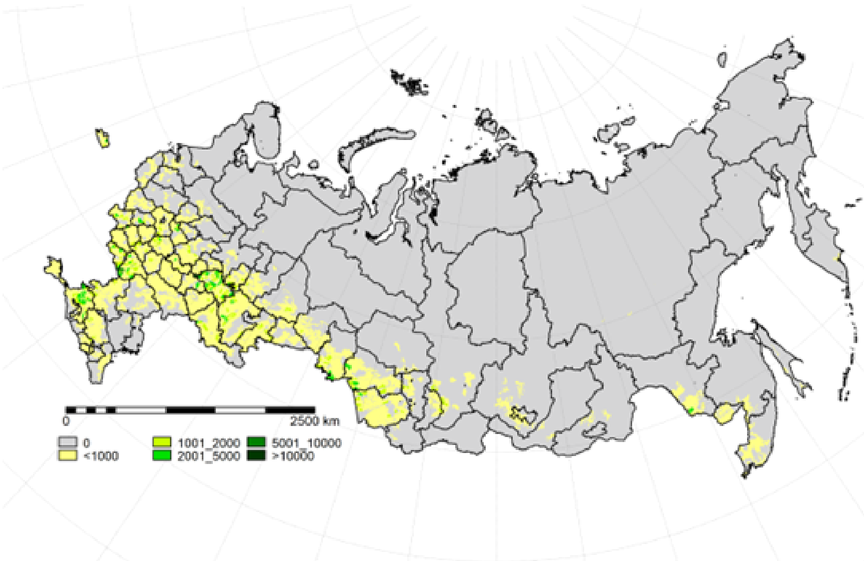


Fig. A26. Maize for forage

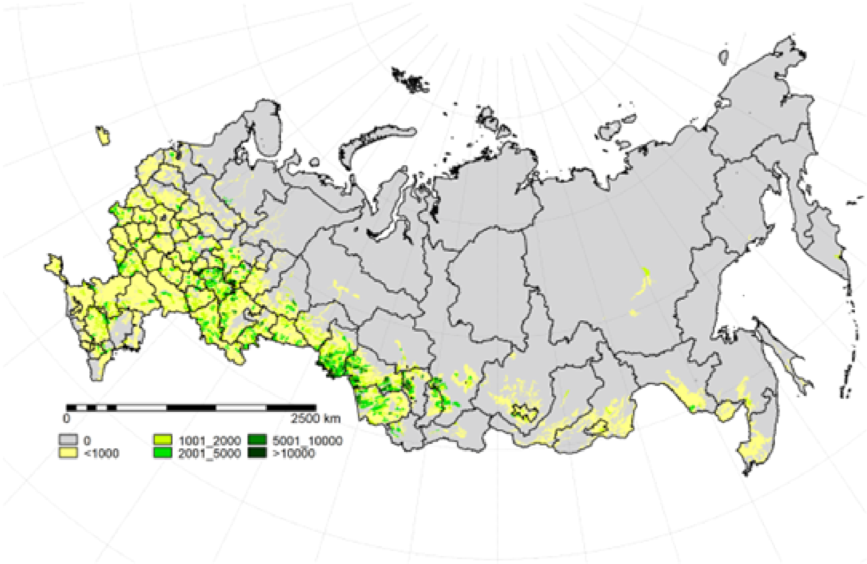


Fig. A27. Annual grasses

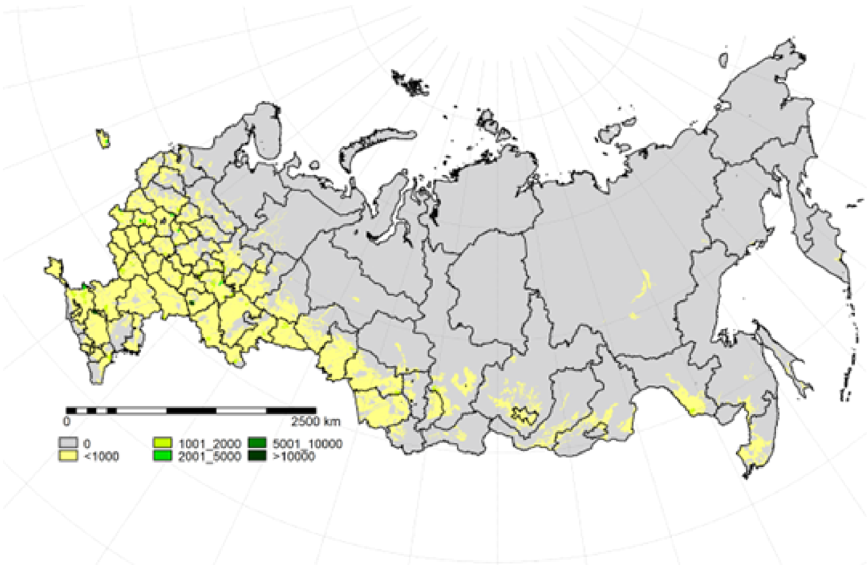


Fig. A28. Perennial grasses

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Пространственное размещение посевов сельскохозяйственных культур в России

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Аннотация. Информация о пространственном распределении сельскохозяйственных культур в России существует только в виде статистических данных, агрегированных на уровне регионов или хозяйств, что не позволяет получить данные о фактическом пространственном размещении посевов. Попытки использовать спутниковые данные для картирования отдельных культур также пока не увенчались успехом. Мы попытались дезагрегировать статистические данные о площадях посевов, используя карту распаханных почв России, информацию о севооборотах и оценку пригодности земель для выращивания конкретных культур. Анализ был проведен по 28 наиболее распространенным в России культурам. Были построены карты распространения этих культур в стране. Карты дают представление о географии посевов в России и могут быть использованы для совершенствования подходов к спутниковому картографированию и мониторингу посевных площадей в стране.

Ключевые слова: посевы, карты посевов, площадь посевов, дезагрегация статистических данных, Россия

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