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Approaches to research and classification of forest fuel

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Abstract

Forests of Ukraine and the whole world in recent decades are regularly exposed to uncontrolled large wildfires. In Ukraine, huge forest areas were burnt in 2009, 2014 and 2015. In 2018, even the northern Scandinavian countries suffered from forest fires. Global climate change (increasing average temperature and aridity) is expected to contribute to the increasing number and area of fires in the future. The occurrence of fire is impossible without the presence of a source of fire, oxygen and fuel (so-called triangle of fire), but only forest fuel (FF) can be controlled by forestry treatment or by prescribed fire. Effective fire management is impossible without the knowledge of the distribution and qualitative characteristics of FFs. This article provides brief information on the history of research studies on FF in Ukraine and in the countries of the former Soviet Union and the factors that influence the formation of reserves and structure of FF. According to those research articles, the most important factors were soil and climatic conditions and characteristics of plantations. Information about the trends in accumulation of FFs in the Ukrainian pine forests is given. After the evaluation of the research works about FF, it was concluded that the study of fuel in Ukraine is fragmentary, and such studies should be continued, but necessarily after the unification of the methods of sampling and recording data about FF. In the future, this work allows the mapping of FF at the national level. The need to continue collecting field data from forest ecosystems is indicated by the use of new world-class methods for the development of fuel models, taking into account the local conditions.

Key words

forest fires, fuel classification, pine forests

Introduction

Forest fires lead to catastrophic consequences not only in Ukraine but also around the world. According to the State Statistics Service of Ukraine, during 1990–2016, 103.6 thousand natural fires were liquidated on the territory of Ukraine. The total area covered by fires is 133.3 thousand hectares, and the average area of one forest fire over the past 27 years reaches 1.3 ha. The forest fires lead to enormous losses in the forest sector of the Ukrainian economy. Negative demographic dynamics, hostilities in the occupied territories of eastern Ukraine and inadequate funding for the forestry sector caused negative social and economic consequences that, together with the negative manifestations of climate changes, aggravated the problem of forest fires on the territory of Ukraine.

Catastrophic fires in 2018 in Greece, Portugal and California with numerous casualties and destruction indicate an increase in the level of fire hazard. Large

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fires in Germany and Sweden in 2018 indicate that the fire risks are rising even in central and northern Europe. Ukraine is in a zone of constant risk of large destructive wildfires due to large areas of of the most fire-hazardous pine forests (30% of total forest area).

The purpose of this work is to analyse the scientific works that are accounting on vegetable combustible materials and their quantitative and qualitative characteristics and to evaluate the issues on studying the FFs in Ukraine.

Results

Most research studies in the area of FFs were conducted in the United States and the former USSR, studies on this issue began in Ukraine only in the 1960s and 1970s. A number of studies were related to the classification of fuel, the study of its properties and its participation in the combustion process (Kurbatsky 1964; Volokitina and Sofronov 2002; Gorshenin 1981; Nesterov 1945a, 1945b; Sviridenko 1999; Usenya 2002; Pyne et al. 1996).

Ecological role

It should be noted that dead fuel (especially coarse and fine woody debris) plays an important ecological role as components of the forest ecosystems. Coarse woody debris (CWD) is generally considered dead woody material in various stages of decomposition, including sound and rotting logs, snags and large branches. CWD plays a crucial role in forest ecosystems. The current amount of woody debris on a given site represents a balance between additions (tree mortality) and depletions (wood decomposition, combustion and transport) (Fraver et al. 2017). CWD is an important contributor to forest biodiversity because it provides essential habitat for saproxylic (dead wood□dependent) species. However, CWD is frequently overlooked in forest management and restoration decisions around the world. To estimate the habitat quality that integrates important characteristics of saproxylic habitat, CWD index was developed (Van Galen et al. 2019). CWD is an important functional and structural component of forested ecosystems, and it plays an important role in nutrient cycling, long-term carbon storage, tree regeneration and maintenance of heterogeneous environmental and biological diversity (Yan et al. 2006).

Classification of forest combustible materials

One of the first scientists who tried to identify and combine the groups of forest fuel load (FFL) in the USSR was Kurbatsky (1974). According to his definition, FFLs are plants and their matter of varying degrees of decomposition, which can burn in the event of fires (Kurbatsky 1974, 1984; Sviridenko et al. 1999). According to the definition of American scientists Pyne et al. (1996), FFs are materials of plant origin, which can burn during a fire. Sofronov et al. (2002) proposed three levels of FF classification:

– Classification of elementary particles in FF complexes.
– Classification of simple complexes (layers) of FF within biogeocenoses.
– Classification of biogeocenoses itself as complicated complexes of FF.

Separation of elementary particles in complexes of FF is widely used in the United States, while not taking into account their very small particles. Under these conditions, two large categories of combustible materials are distinguished: alive and dead (Volokitina and Sofronov 2002; Pyne et al. 1996). Live FFs are divided into two groups: (1) herbs and herbaceous plants and (2) needles, leaves and branches with a diameter of more than 6 mm in tree crowns. Dead FFs are divided into four groups depending on their timelag: light (1 hour), middle (10 hours), heavy (100 hours) and very heavy (1000 hours).

Depending on the spatial location, FF layers are divided into three main groups: 1 – on the ground (surface), 2 – above the ground and 3 – ground fuel (Volokitina and Sofronov 2002; Gorshenin 1981; Sviridenko 1999; Usenya et al. 2002).

Surface FFs include a whole lot of the cover of and undergrowth: above-ground – growth and trees and underground – materials that are below the surface of the soil. The same groups of FF were distinguished in Canada. In addition, in the United States, FF is separated based on the spatial location of FF and on the nature of the spread of fire: (1) bushes, (2) dry herbs or green herbs with a predominance of dry ones, (3) remnants of logging, (4) litterfall, (5) forest litter, (6) humus and (7) duff.

Kurbatsky et al. (1974) distinguished the layers of FFs based on the functions they perform during the fire in addition to their placement. Three groups of FF were identified: (1) combustion conductors, (2) burners and (3) those that hold off the combustion (Kurbatsky 1974;

Sviridenko et al. 1999). Volokitina and Sofronov (2002) also allocated a fourth group, namely materials that do not participate in the combustion process, that is, fuel located outside the combustion zone or those that are not capable to fuel even in the flame of a fire.

The first group of FF plays a key role in the occurrence and spread of fires. In particular, Konev et al. (1972) divided them into (1) dead grass, (2) fallen needle, (3) fallen leaves, (4) lichens and (5) mosses. Yakovlev et al. (1979) in the forests of southwest Yakutia identified six types of ground-based FF depending on the speed of their fire maturation, namely, lichen, dead-coat-noodle, needle, moss, herbal and sphagnum. Sheshukov et al. (1996) classified the FF layers by density: open (up to 0.3 kg· m^{-3}), loose (0.3–4 kg m^{-3}), semi-rye (5–15 kg m^3), sealed (16–30 kg· m^{-3}), dense (31–80 kg· m^{-3}) and very dense (81–130 kg m^3).

Most scientists classified the vegetative fuel layers based on the ability of FFs to ignite, which depends on their physical properties: moisture, size and location in forest phytocoenosis. Kurbatsky M.P (1974). combined FFs into seven groups according to their ability to ignite: (1) mosses and lichens with shallow fall, (2) litter, overhang and peat horizons, (3) grasses and half-calves, (4) fine woody debris, (5) growth and shrubs, (6) needles and branches in the pine forest and (7) trunks of growing trees and live branches with the thickness of more than 7 mm.

Mosses, lichens with needles and fallen leaves are fuel, commonly causing the forest fire. Humidity of these materials, especially lichens, varies even during the day and depends on weather conditions. Herbs and understory vegetation have a steady moisture and cannot burn themselves. They can burn only when litter, moss or lichen is under them. Growth and undergrowth, as well as undershrubs, have a high stable humidity. The peculiarity of forest litter and peat is that their humidity depends on the moisture content of the soil and is in the range of a few percent to 500% or more. These types of fuel dry quite slowly, especially in the conditions of wetlands. Windy, fall rotten stumps and remnants of logging slowly change their humidity within very wide limits. Needles and live branches in the tree stand have a stable and sufficiently high humidity. They burn down only after long period of drying by moving fire on the surface of the soil. Thick branches and trunks of trees are burned very rarely. As a rule, after combustion of needles, leaves and thin branches, they only dry up (Volokitina and Sofronov 2002; Sviridenko et al. 1999).

For developing the classification of FF, Kurbatsky (1974) and Volokitina and Sofronov (2002) used the following main signs for defining the features of FF associated with their combustion: the possibility of ignition, the nature of combustion and the role of burning biogeocoenosis. Under such conditions, the division of the first group of FF has an experimentally confirmed basis.

Classifications of biogeocoenoses, as complicated complexes of FF, were carried out by scientists such as Melekhov, Ovsyannikov, Isaev, Sheshukov and Kurbatsky. Classification of Melekhov I. for assessment natural fire hazard classes was adapted and approved for Ukraine's conditions (Sviridenko et al. 1999).

Assessment of FF reserves

The distribution of forests on such voluminous FF categories reduces the accuracy of determining the classes of natural fire hazard. Since the distribution of FF within the types of forest and plantations is very heterogeneous, it is difficult to predict the possibility of the fire occurrence. In the United States, these systems are NFDRS 78, BEHAVE and FFE and in Canada – CFFDRS (with subsystems for FWI fire risk assessment and FBP fire behaviour prediction) (Hea et al. 2004).

In order to construct such systems, accurate estimation of fuel load (FL) is required. Since FLs differ in their properties and roles in the process of forest plantation combustion, their assessment must be done by dividing them into fractions. There are several methods for assessing the stock of the surface FF. Some of them were considered in the works by Kurbatsky et al. (1974), who substantiated the necessary parameters of the sampling at the test sites, number, area and its location. Methods for assessing the stocks of terrestrial FF are also described by Sofronov and Volokitina (2007). To fully assess the fire hazard in the forests, the stock of the aerial fuel and crown fuel (the standing and supported live and dead fuels not in direct contact with the ground) should be considered.

Ignition ability of different types of fuel

Drying of FF to critical moisture content occurs under the influence of a number of weather factors, and their fire maturation occurs in different ways. Some scientists suggest to use the concept of fire maturation in forest areas for the determination of the fire hazard level. Under such conditions, it is necessary to make maturation scales based on the analysis of surface FF in different periods (spring, summer and autumn), considering the peculiarities of plant vegetation (Volokitina and Sofronov 2002; Kurbatsky 1963, 1974, 1984; Sofronova and Volokitina 2007). Surface type of FFs plays a significant role in the process of occurrence and spread of forest fires: living surface cover, undergrowth and litterfall. FF of this group can quickly change their humidity under the influence of external factors (precipitation and air temperature). They relate to both combustion conductors that support combustion and materials that sustain combustion, depending on the season of the year. They can be ignited in humidity by 25% to 40%. An important factor that determines the FF combustibility is their hygroscopicity. All FFs can be divided into non-hygroscopic, living plants that are able to regulate their moisture content, and hygroscopic, plants whose moisture content depends on the environment. Also, an important factor is the upper limit of moisture content at which the combustion is possible – extinction moisture content. It differs in different types of terrestrial fuel, and many scientists have identified this limit. According to this, Nesterov et al. (1945b) pointed to the limit for *Pleurozium schreberi* (Brid.) at the level of moisture content up to 45%, and Kurbatsky (Kurbatsky 1963, 1974) defined this level on a range from 25% to 40%. In further research fire scientists identified different thresholds for extinction moisture content, for example, Melekhov set this level to 27% (Melekhov and Dusha-Gudym 1979). At the same time, Volokitina gave the data with regard to the limit of extinction moisture content for various fuel types: lichens – 37%, mosses *(Pleurozium schreberi* Mitt.) – 16%, fall of herbs – 16% and fall of pine needles – 23% (Sofronova and Volokitina 2007). Forest plantations with the specified types of ground cover are the most fire hazard. Zibtsev noted that the most dangerous forest type was pine stands with lichens, heather and green mosses, and during droughts, fires can occur even in wet types of forest with a predominance of moss cover and sedges (Law of Ukraine "On Occupational Safety" 1992).

Before 2018 in Ukraine for fire danger assessment by weather condition was used modified Nesterov method (1945b). Fire danger index by Nesterov indirectly express moisture content litter and duff during fire season. According to Zibtsev et al. (2006), the litter ignites for Nesterov index of 300–500. For 700 and more in the conditions of soil type A_2–B_2, there are persistent fires, which can burn the entire litter.

FF complexes as a major factor of the forest sites natural fire hazard formation

One of the main signs of the potential combustibility of forests, which causes the consequences of the negative impact of fire on the forest, is the intensity of the fire, which is largely determined by the reserves of FF in plant associations (Ivanova 2008; Matveev 2006; Matveev et al. 2008). Scientists observed that in dry types of forest (lichen and moss-lichen), fires spread rapidly, and due to the running type of fire behaviour, often it leads to elongated contours. In more humid types of forest (moss, moss-bush and sphagnum), the speed of forest fires is much lower, and combustion has a steady character, which is explained by the increased reserves of FF especially duff layer. Tsvetkov et al. (2006) developed a scale for assessing the factors of fire resistance of larch forests. Their scale included FF stocks as one of the main factors with statistical weight factor of about 0.45, and the stock of FF is a determining factor in the fire resistance of plantations as they determine the intensity of fires and the speed of their spread.

The accumulation rate and the total stock of FF are determined by the type of forest, the age of the stand and the regime of forestry (Law of Ukraine "On Occupational Safety" 1992; Matveev et al. 2008). Kuzyk et al. (2009) indicated that the indirect effect on the accumulation of fuel is carried out by ground conditions, in particular, the soil's richness. Thus, the increase of the humus and mineral element content contributes to the more intensive development of herbaceous vegetation, which in spring and autumn leads to the accumulation of herbaceous litter, which in turn increases the fire hazard.

Patterns of forest litter and duff accumulation

Particular attention is paid to the accumulation of forest litter and its fractional composition. Some scientists, in particular, Ivanov et al. (2008), gave a decisive role in the process of fire and its intensity to the forest litter and its reserves, since it makes up 50% to 80% of the total stock of FF. Shevchuk et al. (2005) noted that the reserves and composition of forest litter are closely related to the types of woodland, ecological structure, forestry conditions and fauna. They also pointed the increasing forest litter with age due to the inhibition of the organic matter decomposition at the stage of humification. Atkina et al. (2005) noted the increase of the tree fallage with age, which leads to the accumulation of litter and its stocks increase five to seven times in 80 years.

The accumulation of litter under different conditions takes place in different ways; besides the capacity of the litter, its stock varies sharply within the same type of forest and depends on the homogeneity of planting in the forest area, microrelief, age of the planting and other factors. In the literature, there are various data on the capacity and the stock of litter and their variability. Atkina and Starodubtseva (2005) gave the following data: variability of litter in mixed forests near Moscow reaches 68%, in the plantations of the Polissya of Ukraine – 15–30%, and in Canadian woodlands – 36–38%. Most often, when considering the process of forest litter accumulation, it is evaluated not as a combustible material but as an important element of natural succession, which determines the soil fertility and the productivity of forest stands. Thus, according to Krykun et al. (2007), the study of reserves and the functional role of litter and precipitation is an integral part of forest biogeocoenosis. Under these conditions, the fractional composition of the litter (Vorobeychik 1995; Atkina et al. 2005) and the influence of anthropogenic pressure on their dynamics are often analysed (Vorobeychik et al. 1995).

It should be emphasised that in most publications, data on the number of FF types are presented, which is limited only by forest litter and organic decay. According to Usenya et al. (2002) in the conditions of the establishment of reserves of combustible materials in forest plantations, this is clearly not enough, since it is necessary to take simultaneously into account the living surface cover. These features are taken into account in their studies to determine the amount of FF group "surface" in plantations of conifer species of the Republic of Belarus (Usenya et al. 2002). For the study of FF, it is expedient to consider them not separately but as on aggregation, since the study of separate litter and separate living surface layer will not give a clear picture of their accumulation and the causes of the occurrence of fires.

The conducted analysis of the data of scientific publications showed that there is a certain spatial variability of reserves of combustible materials in coniferous forests. For example, according to Konev et al. (1972), litter reserves in 30-year-old pine forests of the central part of the subzone of broadleaf forests form 32.4 t ha^{-1}, in fresh subor – 39.2 t ha^{-1}, and in fresh sugrud – 48.3 t ha^{-1}. Medvedev et al. (1976) noted that the stock of air-dry matter of organic residues in pine cranberries in the Bryansk region reaches 72 t ha^{-1}. At the same time, in the pine forests of the Moscow region, the supply of litter varies from 25.1 to 33.0 t ha^{-1} (Usenya et al. 2002).

Konev et al. (1986) emphasised that the amount of living herbs, which are the main combustion conductors for the occurrence of grass forest fires, accumulates in plantations in conditions of excessive moisture, where the processes of decomposition of organic matter occur with low activity, and the smallest number – in the woods with the poor and dry sandy soils. According to Volokvitina in the climatic conditions of the Krasnoyarsk for smoldering fires in plantations on marsh soils with a developed peat horizon, the mass of organic materials involved in combustion can reach 150 t ha^{-1}.

The smallest annual needle fall in the forests of the Arkhangelsk region is observed in lichen pine forests – only 0.7 t ha^{-1} and somewhat larger stock in pine birch trees – up to 1.6 t ha^{-1}. In pine forests of the Novgorod and Yaroslavl regions, it reaches 5.3 t ha^{-1}, the Moscow region – up to 3.5 t ha^{-1}, Voronezh region – up to 4.9 t ha^{-1} and Bryansk region – up to 4.5 t ha^{-1} (Usenya et al. 2002).

Fractional composition of the FFs in pine forests

In addition to the FF stock, their fractional composition is also considered. Thus, according to Matveev et al. (2006), herbaceous plants and shrubs make up from 5.7% to 13.5% of the mass of surface type of FL. Reserves of litter in larch forests range from 4.1 to 24.7 t ha^{-1}, herbs and half-shrubs vary in the range of 1.4–2.2 t ha^{-1}, and mosses and lichens range 3.9–9.7 t ha^{-1}. Tsvetkov et al. (2006) gave a fractional distribution of FF of larch forests: forest litter – 61.1–74.4%, lichens – 2.1–7.4%, mosses – 5.0–14.8% and oats – 1.2–5.0%. According to Volokitina and Sofronov (2008) in the larch forests of north Russia, the reserves of FFL vary in the range of 55.8–87.6 t ha^{-1}, including litter 5.2–55.7 t ha^{-1}. It is noted that reserves of moss and litter layers in homogeneous pine stands fluctuates under the influence of a nano relief within 30%.

The fractional composition of the FFs varies according to the characteristics of the plantings. Thus, with the increase in the completeness of plantations, the share of the herbs decreases and the participation of shrubs and mosses increases; there is a fall increase and, in turn, growth of litter stock. With the increase in the percentage of deciduous species in the composition of plantations, the participation of herbs and shrubs increases. Under these conditions, the stock of mosses, lichens, litters and total stock of FFs are reduced (Matveev 2008; Furyaev et al. 2008). Research studies on the accumulation of FF were also conducted in Canada, the United States and European countries. For example, in the United States, the dynamics of accumulation of FFs in different forest composition were analysed, taking into account annual falling and gumming of litter (Agee et al. 1978).

Based on the investigation of the spatial location of FF and the effect of their humidity on burnout, it has been established that the thickness of the forest litter decreases from the tree trunk to the periphery of the crown, the low humidity of the litter does not have a significant effect on the degree of its burning, and humidity, which varies within 30–120%, causes more complete burning of the litter near the barrel and its less burning on the periphery of the crown and in the gaps. The reason for this is the uneven distribution of litter in forest plantations. Data on their distribution under the canopy of plantations are given in Volokitina and Sofronov (2002). They also investigated the layer-by-layer drying of surface FF and proved that the thickness of its layer does not affect the appearance of a fire, but only determines the intensity and speed of its propagation (Volokitina and Sofronov 2002; Volokitina et al. 1978). The completeness of forest bed burning was studied by Matveev et al. (2006), who found that the occurrence of fires in the bush-moss group of FF is possible at a humidity of 220% and in lichen at 180%. Under such conditions, complete burning of the litter is possible only at a moisture level of 20–30%.

Combustion of FF during wildfires and post-pyrogenic formation of FF complexes

The fires have a significant negative impact on the composition and properties of forest litter, on the processes occurring in it and on the forest soils. After the fires, the elemental composition of the combustible materials and the upper layers of the soil sharply change and the content of humus in the soil decreases; at the same time, the amount of ash elements increases, in particular, the exchangeable Ca, K, P, etc., the content of C and N decreases, and the actual acidity of the soil increases. An important problem is the post-fire restoration of litter; the stock of litter in pine forest with cowberry and motley grass in the first year after the fire amounted to 7.5–8.0 t ha^{-1}, 30 years after the fire – 9.1–10.5 t ha^{-1}, and at the same time, as on the control – 30.4–37.3 t ha^{-1} (Boloneva 2008; Ivanova and Ivanov 2003; Krasnoshchekov and Kuzmichenko 2006). Evdokimenko et al. (2008) gave the following data on the restoration of litter after fires. The amount of needles falling in a year of fire is 240 g m^{-2} and at the control plot – 85 g m^{-2}; during the fire, it was burned down 1540 g m^{-2} of litter and 1120 g m^{-2} of herbs. Increasing the mass of falling needles occurs due to partial damage to crowns of trees. Already a year after the fire, the mass of litter is normalised, and it is directly dependent on the number of needles on the branches, and after 2 years, it becomes 1.5 times weaker than on the control. Therefore, for a complete restoration of the litter and all the functions that it performs, it takes a rather long period of time. In addition, there is a significant disruption of the water regime in the fire, and surface runoff increases due to atmospheric precipitation (Evdokimenko et al. 2008).

Practical application of fuel data in fire management

Different measures and systems based on the FF information are offered to prevent and predict the occurrence of fires. Thus, American scientists have proposed, as a precautionary measure, the elimination of FFs by mechanical means and the control end combustion (Agee and Skinner 2005; Hea et al. 2004). A number of systems for forecasting the emergence, spread and prediction of the consequences of fires have been developed; an important condition for the functioning of which is the availability of data about FFs. A large-scale mapping of FF and the use of meteorological information will allow to effectively predict the behaviour and consequences of fires (Volokitina 2004; Volokitina and Sofronov 2002; Sofronov and Volokitina 2007). The justification of mapping and methods for its conducting are described in a number of publications (Belyakin and Volokitina 2008; Karnaukhov 2008; Volokitina and Sofronov 2002; Redkin et al. 2008).

The current stage of FF in Ukraine

In Ukraine, only fragmentary studies on stocks and characteristics of FFs have been conducted. Kuzyk et al. (2014) in the laboratory studied the combustion parameters of the most common types of aboveground FF, the temperature of ignition of pine needles, oak leaves, herbs and shrubs. They found that the temperature of ignition of freshly cut needles is lower than dry. For tree leaves, there is an inverse relationship, and the lowest temperature is in the ignition of leaves of alder. The laboratory of forest ecology (Ukrainian Research Institute of Forestry and Forest Melioration named after G.M. Vysotsky) conducted research on forest litter reserves in Polissya pine forest of all ages and forest vegetation conditions separately for different layers of mineralization (decaying, enzymatic and humified). It was found that litter reserves increase with age and trophy of pine forests, their spatial placement within the forest species is also heterogeneous, most of the litter is accumulated under the tree trunk, with the age of planting the proportion of the humified layer increases, and the volume mass of the litter also increases (Voron et al. 2018). The scientists of the National University of Bioresources and Nature Management of Ukraine conducted a study on the surface FF stocks using a selection of litter on the layers of mineralization, while simultaneously taking FL into fractions, using the US Forestry methodology (FIREMON; Hurzhii and Yavorovsky et al. 2018). Employees of the East European Fire Monitoring Center began the creation of a pyrological geoportal within the framework of the integrated fire management system (Zibtsev et al. 2018), the main input parameters for which will serve data on the patterns of accumulation of different types of FF and the dynamics of their humidity. Based on this, the study of the dynamics of accumulation of FL in various types of landscapes is a priority task of pyrological research in Ukraine.

Conclusions

1. Analysis of scientific articles has shown that the danger of natural forest fires is determined by the presence, reserves and nature of the FF and their readiness to ignite.
2. When determining the FFL, all vegetative fuel materials, and not only forest ones, should be taken into account, as forest lands are also not covered by forest areas (glades, wastelands, etc.), which may also cause fires.
3. The formation of stocks and structure of combustible materials affects a number of environmental factors: soil and climatic conditions, relief, tax characteristics of planting, etc.
4. It was established that the study of the trends of the FF accumulation in Ukraine is fragmentary and requires additional research and unification of the methods about FF sampling and accounting. In the future, this will allow the mapping of FFs on a national scale.
5. Accumulation of reliable data about FF stocks in forest and non-forest lands may only be possible if scientists agree on the methods of accounting and selection of combustible materials.

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