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UNFAVORABLE CLIMATIC FACTORS AND THEIR IMPACT ON THE DECLINE OF SPRUCE AT THE KOPAONIK NATIONAL PARK (CENTRAL SERBIA)

Goran Cesljar[1,*], Ljiljana Brasanac-Bosanac[1], Ilija Dordevic[1], Sasa Eremija[1], Marija Milosavljevic[1], Filip Jovanovic[1], Ljubinko Rakonjac[1], Srdan Simovic[2]

[1]Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
[2]Kopaonik National Park, Suvo Rudište bb, 36354 Kopaonik, Serbia

ABSTRACT

The paper presents the results of research on the influence of natural (biotic and abiotic) factors on the decline of spruce [Picea abies (L.) Karst.] at the Kopaonik National Park (Republic of Serbia), in the period from 2010 to 2019. As an indicator of the influence of unfavorable climatic factors on the decline of forests in the Kopaonik National Park, the share of random yields of wood volume in the total allowable cut, resulting from the overpopulation of bark beetles, was determined. In order to understand the causes of decline, a sample plot, located in pure spruce stand older than 60 years in the northwest exposure and at the altitude of 1720 m, was used to monitor and assess the impact of air pollution and its effects on forest ecosystems. Furthermore, the data on temperatures and precipitation amounts during the year and in the vegetation period were analyzed in order to understand and connect the influence of unfavorable climatic factors with the decline of trees more clearly. A comparison was made between tree mortality, when occurred, with the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) as the most commonly used indicators for monitoring drought. It was stated that the decline of trees was initiated by the influence of unfavorable climatic factors during three consecutive years (2011–2013), accompanied with snowstorms during the winter of 2012, which created favorable conditions for overpopulation of bark beetles as secondary pests. As a result, one of the largest deforestations was recorded on the territory of the Kopaonik National Park. These results indicate that changes in precipitation and air temperature, whose deviations from the decade long average have been occurring regularly for several years, have significantly weakened the vitality of trees, and thus increased their predisposition to the increase of already present bark beetles.

KEYWORDS:
Forest decline, climate factors, drought, bark beetle overpopulation, random yield of wood volume, Kopaonik National Park

INTRODUCTION

Decline of forests is one of the most recent problems in the world and in the Republic of Serbia, both from economic and ecological aspects. By observing only the last decade in Europe, the highest temperatures, without precipitation, have been recorded. It doesn't take long before a year or a season is characterized as the warmest and driest since the beginning of meteorological measurements in countries all over Europe [1, 2, 3]. The same observations are made globally [4]. These events greatly affect the resistance of different tree species. The research of Schuldt *et al.* [5] states that even species which are considered drought-resistant, such as pine (*Pinus nigra* J.F.Arnold) and beech (*Fagus sylvatica* L.), suffer long-term damage, with spruce (*Picea abies* /L./ Karst.) being most affected.

Decline of the forests is a result of number of factors. A numerous researchers deal with this issue. Some of them point out that unfavorable climate factors are dominant and primary in terms of forest mortality [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. Climate change, at the local or regional level, increases the risk of extinction of certain plant species [19]. Droughts, accompanied by high temperatures, have a strong impact on forest ecosystems and are predisposed to outbreak of bark beetle in coniferous forests [20]. Some authors note that there may be a change in structure and composition of tree species in a particular area affected by drought, which is directly caused by drought [21], or insect attacks on trees weakened by drought [22], where the end result is the same. Unfavorable climate factors lead to decrease in stability of the entire ecosystem, which causes a disturbance of the biological balance and an increase in number of insects and phytopathogenic fungi, with the forest decline as a final outcome. If, in addition to all the above, natural disasters such as snow, wind or ice occur, then the consequences in national parks are inevitable.

One of the main problems in national parks, as strictly protected areas, is that forest management is not allowed as in unprotected forests, where the amount of dead wood is much smaller, since sanitary feelings, removal of fallen trees after snow-brakes and windbrakes and other sanitary measures are allowed. In accordance with the previously presented approach of intensive protection of forest ecosystems, it is important to point out the fact that national parks are one of the highest forms of environmental protection and represent ideal areas for studying natural processes and their relations that are not affected by humans. Within national parks, especially in the first zones of protection, forests are left to run its own course, so it is only possible to monitor the development without any management.

Due to projected climate change [23], primarily considering the frequency of extreme climate events, there is a need for a strategy that will adapt existing forests to future conditions [24]. This scenario can be very important for forest ecosystems in which spruce is the main species because it is susceptible to many risks, such as windbreaks, snow-breaks, pathogens and pests (e.g., bark beetles). In the research of Neuner *et al.* [25], it is noted that spruce has less chances of survival if it is found in clean stands due to the warm climate. Also, Krupková *et al.* [26] and Bolte *et al.* [27] note that spruce is prone to both biotic and abiotic influences, where drought plays a crucial role, due to its shallow root. In fact, drought is a major cause of spruce decline [28], and bark beetles are one of the first insects to attack weakened spruce trees. Monitoring the changes in trees, affected by the decline process, is necessary in order to understand the cause itself, because it is known that several factors are linked. Vital spruce trees have several levels of defense system against bark beetle attacks. The first level of defense is the release of resin after the bark beetle penetrates the bark. Trees with a thicker bark and higher concentration of resin sacs are more successful in repelling attempted attacks. The second level of defense involves changes in metabolism near the entrance hole [29, 30], and the third is a systemic change in the complete metabolism of the host tree. The biology of most bark beetles is adapted to the physiological state of the host, which means that they burrow only into physiologically weakened trees (secondary pests). A small number of insect species is able to attack completely healthy, vital trees, under certain conditions, i.e., they become primary pests. Eight-toothed (*Ips typographus* L.) and six-toothed spruce bark beetle (*Pityogenes chalcographus* L.) are known to have the ability to dramatically multiply [31]. *I. typographus* and *P. chalcographus* are the most significant, economically harmful insect species in natural spruce stands in Europe. Research in 24 European countries confirmed this claim, where the eight-toothed spruce bark beetle is ranked first, and the six-toothed spruce is ranked third among the most important economically harmful spruce organisms [32]. Research has also confirmed that 8% of the total damage in Europe's forests, between 1850 and 2000, was caused mainly by *I. typographus* [33].

Continuous monitoring of the forests conditions is performed within the ICP Forests program [34] which is one of the most diverse approaches to researching the impact of various factors on forest ecosystems. Furthermore, it can gather information that is important in determining what happened in the previous period. Otherwise, by ascertaining decline of forests at a certain area, at a precise moment, without prior continuous monitoring of the condition, it is not possible to determine, with certainty, the reason for decline, due to various factors that may have influenced that condition.

Taking into account unfavorable climatic factors and random yields of wood volume, as their end result in interaction with bark beetles, the main goal of this paper is a better understanding of these impacts, primarily long-term drought and its effects on decline spruce forests in Kopaonik National Park. Thus, the impacts of spruce tree decline mentioned here combine the personal observations of teams collecting data from a sample plot, data from Kopaonik National Park on random yields of wood volume and data on temperatures and precipitation from the main meteorological station on Kopaonik by calculating a standardized precipitation index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI).

MATERIALS AND METHODS

Within the Kopaonik National Park, a permanent survey area was set up in 2010, i.e., Level II bioindication point as part of the ICP Forests program [35], whose main goal is to gain a better understanding of the cause-and-effect relation between forest ecosystems through intensive monitoring of natural (biotic and abiotic) stressors. This sample plot is located in a pure spruce stand older than 60 years, at the northwest exposure and at an altitude of 1720 m. During the years of research, the decline movement of all spruce trees was monitored in this sample plot. The basic method is based on monitoring defoliation according to the ICP Forests methodology [35] (Table 1).

TABLE 1
Assessment and categorization of defoliation according to the ICP Forests methodology

Classes of defoliation	Leaf/needle loss (%)	Degree of defoliation
0	0–10	None
1	>10–25	Slight (warning phase)
2	>25–60	Moderate
3	>60–100	Severe
4	100	Dead

In addition to the climatic characteristics of the research period (2010–2019), which relate to air temperature and precipitation data during the year and during the vegetation period, from the main meteorological station Kopaonik (RHSS) (coordinates: longitude 20°48'E, latitude 43°17'N; altitude 1710 m a.s.l.), which is located in the immediate vicinity of this sample plot, the problem of decline spruce forests is explained through the participation of random yield of wood volume in the total allowable cut gathered in all four forest management units of Kopaonik National Park, after extreme climatic events (2011–2013) in the period from 2014 to 2019.

In order to relate the drought period to the decline period of spruce trees, a standardized precipitation index (SPI) was calculated by McKee *et al.* [36] and Standardized Precipitation Evapotranspiration Index (SPEI) according to Vicente-Serrano *et al.* [37]. For the purposes of calculating the drought period according to the SPI, precipitation is the only input parameter, and to define the drought intensity, the categorization shown in Table 2 was used. We calculated the SPI for the six-month period (SPI-6), for the vegetation period (April–September), and the annual SPI (SPI-12) based on the data of the main meteorological station on Kopaonik. To calculate the SPEI, which in addition to precipitation is also based on temperature data, the global SPEI database was used [38]. For SPEI, we calculated time series at a single grid cell according to coordinates (43°25', 20°75'), which correspond to the research area. SPEI was also calculated for six and 12 months (SPEI-6 and SPEI-12), and categorization of humidity conditions was estimated based on the values shown in Table 3.

After obtaining SPI and SPEI results for dry periods, a comparison between dry period and tree mortality was performed.

For a total of 195 trees of spruce (analyzed in 13 groups, each consisting of 15 trees), annual mortality rates were calculated for two observation periods (2010–2014 and 2015–2019) based on monitoring data of defoliation according to the ICP Forests methodology [35] (trees with defoliation of 100% were considered dead). According to Sheil et al. [40], the true annual mortality is defined correctly by the following equation: $m = 1 - (N_1/N_0)^{1/t}$, where N_0 and N_1 are population counts at the beginning and end of the measurement interval – t. Given that *m* has been recommended as a standard quantity for comparing annual mortality rates in plant ecology [40], it was adopted as an annual mortality rate in this study. The variation in mortality rates was captured by using the mortality rate of each of the 13 groups of trees analyzed as a subpopulation. For calculating *m*, two 5-year intervals were used, because a 5-year interval is the most commonly used census interval length and it has been recommended by Lewis *et al.* [41] for maximizing the intercensus and intersite comparability. Before performing the statistical analysis, raw data on annual mortality rates were tested for normality. Since the assumption that these data come from normal distributions was not confirmed, the medians (M) were used for both intervals of observation, median absolute deviation (MAD) was determined

TABLE 2
Categorization of moisture conditions by SPI – Source: RHSS [39]

Category of moisture conditions	SPI values
Exceptional drought	SPI ≤ -2.326
Extreme drought	-2.326 < SPI ≤ -1.645
Severe drought	-1.645 < SPI ≤ -1.282
Moderate drought	-1.282 < SPI ≤ -0.935
Minor drought	-0.935 < SPI ≤ -0.524
Near normal	-0.524 < SPI< +0.524
Slightly increased moisture	+0.524 ≤SPI< +0.935
Moderately increased moisture	+0.935 ≤SPI< +1.282
Considerably increased moisture	+1.282 ≤SPI< +1.645
Extremely wet	+1.645 ≤SPI< +2.326
Exceptionally wet	SPI ≥ +2.326

TABLE 3
Categorization of moisture conditions by Standardized Precipitation Evapotranspiration Index (SPEI)

Category of moisture conditions	SPEI values
Extreme drought	≤ -2.0
Severe drought	-1.99 to -1.50
Moderate drought	-1.49 to -1.00
Near normal	-0.99 to 0.99
Moderate wet	1.00 to 1.49
Severely wet	1.50 to 1.99
Extremely wet	≥2.00

for each median, and the comparison and determination of the difference between the medians were carried out using the Kruskal-Wallis test (KWt). All statistical analyses were performed using the Statgraphics software (2009; Statpoint Technologies, Inc., Warrenton, VA).

RESULTS AND DISCUSSION

Influence of climatic factors on spruce decline. It is known that forest ecosystems can withstand a one-year drought without major impacts on them. However, repeated exposure to perennial droughts can have significant impacts on their functioning [42]. During these researches, on the entire territory of the Republic of Serbia between 2011 and 2013, the highest temperatures without precipitation, for a longer period of time, were recorded during the year and during the vegetation period, after which the decline of both individual trees and larger forest areas was observed. Particularly pronounced unfavorable climatic conditions, that affected the forest decline, were recorded during 2011 and in the vegetation period during 2012 [11, 18, 43]. Also, this dry period was recorded throughout a larger part of the European continent, which is confirmed by the data of the European Environment Agency – EEA [44]. Radulović *et al.* [45] cite drought as the main factor in the decline of coniferous forests in Serbia, while Spinoni *et al.* [46] emphasize that the frequency and severity of droughts increased especially in southern and eastern Europe during summer and autumn. Several studies, on the decline of spruce forests in Serbia in protected areas, such as Golija Nature Park [47], Tara National Park [48] and Kopaonik National Park [49], indicate that the decline was primarily caused by the influence of unfavorable climatic factors over a longer period of time, which preceded the mass decay of spruce stands. Drought is cited as the main trigger followed by parasitic fungi, windbreaks and snowbreaks (a pronounced problem in National parks), which led to the gradation of bark beetles as secondary pests.

In order to confirm previous research and better understand the consequences of the drought period, using new results on the spruce forest decline for the Kopaonik National Park, we calculated the deficit or surplus of precipitation based on SPI, with temperatures based on SPEI during the vegetation period (SPI-6, SPEI-6), which is shown in Figure 1, and on an annual basis (SPI-12, SPEI-12) in Figure 2.

The attached graphs show that the extremely dry period resulted in a deficit of precipitation, if we look at the whole year of 2011 (SPI-12), and especially the vegetation period of 2012 (SPI-6). These deficits actually show that the lack of precipitation was extremely low during these two years, i.e., it lasted for the whole year of 2011 and during the vegetation period of 2012.

In addition to precipitation, which is the only input data for SPI, we also included temperatures by calculating SPEI, which allows this index to calculate the impact of temperature on the development of drought. According to the presented methodology, SPEI values were calculated for a six-month (SPEI-6 – Figure 1) and twelve-month period (SPEI-12 – Figure 2). The attached Figure 1 shows the wet or dry events, over a six-month period, for the ten-year research interval in which the vegetation period was observed. It can be seen that 2012 was extremely dry, compared to previous and subsequent years, where it must be borne in mind that the presentation of SPEI 6 corresponds to September each year and represents a vegetation period. Also, it is noticed that some months, within this period, have the epithet of extreme drought. However, if we look at the periods a decade or two before this research [38], it can be clearly seen that 2012 is the driest year in the area of NP Kopaonik. Similar to the values of SPEI-6, the values of SPEI-12 also correspond to December of each monitored year and represent the annual SPEI (SPEI-12 – Figure 2). This review also highlights the drought period, which shows a prolonged drought during 2011 and 2012. It can be noticed that both indices (SPI and SPEI) show similar values during the years with an intensive drought.

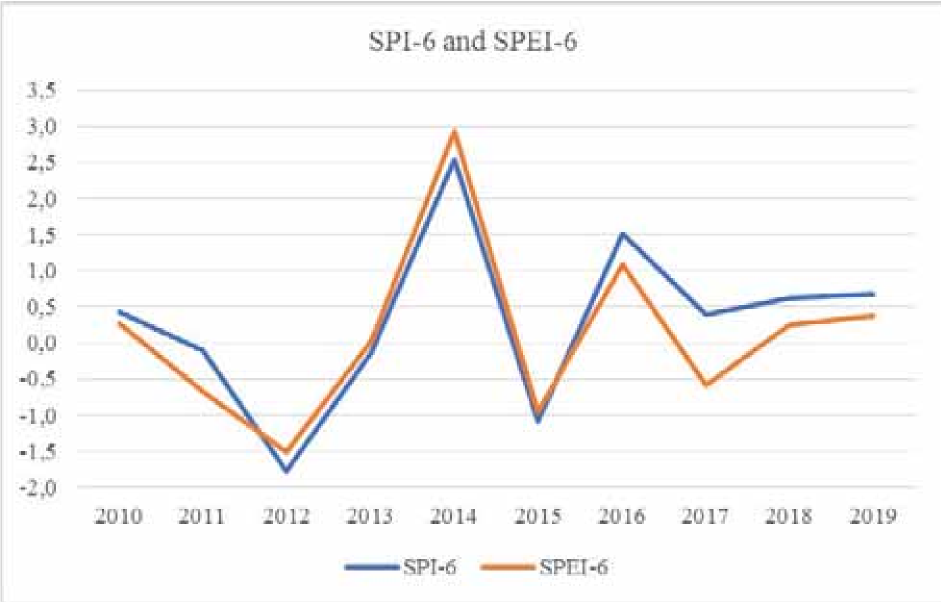

FIGURE 1
Moisture conditions in the growing season (April–September) in the Kopaonik National Park

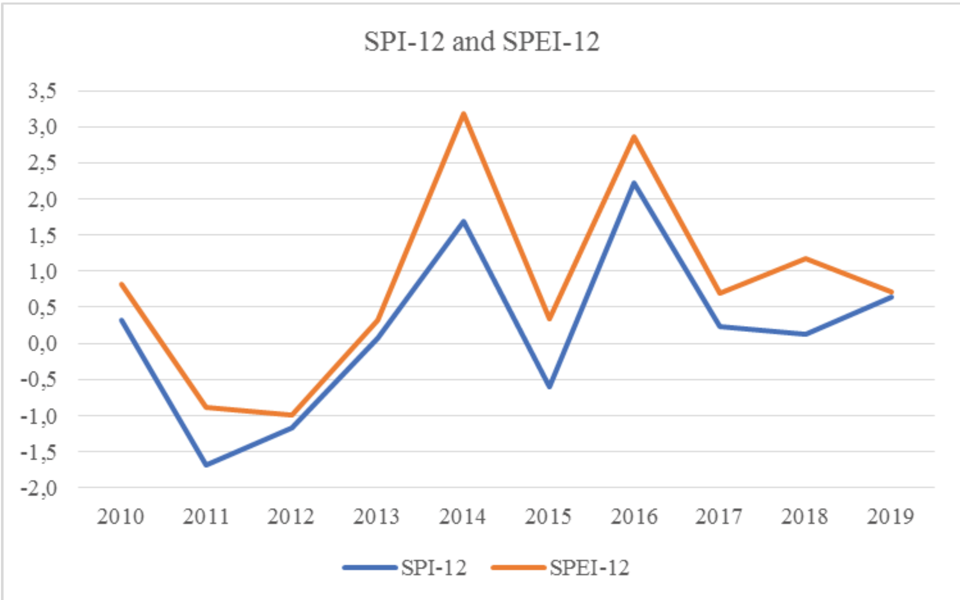

FIGURE 2
Moisture conditions on the annual level in the Kopaonik National Park

Spruce decline in the sample plot. Based on the ICP Forests methodology (part IV) [35], in the Level II sample plot – Kopaonik, within subfield 2, 30 trees were selected and condition of their crowns was assessed. However, in order to get a clearer picture and determine the cause of the possible tree decline, all trees within this sample plot (primarily defoliation) were observed. Since the Level II Kopaonik sample plot was set up, cases of individual trees, being attacked by the two most dominant species of spruce bark beetles, *Ips typographus* and *Pityogenes chalcographus*, have been registered. In the beginning, the attack was of low intensity and sporadic, and after extreme climate conditions, which were registered from 2011 to 2013, with snow and wind breaks in 2012, in 2013 the attack entered its culminating phase in some parts of the stand. Out of the total number of isolated trees (195), in the sample plot, 26 of them (or 13.4%) were attacked by these two most important species of spruce bark beetles, while in 2013 19 trees totally dried up [50]. Then, by 2015, the number of dry trees reached 35 (or 18% of the total sample plot). As an additional illustration of this phenomenon, a general overview of the condition of the spruce stand, in the sample plot of Level II Kopaonik is given (Figure 3), where the trees that dried in the period 2013–2015 are marked in red (Figure 3a and 3b). Also, Figure 3c shows a group of dried trees in the sample plot during 2013, while Figure 3d shows

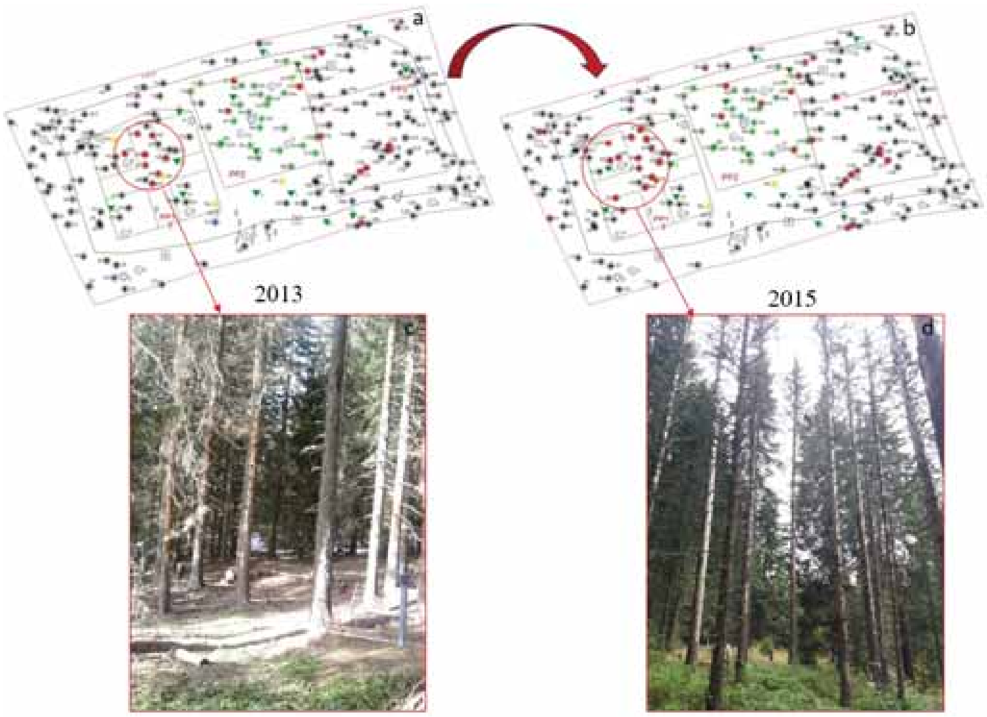

FIGURE 3
Spruce decline from 2013 to 2015 in the Level II sample plot – Kopaonik

the same group of dried trees that increased by 2015. A separate group of trees shows characteristic drying circles after bark beetle attack. Such phenomena of spreading of bark beetles and drying of trees are also detected in a large number of localities in the first protection zone of the Kopaonik National Park, for the same period.

In the same sample plot (total number of spruce trees 195), annual mortality rates were calculated for two observation periods (2010–2014 and 2015–2019) based on monitoring data of defoliation (trees with defoliation of 100% were considered dead). The results of the descriptive and non-parametric statistics for the annual mortality rates of spruce in the Kopaonik National Park for two observation periods are presented in Table 4. The medians of the annual mortality rates were 0.02 and 0.00 for the observation periods of 2010–2014 and 2015–2019, respectively. According to the KWt, there is a statistically significant difference at the 95% confidence level ($P = 0.04$) between the medians that represent the two observation periods. The Box and whisker plot (Figure 4) shows that the median of annual mortality rate for the first observation period (2010–2014), which was affected by drought, was higher than the median obtained for the second observation period (2015–2019).

Influence of spruce decline on the increase of random yield of wood volume. After the extreme climatic events were recorded, for the period 2011–2013 on the entire territory of the Republic of Serbia, forest areas affected by decline were easily observed. Despite the higher altitude, which is characterized by a humid climate (Kopaonik mountain), there was a deviation from the usual averages of precipitation and temperatures, for the mentioned years. According to the Forests Act of the Republic of Serbia (Article 45) [51], extraordinary measures for forest protection are adopted in case of significant disturbances of biological balance and serious damage to forest ecosystems caused by natural disasters. Natural disasters in forests are considered to be significant disturbances of the biological balance and the occurrence of serious damage to forest ecosystems. These damages can be caused by fires, decline, plant diseases and pests, windbreaks, snowstorms, floods, torrents, landslides and other unforeseen factors over the large areas of forests and forest land [51]. In this case, as a result of natural disasters, primarily prolonged droughts with snow and windbreaks, decline of forests occured, thus affecting the increase in yield (random yields) in the total felled wood volume. Random yield is defined as the amount of felled timber that is not intended for felling by regeneration felling and thinning plans, and the reason for its felling is accidental and is the result of natural disasters or other unforeseen circumstances, while irregular yield includes felled timber from trees which will be used for other purposes (roads, mines, etc.). Random yield for the entire area of the Kopaonik National Park, after the drought period (2014–2019), can be observed as the best indicator of tree decline. Table 5 shows the problem of decline spruce forests in all four forest management units of the Kopaonik National Park through the participation of random yield of wood volume in the total allowable cut achieved in six years of management. Also, the problem of yield sustainability over a ten-year period is presented (Figure 5).

Table 5 shows that the volume of felling, in the first six years of the management in the area of NP Kopaonik, was significantly above the planned annual dynamics. The structure of the total allowable cut realized was very unfavorable, because the random yield dominated with 40%, while in 2017 the share of random yield was as high as 61%. If we look at the entire ten-year management period (2014–2023), the achieved allowable cut in the first six years was already at 72% of the planned, which implied significant reductions of all types of felling by the end of the period (Figure 5) and indicated the seriousness of tree decline when the aforementioned random yields occurred. It must be noted that the largest percentage of random yields was obtained from the first protection zones where the droughts were most intense and where it was necessary to "react", so that the scale of the drought would not take on the epithet of disaster.

TABLE 4
Descriptive and nonparametric statistics for the annual mortality rates of spruce in the Kopaonik National Park for two observation periods

Period of observation	Sample size	M	MAD	MIN	MAX	Range	Average rank in KWt	Test statistic	*P*-value
2010–2014	13	0.03	0.02	0.00	0.14	0.14	16.50	4.26385	0.0389283
2015–2019	13	0.00	0.00	0.00	0.05	0.05	10.50		

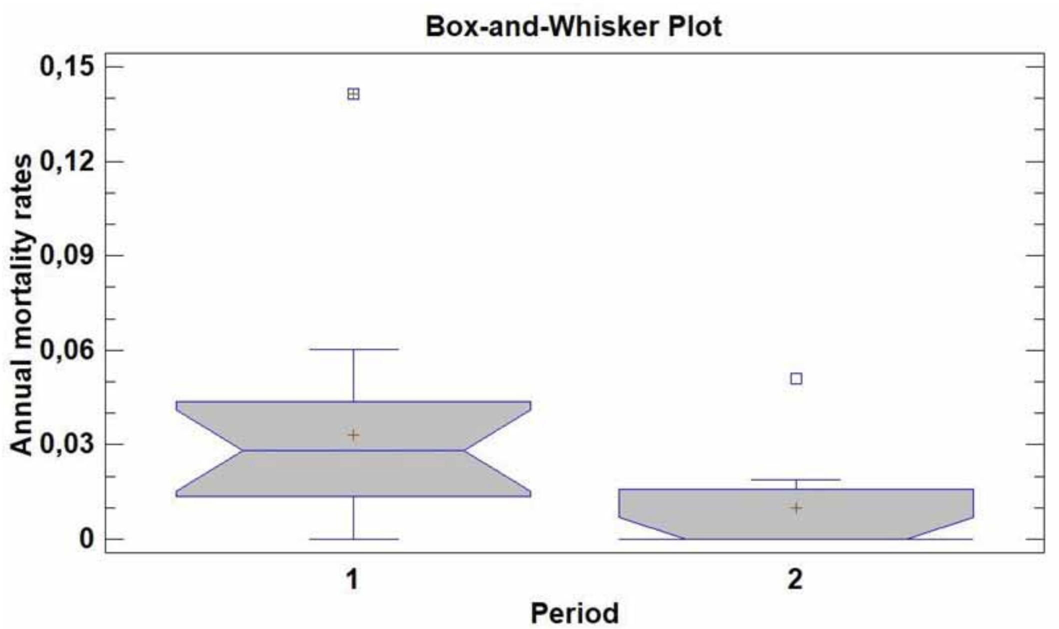

FIGURE 4
Box and whisker plot of basic statistical parameters of the annual mortality rates of spruce in the Kopaonik National Park for two observation periods: (1) 2010–2014, and (2) 2015–2019

TABLE 5
The structure of the felled spruce volume for the management period 2014–2019 in the Kopaonik National Park. Data source: NP Kopaonik

Year	Regular yield m^3 (1)	Random yield m^3 (2)	Irregular yield m^3 (3)	Total yield (m^3) (1+2+3)	Proportion of random yield (%)
2014	18 311	11 494	1 142	30 947	37
2015	13 442	10 955	640	25 037	44
2016	20 489	11 584	204	32 276	36
2017	9 149	14 879	461	24 489	61
2018	10 672	7 419	1 621	19 712	38
2019	13 796	5 817	3 218	22 832	25
Total	85 859	62 148	7 286	155 293	40

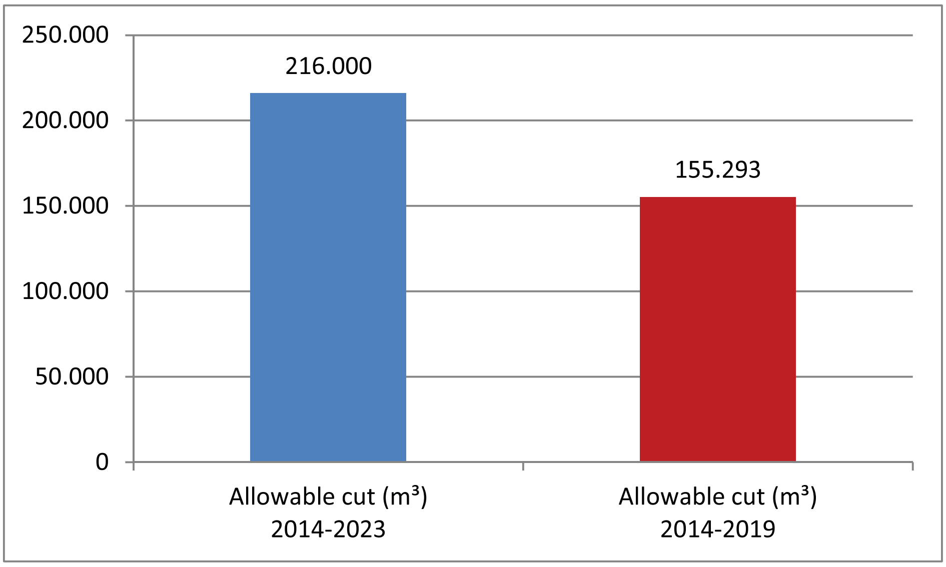

FIGURE 5
Allowable cut in the Kopaonik National Park. Data source: NP Kopaonik

Decline, which occurred on a large scale, where the random yield was a dominant part of the main yield, resulted in a serious violation of the principle of permanence (sustainability) of yield, which required urgent changes and amendments to forest management plans. The problem was further complicated by the fact that any change in the planning document had to be approved by the relevant Ministry.

Problems, from the planning aspect, caused by this phenomenon of strong intensity, are manifested in losses in production, structure and stability breaking of stands, uncertainty in achieving management goals, inability to realistically determine and respect the prescribed measures to achieve goals and jeopardizing the real purpose of management, as well.

CONCLUSION

National parks, as strictly protected areas in which every human activity is regulated by law, are not physically separated or detached parts of nature, but they are also affected by all kinds of biotic and abiotic factors present in the entire ecosystem. In this regard, national parks are ideal areas for monitoring the aforementioned factors.

Forest decline in the Kopaonik National Park can be attributed to the influence of three groups of factors – predisposing, stimulating and contributing. The stand and its age can be the predisposing factors. Incentive factors, and in this case the most influential, are physiological drought and extremely hot and dry three consecutive years (2011–2013), while contributing factors are damage from snow and wind in 2012, together with climatic factors and root rot fungi. The main factor in forest decline, which determines the total mortality of trees, can be considered the gradations of bark beetles, which accompanied all previously mentioned factors.

Very pronounced, and so far unnoticed, forest decline in the Kopaonik National Park, during several years (2014–2017), and certain circumstances related to the impact of very unfavorable climatic characteristics on the growth and development of vegetation in the period 2011–2013, as well as the overpopulation of bark beetles after these events, indicate their connection and contribution to the large-scale forest decline.

Looking at the whole area of Kopaonik, during the study period, it was found that the decline started from the first degree of protection due to impossibility to sanitate the areas that have been affected by wind and snowbreaks, especially after the winter of 2012, when a large amount of snow fell, just before and after a vegetation season, with an extremely low rainfall and extremely high temperatures. It caused favorable conditions for the attack and overgrowth of bark beetles. Due to the previously mentioned factors, there was a large percentage of the share of random yields of wood volume in the complete management of forests.

Decline, caused by unfavorable climatic factors such as high temperatures without precipitation over a long period of time, consumes and affects all forest ecosystems, both in protected (as is the case in national parks) and in forests that are not protected. However, a significant feature of the national park management is that adequate measures cannot be applied, at a given time, which can sometimes be key to mitigating decline progression due to secondary drying agents (e.g., bark beetles). On the other hand, a plus side of this kind of management is reflected through scientific research, because in national parks one can see the original influence of nature and its effect on forest ecosystems.

If we want to preserve forests, intensive monitoring can be a valuable tool in making timely decisions in the process of forest protection within national parks, where sanitary felling is not allowed and where administration is often an aggravating factor, when it is necessary to act quickly. It is obvious that humans have done a lot to upset nature's balance. Therefore, we are obligated to help nature, whenever possible, overcome the problems so it does not get out of control and could not be stopped later.

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CORRESPONDING AUTHOR

Goran Cesljar
Institute of Forestry
Kneza Višeslava 3
Belgrade 11030 – Serbia

e-mail: cesljargoran@gmail.com