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ADAPTIVE FOREST MANAGEMENT: CASE STUDY OF SESSILE OAK (*Quercus petraea* (Matt.) Leibl.) FORESTS ON OZREN MOUNTAIN OF THE REPUBLIC OF SRPSKA

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Adaptive management is a basic concept of managing forest ecosystems in the face of increased risks such as climate change. Therefore, there is a need to develop key theories and information on which adaptive forest management is based on. This paper deals with the overview of basic information on adaptive forest management, with particular reference to its importance in relation to examples of sessile oak forests drying and climate change in the Republic of Srpska, Bosnia and Herzegovina. Silviculture of sessile oak forests affected by acute and chronic drying of the trees should be based on the preservation of the complete set of stands and miscibility with black pine on shallow serpentinite and peridotite soils. The paper deals with the possibilities of adaptive management of sessile oak forests and concludes with a description of adaptive management activities.

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Introduction

Adaptive management is the monitoring of activities (controls) in order to adapt future plans and strategies to the desired management effects. The first ideas about adaptive management of natural resources are described in the papers of Holling C.S. (1978) and Walters C.J. (1986) [13, 43]. The main causes that influenced the implementation of adaptive forest management are related to basic forestry principles (sustainable development, common social interests, forest functions, forest management goals, obligations of forest users, etc.). The basic three types of adaptive control are reactive, passive and active adaptive control [7, 44]. Reactive management implies that management results are used for subsequent decisions that are expected to lead to improved results and achievement of goals. This form of management evolves from inexperience in management as it takes on all the benefits that come from the application of earlier management systems. Passive adaptive management is based on the prediction of ecosystem response to the earlier activities of the control mechanisms. Passive monitoring and evaluation of management is carried out before the start of management activities and there is no satisfactory control over the response to the management mechanism as monitoing is not sufficiently represented. The key problem is that in passive management, the answer to the question “was the impact of control mechanisms on the ecosystem caused by a management activity or a natural process?” in passive adaptive management, decisions are made mainly on the basis of quantitative indicators, but insufficient attention is paid to unforeseen events (risks).

Active adaptive management can establish a cause-and-effect relationship between management activities and ecosystem changes based on the monitoring of experiments (“learning from practice”). This model involves the creation of multiple parallel control systems that can be evaluated and compared simultaneously [7], and the system that is most favorable in the current state of the ecosystem is applied. Unlike traditional approaches to resource management, decision-makers in active adaptive management systems are fundamentally changing relationships. According to the EUFORGEN (European Forest Genetic Resources Program), an equal level of decision-making between scientists, managers and the public has been identified in the concept of the so-called. Integrated Adaptive Control [21, 37]. Active adaptive management takes precedence over passive because monitoring is integrated into the management process and decision making in forestry is based on adapting plans to change based on control results. Unforeseen circumstances are continuously monitored during the implementation of the plans. This means that the basic feature of active adaptive management is the monitoring and control of ecosystem responses to management actions. However, it is considered that there are also aggravating circumstances for its application because it is more expensive and complex [43].

Two strategies have been developed within the adaptive management of forest ecosystems [5]. The first relates to the conservation of existing forest structures that can be applied to stands at the end of the production period, stands made of resistant tree species and stands with high environmental and economic value. The second is passive adaptation of forest ecosystems, which can be applied in stands of low ecological and economic importance and with high costs of active adaptation. The third is the active adaptation, which is applied in stands made of species with a pronounced climate tolerance, in stands with a pronounced purpose function and a high risk of threatening factors of biotic and abiotic nature. This paper is based on a case study level to partially influence the transfer of scientific knowledge to the actual conditions of management of oak forests affected by the drying process.

Monitoring and the importance of climate change risk assessment

The development of adaptive management systems is based on monitoring, which determines the effects and takes measures to improve the state of forests [15]. Adaptive management requires information on the response of ecosystems (climate, changes in soil characteristics, occurrence of pests and diseases, etc.) to management mechanisms [10]. Forest ecosystems have a rather large adaptive potential, but risk factors such as fires, pests, diseases and climate change require management measures aimed at maintaining the balance of forest ecosystems [47]. In the context of adaptive management, the most important is the control method of forest management, which, based on additional information, despite the risks, can better determine the system of measures that can achieve the set goal [6]. The basic way of quality monitoring and control of forest management consists in periodic forest inventory, which connects forest management planning with management mechanisms. Forest inventories for the purpose of development of operational management plans in the Republic of Srpska refer to a period of ten years and the collected data are used for the preparation of forestry bases that are implemented in chronological order by forest management companies. Advantage of adaptive management is that plans are adjusted based on the results of monitoring to new contingencies. Adaptive management in forestry goes through several stages, from defining management problems to analyzing the effects of management and incorporating the results of the analysis into the plan (Fig. 1).

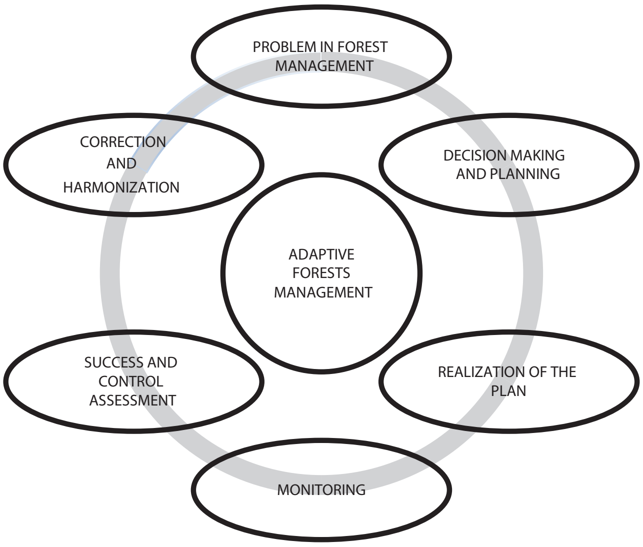

Fig. 1. Phases of adaptive management

Uncertainty in forest management, which can lead to environmental, social and economic losses, is a risk. Management risks are caused by instability of biocenosis and habitat and depend in particular on negative biotic and abiotic influences. In order to reduce the risk in forest management, there was a need to develop management mechanisms that enable the adaptation of forest ecosystems. Climate change is cited as a global problem that complicates forest management risks [27, 35]. Studies show that there is a global warming trend that is reflected in an increase in average temperature by 0.8–1.2 °C since 1900 [11, 26].

Many adverse events in the early 21th century, such as the extreme drought in central Europe in 2003, led to a large decline in the vitality and productivity of forests [8], followed by fires in southern Europe (Portugal, 2003; Greece, 2007) and storms (Germany, 1990 and 1999, France, 1999; Slovakia, 2004; Southern Sweden, 2005; Central Europe, 2007) also destroyed large areas of forests [9, 34]. The destruction of large forest areas due to catastrophic fires affected areas and countries of other continents (Siberia, Brazil and Australia) during 2019. Extensive research worldwide indicates that future disturbances caused by drought, wind and snow will be more severe and temperature local and annual changes will vary greatly [36]. However, it is considered that the climate variable determining wind disturbance (frequency and intensity) will be the most influential in the future. Research has also highlighted the need to analyze the interactional effects of climate change as an incentive for tree mortality, emphasizing the strong dependence on the level of development of biotic disorders. The complexity of interaction disorders complicates predictions of future changes in forest climate in space and time. Risks in forest management force foresters to accept “avoiding the uncontrolled and managing the inevitable” [4]. However, due to the biological and economic aspects of production, forestry makes it difficult to accurately predict uncertainty, that is, the occurrence of risks.

Significant uncertainties in forest management are caused by: forests heterogeneity; volatility of economic conditions in forestry; fluctuations in natural phenomena (climate change, natural disasters, storm winds, fires, etc.); inadequate risk and impact assessment; lack of preventive measures, etc.

The major problem is that climate change is occurring at a much faster rate than expected [19]. Adaptation of forests to climate change is a basic prerequisite for maintaining the structure, vitality and functioning of European forest ecosystems, including their logging and their importance for carbon sequestration [30]. According to forecasts, temperatures in Europe will increase by 1.0–5.5 °C annually over the next 100 years; global warming is likely to reach 1.5 °C between 2030 and 2052. If temperatures continue to rise at the current rate and the incidence of heat waves longer than 7 days as droughts occur will increase [25]. The temperature in the southern parts of Europe increased by about 3.0 °C in summer compared to the reference time period 1961–1990. In Europe, more frequent and intense rainfall is expected during autumn and winter and summers will be extremely warm and dry. As a result of global climate change over the next 50–100 years, it is assumed in Europe that very harsh and unstable weather conditions can occur [26].

Adaptive management to prevent forest management risk: Case Study – Sessile oak forests on Ozren mountain in the Republic of Srpska

The drying of sessile oak forests in the Republic of Srpska and Serbia was established at the end of the 19th century, and the last major drying, which continues today, began in 1980 [16]. On Ozren mountain in the Republic of Srpska, Bosnia and Herzegovina (BiH) (Fig. 2), over 1.000 ha of the sessile oak forests have been dried. These forests typologically belong to the high sessile oak forests and mixed forests of the sessile oak and black pine (*Pinus nigra* Arn.) on shallow (sometimes deep) eutric brown and distric soils on serpentines and peridotites. The area is located at an altitude of 500 to 800 m.

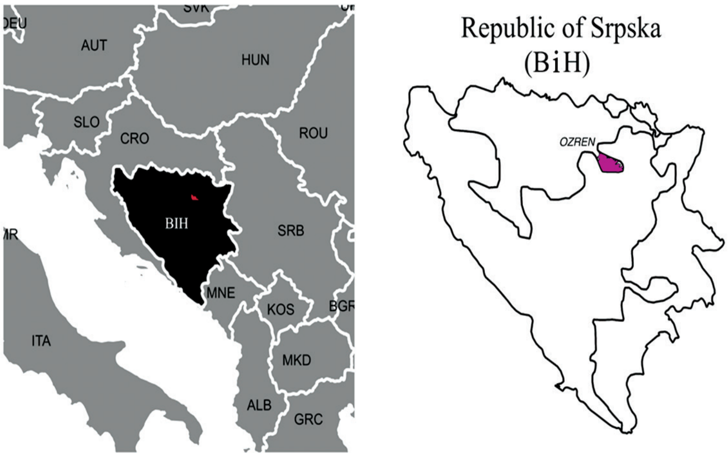

Fig. 2. The geographical location of Ozren Mountain

The drying of the sessile oak forests on Ozren mountain is a consequence of the settlement of damage caused by the intense drought, where shallow soil dominates on serpentinite and peridotite geological ground. The forests of the sessile oak in the Ozren area can be characterised by: insufficient production effects; unfavorable age structure; unsatisfactory health.

Comparing the basic elements of the structure of sessile oak stands affected by the drying process, it can be characterised by decrease of the share of sessile oak in the mixture ratio by 20 %, the current volume increase by an average of 1.0 m^3/ha and the stand canopy by 20 %. The productivity of high sessile oak forests in this area is much less than optimal. This is especially true for mature stands where the optimum volume should be around 200 m^3/ha [28]. The stands affected by drying are dominated by stands whose mature trees are of 80 to 100 (120) years old and in which, after heavy felling, the stand canopy has been completely “broken” in the previous period, so the yield of acorns is very modest. The largest number of the sessile oak trees on Ozren (over 90 %) is affected by crown drying and defoliation over 80 and 95 % according to the classification system for the vitality assessment of tree crowns [14].

Ozren forests have been exposed to the trend of rising air temperatures for many years (Fig. 3). The analysis of the time series and the trend of temperature changes were performed according to data from the meteorological station in Doboj for the period of 1961–2018.

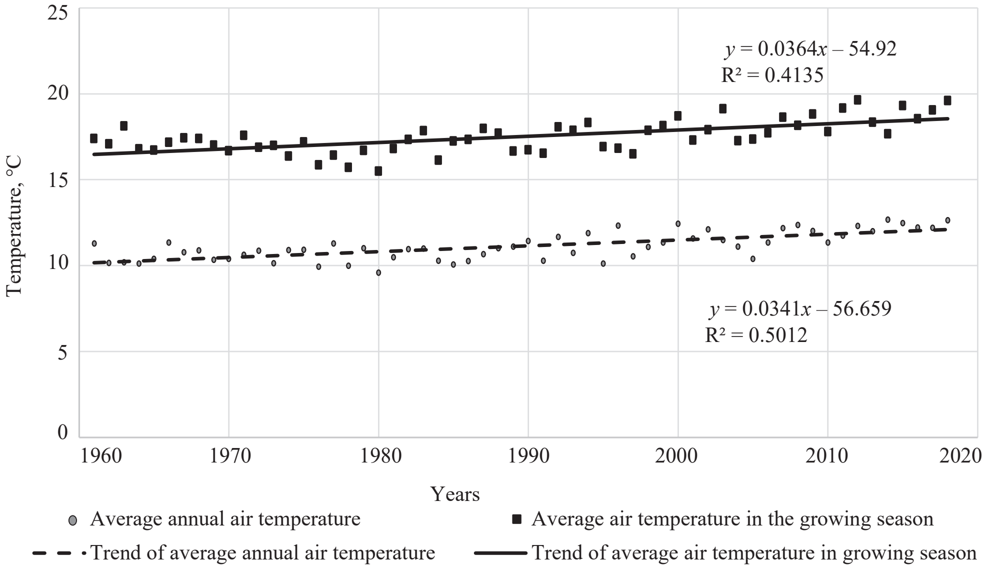

Fig. 3. Average temperature trend in the Doboj area (1961–2018 period)

The annual cumulative trend of rising air temperature averages 1.6 °C. A very high cumulative trend of increasing average absolute maximum air temperatures in the period from 1990 to 2018 was observed, which is as high as 3.8 °C. Also the number of tropical days has been evidently higher in the last decade and ranges on average from 3 to 6 days a year. Analysis of the trend of moving decadal average annual air temperatures over the analyzed period shows a sudden increase in air temperature of 19 decades (Fig. 4).

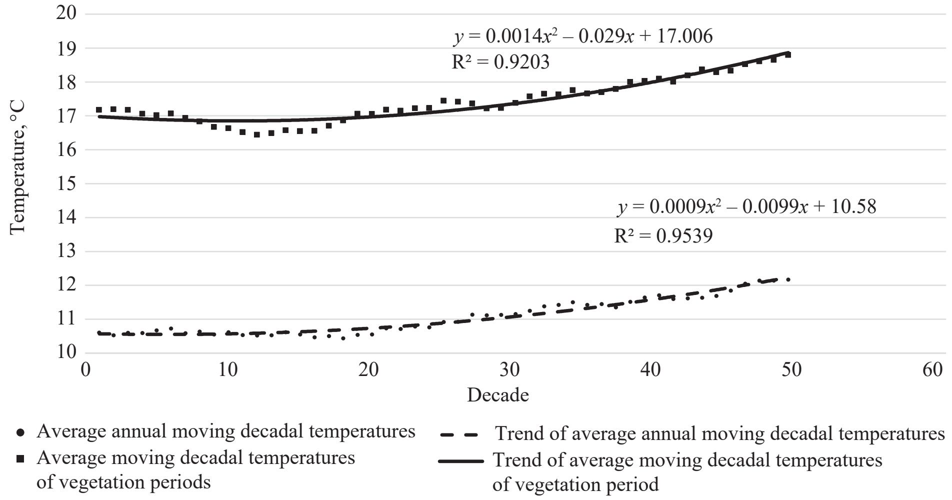

Fig. 4. Trend of average moving decadal temperatures

Continuous runoff during the vegetation period is characteristic for 21 year, and the transitional type of runoff (pronounced exorcism) during the vegetation period is characteristic for 15 years of the series analyzed. Reduced water runoff was during the dry summer months and is typical for 2011. The trend in the flow of this drought index for the growing season shows a decline in values and an increase in the duration of drought in the vegetation period. Using the Preslers drill bit from trees with a pronounced initial phase of crown tip drying, the width of the growth rings was measured using the CooRecorder 7.6 and CDendro 7.6 computer programs. A sinusoidal flow of the latitude line was observed (Fig. 5), with two periods of intense decline in latitude annual rings (the first period from 1961 to 1980 and the second significantly more pronounced from 2010 to the end of the analyzed period). These dry periods caused the acute and chronic form of drying of oak. The acute form results in a very intense drying process that begins and ends in a single season. The chronic form is a long process in which the trees dry gradually and the process usually begins with the appearance of dryness which gradually spreads and engulfs the entire crown.

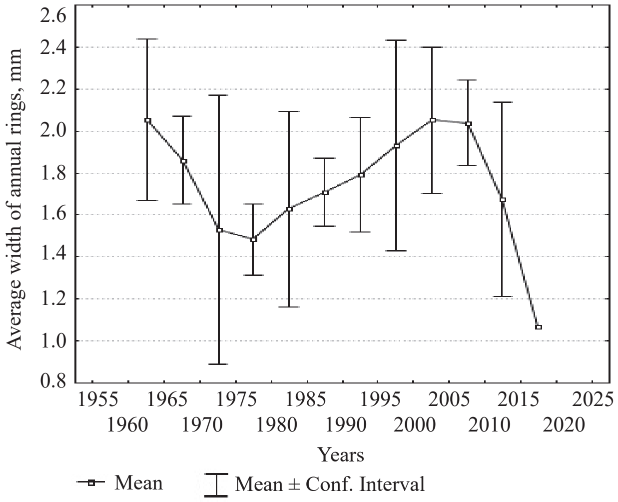

Fig. 5. Average width of annuals of sessile oak trees in the initial stage of drying

Climate can be considered as a first-degree sudden factor that paves the way for the arrival of other factors leading to the sessile oak forests [16]. Climate change, followed by pathogenic organisms and defoliators, have the greatest impact on decaying of sessile oak forests [32]. These factors can be attributed to inadequate silviculture practices as well as the assumption that there is a significant participation of mature stands in the sessile oak forests on Ozren mountain in the Republic Srpska.

Another problem in forestry is the slow and relatively low adaptability of the sessile oak forests under new climate change conditions, as well as lack of precise information on the degree of threat and degree of risk of individual forest communities. Namely, after severe droughts on relatively large areas on Ozren mountain, all communities do not respond in the same way because their sensitivity is different. The risks of forest management (e.g. “multiple stress”) and the long-term nature of the production process complicate the effects of silviculture, especially on areas that need to be rehabilitated after the drying of forests. There are at least three factors of climate change that trees need to adapt to: temperature increases, increased carbon dioxide concentrations, and increased nitrate deposition. Therefore, silviculture has a special importance and a preventive role in forest protection [22, 23]. However, targeted silviculture practices can be very useful in reducing the risk of forests management. If inadequate silviculture practices create favorable conditions for the development of pests and diseases, we reduce the vitality of forests, which may, for example, encourage the gradation of some insects [3, 31, 36, 45, 46], such as *Lymantria dispar* in deciduous forests [12]. Most pathogenic fungi of temperate forests require temperatures between 20 and 30 °C for optimal mycelial growth [40].

Soil moisture deficiency increases the possibility of fire, as well as water supply and soil temperature in the interconnection create conditions for harmless saprophytic organisms or, conversely, for dangerous pathogens. Also, the degree of adaptation of trees to soil structure, acidity and nutrient availability may affect the success of natural regeneration in conditions where the forest is threatened by drought. The need for adaptive silviculture practices of forests that are threatened by drought is increasingly expressed today. Young stands now formed by afforestation or occurring after natural regeneration usually have a production period that overlaps with climate change scenarios from 2070 to 2100. These stands will be exposed to the drastic risks that await them over a lifetime. According to the scenarios and models presented in the third national report on climate change in the Republic of Srpska, BiH [42], the trend of increasing the average annual air temperature by 2030 compared to the base period 1961–1990 will be up to 1.0 °C. It also envisages a reduction in the area under forests and a reduction in the average annual CO_2 storage capacity, partly due to the drying up of forests. The highest increase in air temperature is expected in summer (up to 1.4 °C). In the period from 2071 to 2100, according to the scenario A2, a rapid increase in temperature is expected, up to 4 °C annually and up to 4.8 °C in summer. CO_2 emission by population in the Republic of Srpska (BiH) is 5.18 t/yr, which is slightly more than half of the European average (9.93 t/yr per capita). If the CO_2 content in the air is greater than 0.05 %, the intensity of photosynthesis decreases, the plants are physiologically weak and the productivity of the trees decreases [17]. It is assumed that an increase in air temperature by about 3.0 °C leaves forest vegetation with a similar consequence as the shift of vegetation altitude by 500 m above sea level. Most climate models predict major changes within the forest range. Species with small habitats will be particularly endangered, and climate extremes will be a major problem for limiting habitats of many species. This will especially affect species with a narrow ecological valence. The most threatened will be the xerothermal and continental areas where the sessile oak forests are located. The greater the difference between the current species composition and future forest types that future natural vegetation will make, the more intensive forest management practices will be required [21, 23].

In such circumstances, there is a need to develop adaptive forestry management that can provide useful forest functions even in uncertain conditions. Silviculture is facing the most difficult task because, based on the current state and projections of uncertain events and risks, positive effects are expected in the future on services provided by forest ecosystems. One way of adaptive management is to compare the present composition and natural regeneration of species with the expected vulnerability and degree of adaptation of the main tree species in different change scenarios. The second strategy concerns the formation of mixed and uneven-aged stands [12, 25] that have a greater possibility of complementary adaptation to environmental conditions [17, 24, 33]. In addition to adapting to future climates, mixed forests are considered to be superior in terms of economy [17, 18] and ecosystem functioning [2, 17]. Possibilities of creating mixed stands of the sessile oak and black pine in poor serpentinite-peridotite habitats represent one of the adaptive management options. In highly exhausted and erodible terrains in the Ozren area, it is possible to enter black pine artificially. As a pioneer species in these habitats, black pine can create the prerequisites for natural restoration of sessile oak. Adaptive management of the sessile oak forests affected by droughts under the influence of climate change involves monitoring the succession of vegetation and natural regeneration together with black pine. In order to remedy the effects of forest drying, silviculture should be based on maximizing growth and vigor, adapting tree species to habitat conditions and increasing the diversity of endangered stands.

Adaptive silviculture in drought-affected stands in the Ozren area can be classified into the following groups: eliminating the effects of drying; natural and artificial restoration of stands; tending of stands and amelioration of degraded stands; saving economic benefits; preventive protection of stands.

Removal of the consequences of drying should be done by sanitary felling. The surfaces with the highest degree of urgency are treated first. These are areas with very poor tree health. Sanitary felling should remove all the sessile oak trees that are affected by the drying process in the advanced stage (standing dead wood), trees with heavily reduced crowns, then infected and diseased trees. These tree fellings are of preventative importance because they reduce the potential for the harmful factors. It also prevents the emergence of oak bark beetles (*Scolytus* sp.) as it can transmit infection by vascular fungi [20, 41]. If the stand canopy is less than optimal (0.7) and tree mortality is greater than 30 % then there is justification for applying fellings to save economic benefits. Tree marking is simple and involves only dead and dying trees.

To minimize potential negative impacts the adverse factors, we need to implement various prevention and adaptation measures with different timeframes for implementation [1]. Basically, preventive actions can be classified into three main categories: legal, silviculture and direct [22]. The main element of forest management planning under risk conditions is a clear silviculture objective. For forests of productive character (economic forests), the primary goal is to produce the maximum amount of quality timber volume in the shortest possible time while maintaining optimal habitat potential and at the lowest cost possible. This means that, in practice, the optimal quantity and structure of wood assortments should be ensured by applying operational management plans. Therefore, it is necessary to identify more possibilities for forest management (adaptability of forest management). This would systematically reduce uncertainties and increase the likelihood of success over a relatively long forestry production period. They typically, as well as environmental factors, act as complex and complementary as integrated risks and often lead to offsetting negative effects.

Preventive silviculture practices are the best way to prevent the occurrence of forest drying [7, 29, 38, 39] and they represent a good health status of forests. In order for these practices to open up full effects in management, they must be implemented in even aged stands throughout the production period (rotation). Silviculture effects are most influential when applied several years before health problems occur. Another significant component of preventative methods is sanitary felling. Their application seeks to prevent the cause and duration of damage. However, these measures should be timely because they prevent the occurrence of damage to biotic and abiotic origin. Significantly, forest management measures should be consistent with the underlying function of the forest, depending on its occurrence. The basic problem is that we often don’t know the primary cause of a negative phenomenon. Therefore, silviculture practices are not adequate for preventive problem solving and acting in accordance with the risks identified. The structure and resilience of forest stands is greatly influenced by the tree composition of the stands, tending of stands and natural regeneration forests.

Conclusion

Adaptive forests management requires the identification of threatening factors (risks), defining their duration and frequency of occurrence. In addition, it is important to know the cost structure required for preventive and adaptive forest management.

Forest ecosystems have a fairly high adaptive capacity however for developong forest management plans, it is necessary to list potential risks, whether they are harmful and to identify risky deviations from the normal (optimal) state of the forest ecosystem. Adaptability to decision-making depending on the risk of climate change implies a broader range of decisions.

Due to the risk of forests management and their sensitivity, different silviculture practices are recommended depending on the type of pests, diseases, fires, winds, etc.

To reduce the risks of future forest disturbances, a stronger understanding of the relationship between silviculture, the likelihood of risk occurrence, and the sensitivity of forest ecosystems is needed. It is necessary to adhere to modern principles of the close to nature silviculture and adaptive forests management. Due to the ecologically negative effects of drying that threaten the complete disappearance of the oak sessile stands, it is necessary to remediate the surfaces in accordance with the activities foreseen for emergency situations in the field. The silviculture practices in the Ozren mountain area should be aimed at preserving the stand structure and creating mixed stands with black pine on the geological base of serpentine and peridotite. Afforestation of difficult terrain, such as often natural sessile oak habitats, will be increasingly complex and difficult, and will require adaptability of species and genotypes introduced to remedy the effects of drying sessile oak forests. In an economically difficult conditions, timely and preventative silviculture practices should play a major role in reducing the risks associated with adaptive forest management. One of the main tasks for adaptive management is the maintenance and development of such forests, which are adapted to the integrated risks. Dynamic monitoring, inventory and control of forest management is required for the sustainable development of forestry and the successful implementation of adaptive forest management.

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АДАПТИВНОЕ УПРАВЛЕНИЕ ЛЕСНЫМ ХОЗЯЙСТВОМ: НА ПРИМЕРЕ ЛЕСОВ СКАЛЬНОГО ДУБА (*Quercus petraea* (Matt.) Leibl.) ГОРЫ ОЗРЕН РЕСПУБЛИКИ СЕРБСКОЙ

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Адаптивное управление является основной концепцией управления лесными экосистемами в условиях постоянно изменяющего климата. В связи с этим, необходимо найти информацию и разработать основные теории, на которых основано адаптивное управление лесным хозяйством. Данная работа дает общее представление об адаптивном лесопользовании в контексте усыхания дубовых лесов и изменения климата в Республике Сербской (Босния и Герцеговина). Разведение лесов скального дуба, подверженных острому и хроническому усыханию, должно основываться на сохранении всех древостоев и способности к произврастанию совместно с черной сосной на неглубоких серпентинитовых и перидотитовых почвах. В статье рассматриваются возможности адаптивного управления лесами скального дуба и дается характеристика мероприятий по адаптивному управлению.

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Ключевые слова: адаптивное управление лесным хозяйством, усыхание леса, скальный дуб, изменение климата.

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