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Exploring Tourist Preferences on the Visitor Management System: the Case Study of Plitvice Lakes National Park

Carlotta Sergiacomi[1,*], Dijana Vuletić[2], Alessandro Paletto[3], Claudio Fagarazzi[1]

(1) University of Florence, Department of Agriculture, Food, Environment and Forestry, p.le delle Cascine 18, I-50144 Florence, Italy; **(2)** Croatian Forest Research Institute, Division for International Scientific Cooperation in Southeast Europe, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia; **(3)** Council for Agricultural Research and Economics (CREA), Research Center for Forestry and Wood, p.zza Nicolini 6, I-38123 Trento, Italy

*** Correspondence:** e-mail: carlotta.sergiacomi@unifi.it

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ABSTRACT

This study aims to develop an online survey on the tourist perception of the visitor management system of the Plitvice Lakes National Park in Croatia. As tourists are particularly sensitive to organisational issues related to the Park management, a bottom-up approach based on visitors' opinions has been applied. First of all, a brief chronology has been reconstructed that retraces the most significant stages of the Park. Subsequently, an online questionnaire was structured on the basis of the current Park Management Plan with a focus on the macro-topics concerning the visitor management system. The survey was distributed using the Google Form application. A total of 214 questionnaires were collected in the period between May and July 2022. The sample was statistically analysed to detect the main habits of the Park users. The Mann-Whitney-Wilcox U test and the Kruskal-Wallis test were applied to identify the differences in the priorities attributed by visitors to the various management actions. Among the main findings of the research, the authors identified that national visitors (i.e. Croatian) place a higher priority on the implementation of services and infrastructure than tourists from other countries. In addition, those who have visited the Park on multiple occasions have higher safety expectations than those who have only visited the Park once. This category of visitors also considers it more important to take into account the opinions of visitors. Furthermore, with regard to retail and souvenir shops, tourists are generally inclined to set a lower priority for intervention than that attributed to other management aspects. The results of this study can be of great value to Park managers, who should consider visitors as key stakeholders in the decision-making process that is the foundation for managing this important natural resource.

Keywords: visitor perception; tourist satisfaction; natural resources management; park management; nature-based tourism; national parks; protected areas

INTRODUCTION

In post-modern society, the sustainable tourism sector is one of the key activities to be developed while preserving natural resources for future generations (Sandell 2016). Firstly, tourism is an economic activity and therefore can have an environmental impact (Smolćić Jurdana 2009). This is a key factor that managers need to take into consideration in planning and managing nature-based destinations. In general, a tourist destination is primarily a complex system which incorporates tourist attractions, structures and accommodation facilities (Radisic and Basan 2007). In fact, there is a strong connection between the provision of infrastructure and services and the tourist development of a given area (Mandić et al. 2018). In this context, the main objective of tourism managers is to satisfy visitors' demands without compromising the integrity of the sites (Mandić 2021, Perera et al. 2015).

Over the past decades, the natural environment has become an increasingly popular tourist destination, especially as regards protected areas (PAs), in general, and national parks (NPs), in particular (Smolćić Jurdana 2009, Lundmark and Müller 2010, Wolf et al. 2015, McCool et al. 2021). According to the Flash Eurobarometer 499 "Attitudes of Europeans towards tourism" Report (European Commission 2021), in 2020, the natural environment was identified as the main driver - on a par with the cost factor - in the choice of tourist destination for 43% of European travellers. Furthermore, the current scale of tourist flows to nature-based destinations requires an additional effort by managers to minimise the negative impacts of tourism on natural ecosystems (Smolćić Jurdana 2009). These impacts are often related to managing tourism infrastructure and services (McCool et al. 2021), which require special attention. In particular, the management of the PAs is characterised by a trade-off between the objectives of nature conservation and tourism promotion (Mandić 2021).

Taking those considerations into account, the present study focuses on the tourist management system in one of the European PAs most affected by international tourist flows, the Plitvice Lakes National Park (PLNP) in Croatia. A bottom-up approach was applied in this study, which was based on the opinions of visitors, who are seen as the main judges of the quality of the tourist destination (Radisic and Basan 2007). The most relevant management problems for PLNP visitors were identified based on the findings of a previous study (Sergiacomi et al. 2022). In that study, the authors found that visitors are particularly sensitive to both organisational issues related to overcrowding, and to the planning of visits to the PLNP, in order to enjoy the best of its natural beauties. The research questions of this study, are as follows:

- RQ1. What are the management issues related to the visitation system identified as a priority by PLNP tourists?
- RQ2. How does the visitor's perspective coincide with the vision outlined by managers in the current PLNP Management Plan?

In the literature, few recent studies have been conducted on issues strictly related to the management of nature-based destinations directly involving visitors of PAs (Cihar and Stankova 2006, Arnberger et al. 2012, Belkayali and Kesimoğlu 2015, Abdullah et al. 2018). Thus, this research aims to fill this gap by exploring the views and preferences of visitors on some key aspects of PLNP management.

The remainder of the paper is organised into the following sections. The second section provides a literature review of nature-based tourism, in particular the participatory management of these types of tourist destinations. The methodology used is illustrated in the third section. After that, the main findings are presented in the fourth section, while the fifth section discusses the results. Finally, the sixth and final section analyses the limits of the study and provides useful applications and future research.

STATE OF THE ART

Nature-based Tourism

In the literature, there are many different and sometimes conflicting definitions of nature-based tourism. Since nature can assume different meanings for different types of tourists (Lundmark and Müller 2010, Sandell 2016), nature-based tourism is a very wide category. It includes both general visits to pleasant natural landscapes, and many specific activities that can be enjoyed in nature (e.g. sports; outdoor education; nature conservation). In particular, PAs and nature reserve areas (especially NPs) represent the predominant setting for nature-based tourism activities (Smolćić Jurdana 2009, Kaffashi et al. 2015, Perera et al. 2015, Sandell 2016, Vurnek et al. 2018).

In recent years, demand for nature-based destinations has increased significantly. In fact, trends have shown that this specific segment continues to grow much faster than the development of the tourism sector in general (Smolćić Jurdana 2009, Lundmark and Müller 2010, Kaffashi et al. 2015). This is mostly due to the modern urgency of returning to nature (Stoleriu et al. 2019, Niezgoda and Nowacki 2020). At present, it is widely recognised that this need stems from nature's ability to generate human well-being, both physically and mentally (Wolf et al. 2015, Roberts et al. 2018, Plunz et al. 2019, Niezgoda and Nowacki 2020). As such, this growth requires increased managerial responsibilities and skills on the part of NP administrators, to meet tourists' leisure needs and to ensure the efficient conservation of natural resources (Mandić 2021, Perera et al. 2015).

Moreover, visitor perception of nature-based destinations is strongly influenced by external components. These components are related to tourism management (Stoleriu et al. 2019), such as: good accessibility; proposal of differentiated activities; availability of transport means; security of visits. Therefore, in NPs the development and maintenance of tourism infrastructure is extremely important, both economically and for the conservation of natural ecosystems (Mandić et al. 2018, Mandić 2021). Particularly, in countries where the economy is strongly dependent on tourism, management aspects relating to tourist destinations are of fundamental importance. This is the case in the Republic of Croatia, where PAs are selected as one of the main reasons for visiting the country (Marković et al. 2013, Lončarić et al. 2021).

Thus, in a similar landscape becomes more and more important to provide an exhaustive picture of nature-based tourism. It also becomes important to cover the demand-side and deepen how people perceive their recreational experiences in nature-based destinations (Lundmark and Müller 2010).

Participatory Management of Nature-based Tourist Destinations

The importance of stakeholder involvement in nature-based destination planning and management is generally recognized (Mandić 2019, Pezdevšek Malovrh et al. 2019). In the international literature, many different methods are used to gather stakeholder input (Paletto et al. 2017), including focus groups, interviews and questionnaires. Particular attention is paid to the forest recreation sector. Some explored the aesthetic preferences of users for different types of forest management (Paletto et al. 2018), while others looked at visitor uses and urban forest conditions (Krajter Ostoić et al. 2017, Kičić et al. 2020). Specifically, these latest studies have increased over the course of the spread of the SARS-CoV-2 pandemic (Marin et al. 2021).

Other categories of stakeholders have been extensively involved in surveys on natural sites management, such as: managers (Moreno et al. 2014, Pietilä 2019), staff (Mandić

2021, McCool et al. 2021), or the local population (Héritier 2010, Jones et al. 2015). Conversely, visitors are rarely involved in management surveys. Only a few studies have recently engaged NP users to express their views on purely management aspects. In their research, Cihar and Stankova (2006) interviewed visitors to the Podyji/Thaya River Basin National Park (Czech Republic) and other stakeholder groups (i.e. local residents and representatives of local governments) to obtain their opinions on the management of the nature conservation. However, those authors themselves recognized that tourists have a fairly low knowledge of environmental dynamics and problems. Therefore, they are not the best class of stakeholders to be involved in this aspect of management. In another study conducted in the Gesaeuse National Park (Austria), visitors were the subject of a survey aimed at studying the relationship between tourist affinities with NPs and their attitude towards the management of visits with respect to nature conservation (Arnberger et al. 2012). Thereafter, Belkayali and Kesimoğlu (2015) for the Kure Mountains National Park (Turkey) and Abdullah et al. (2018) for the Penang National Park (Malaysia) also engaged visitors and other categories of stakeholders. The goal has always been to analyse the opinion of tourists on the relationship between the management of tourism in parks and environmental issues.

Actually, visitor feedback proved effective in developing good management practices for nature-based destinations. Indeed, they represent the main subjects who perceive the results of a good or poor management of the places. Therefore, comments from visitors may provide important suggestions for improving visitor satisfaction (Kaffashi et al. 2015, Marin et al. 2021). In fact, to take into account the dual purpose of nature conservation and recreation, the tourist point of view is of great importance (Perera et al. 2015).

In addition, the scarcity of visitor satisfaction data makes it a field of investigation to explore further (Mandić 2021). A new hypothesis is to transform the current system of monitoring and managing visitors in the PAs into a “third generation” model (Mandić 2021). From this point of view, visitors will become an opportunity, actively contributing in defining management strategies. Moreover, the use of management strategies that derive from the users themselves, can help them to become aware of the values and limitations of PAs, educating visitors and minimising their potential negative impacts (Kaffashi et al. 2015). Therefore, involving visitors as co-protagonists in the management of nature-based destinations represents a stimulating challenge for the world of research and administration.

MATERIALS AND METHODS

Study Area

The Plitvice Lakes National Park (PLNP) - one of Central Europe’s most visited natural sites (McCool et al. 2021) - is located in the mountain hinterland of the Republic of Croatia, in the counties of Ličko-senjska and Karlovačka. The PLNP is part of the Dinaric karst area and is the largest national park in the country with nearly 30,000 hectares of forests, lakes and caves. The aquatic area of the PLNP represents about 1% of the total surface and is the most important attraction for visitors (Vurnek et al. 2018, Mandić 2021). The remaining 99% of the surface consists mostly of forests and grasslands. Within the boundaries of the PLNP, there are 20 settlements that do not exceed the level of several hundred inhabitants (based on the 2011 Census). Local farms produce cheese, jam, and honey, which are incorporated as traditional products in the PLNP sales system. The surrounding area includes small farms and accommodation facilities.

The PLNP is administered by a Director General and a large staff, who are under the supervision of the Plitvice Lakes National Park Public Institution (PLNPPI). The PLNPPI was established by the Republic of Croatia and falls under the authority of the Ministry of the Environment and Energy (MEE). The PLNP has to comply with two current regulation forms. One is the Physical Planning Act (Official Gazette 153/13), which defines what can be built within the area. The other is the Nature Protection Act (Official Gazette 88/13, 15/18, 14/19, 127/19), which requires the PLNP to prepare and adopt a management plan as a key policy governance document.

Furthermore, the PLNP is the oldest PA in Croatia and has covered many important milestones in the over 70 years of its existence (Figure 1). In fact, shortly after the end of World War II, the Yugoslav government named it NP (8 April 1949). Initially, the PLNP had no real management system, but it was simply served by trails that led tourists to major waterfalls and lakes, and to the canyon area. It was only in the early 1950s that the first accommodations were constructed, including hotels, restaurants and campsites. In 1979, the PLNP was granted UNESCO World Heritage Site, thanks to the universally recognised value of the exceptional tufa formation process taking place there. An major wound was left by the Croatian Homeland War (1990–1995), during which many structures were destroyed or extensively damaged, and many mines were scattered in the PLNP area. Since 1995, the PLNP staff has been recovered, user fees have been set and a first administrative program has been implemented. In 1997, the PLNP area expanded to the current surface of 29,630 hectares. Until the 2000s, the PLNP received significant but steady flows of visitors. For this reason, the General Management Plan developed in 2007 focused mainly on the multiple natural ecosystems of the PLNP, while little attention was given to the system of visits. In particular, the 2007 Plan paid more attention to the preservation and enhancement of the territory’s cultural and historical values, crafts and local traditions. Some limited changes have also been proposed in the trail network and internal transportation (e.g. the conversion of panoramic buses from diesel engines to electric motors). Nevertheless, few interventions were actually carried out in response to increased visitor flows. As regards the importance of the PLNP for the biodiversity conservation, this was underlined in 2013 when the PLNP was declared Important Bird Area (IBA) and Special Area of Conservation (SAC) within the Natura 2000 network. The Nature Protection Act requires the renewal of NP management plans every ten years. As a result, a new planning process was launched in 2016, with the primary goal of addressing the pressing issue of visit management. Between 2015 and 2018, several workshops and training seminars were organised for PLNP staff by external experts in the management of visits (McCool et al. 2021).

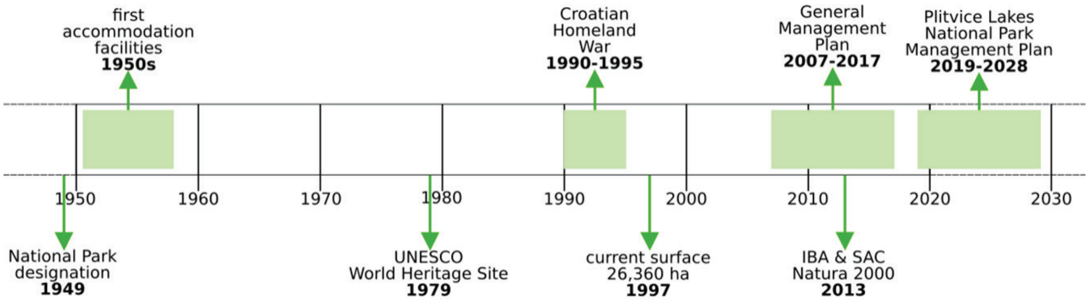

Figure 1. Main stages in the history of Plitvice Lakes National Park.

The current Plitvice Lakes National Park Management Plan 2019-2028 (2019), which set out to address these challenges, came into force in 2019 (Figure 2). After an introduction to the PLNP area, the Plan organises the chapter dedicated to management into five main themes: Conservation of natural values (theme A); Conservation of cultural heritage (theme B); Visitor management (theme C); Support to sustainable development of the local community (theme D); Capacity development and management of Public Institution (theme E). Each theme is further divided into a number of specific objectives, which are in turn organised into macro-topics containing several actions (see for example: theme C - Visitor management, Figure 3).

Questionnaire Survey and Sampling Method

This study is based on a demand-driven survey of nature-based tourism management in the PLNP. First, two interviews with PLNP managers were undertaken. This preliminary stage proved to be useful both for deepening the process of drafting the current Management Plan, and for identifying the steps within which visitors have already been involved as stakeholders. Given the recent adoption of the Plan, visitor opinion has not yet been deeply taken into account, in particular as regards the evaluation of the PLNP management. For this reason, an online questionnaire was structured according to the current Management Plan. Visitors of the PLNP were chosen as the privileged interlocutors of this survey. In particular, user inputs are recognized as an effective support to improve management practices (Marin et al. 2021). In fact, unlike visitors, other stakeholders - e.g. park managers and administrators; staff members; public institutions; and local people - have already participated in extensive interviews and focus groups (Mandić 2021, McCool et al. 2021). The questionnaire was designed to identify visitors' perceptions of certain topics related to the visitor system theme, which are considered fundamental to the management of the PLNP. The topics were taken from both the Plan and interviews with PLNP managers.

According to a previous study (Sergiacomi et al. 2022), visitors are very interested and often express opinions about management aspects, which can impact making their experience memorable, either positively or negatively. For this reason, only the action groups included in the macro-topics concerning the Visitor management (i.e. theme C) in the current Management Plan were considered (Figure 3). From the original set of 25 macro-topics, three of them were not included in the survey, because they were considered out of the interest and the perception of the visitors (i.e. Applied research for visitation management purposes and Improving quality and diversity of the offer and feasibility of business operations) or because they partially overlap with another topic (i.e. Development studies and plans with Maintenance, renovation, construction and quality improvement of facilities) (see Figure 3). The questionnaire opens with a short presentation of the research project. The first section contains some questions concerning memories related to the last visit to the PLNP and its relative date (month and year). In the following five sections, visitors were asked to assign a priority level to each macro-topic group of actions related to theme C. In the current Management Plan, priorities for individual actions were assigned on a scale ranging of one to three. Within each macro-topic analysed - which contains multiple actions (see Figure 3) - the mean priority level assigned by PLNP managers was calculated. However, in the questionnaire a 9-point Likert scale (from 1 = low priority to 9 = high priority) was used to allow visitors to express their priority levels. Subsequently, the 9-point scale was transformed into a 3-point scale to facilitate the comparison between the priority scores obtained through the questionnaire and the average scores obtained for each macro-topic within the current Management Plan. In this way, in both cases, values close to the second decimal place were obtained, which make them easy to comparable. These sections were intended to compare the mean priority values assigned to the different action groups. This has been done in order to interpret: the behaviour of the different types of visitors, and the discrepancies in the evaluations given by users and managers. Lastly, a final section was dedicated to collecting information on the profile of respondents (e.g. age; gender; highest level of education; country of origin). A final place was given to free comments and suggestions.

The questionnaire was drawn up via the Google Form application and translated into six languages (i.e. English, Deutsch, French, Italian, Spanish and Croatian), in connection with national and international visitors from the countries for which the most important tourist flows come from (Plitvice Lakes National Park Management Plan 2019-2028, 2019). Prior to disclosure, a pre-test was conducted with a sample of seven visitors - who were also experts of the forestry sector - to ask them for suggestions to improve the clarity of the survey. The questionnaire was distributed by the main social media platforms of the PLNP, and then by e-mail via the PLNP newsletter.

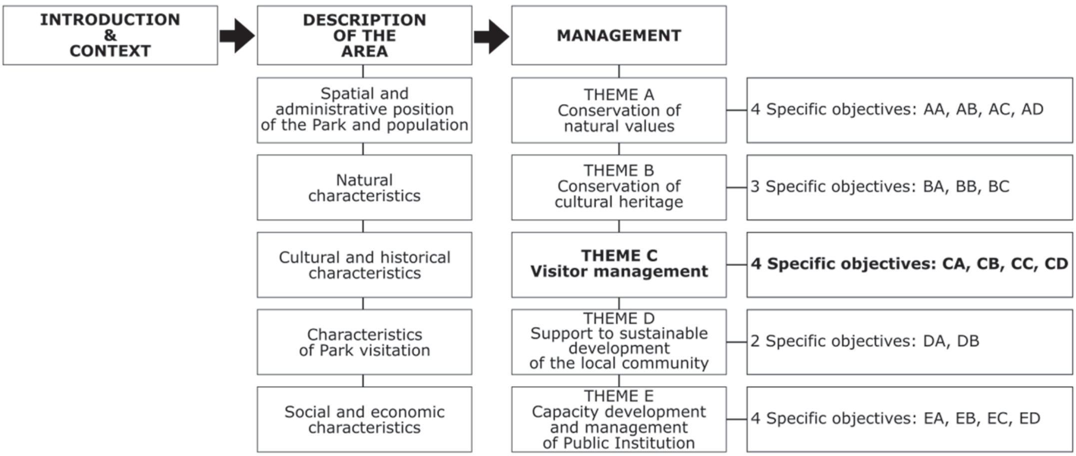

Figure 2. Plitvice Lakes National Park Management Plan 2019-2028 map.

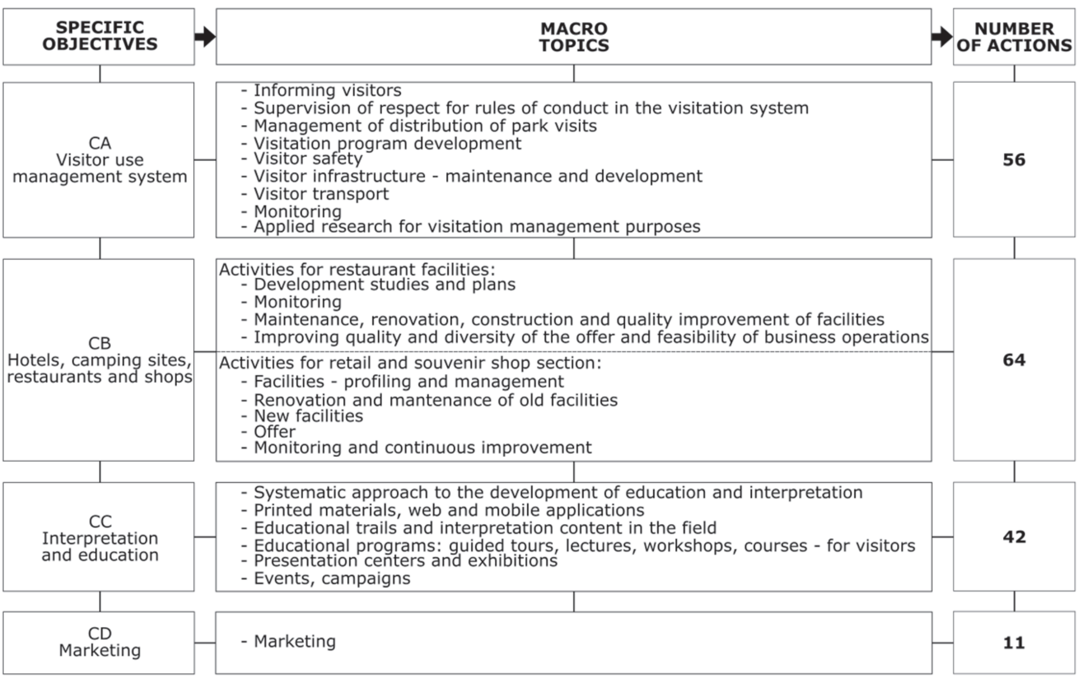

Figure 3. Specific Objectives of Theme C. Visitor management (Plitvice Lakes National Park Management Plan 2019-2028).

RESULTS

Description of Sample Characteristics

At the end of the data collection period (May-July 2022), 214 questionnaires were collected. Since the study refers to the current Management Plan, 25 of the questionnaires originally collected were rejected as they referred to visits conducted prior to the implementation of the Plan in 2019.

Table 1 presents respondents' socioeconomic characteristics. Most of the sample is in the 30-50 age group. For what concern the gender, the majority of interviewees were female. In terms of origin, Croatian visitors represent the greater part of the group examined.

Regarding the key features of the visits to the PLNP (Table 2), over half were conducted in 2021. Following the natural trend of tourism flows, the majority of the

Table 1. Individual variables: socioeconomic aspects.

Variables	Numbers	% Total
Age class		
< 30	37	19.6
30 - 50	102	54.0
> 50	50	26.4
Gender		
male	64	33.9
female	118	62.4
do not wish to respond	7	3.7
Origin		
National (Croatia)	102	54.0
International	87	46.0

Table 2. Individual variables: visit habits.

Variables	Numbers	% Total
Number of visits		
1 visit	70	37.0
2 visits	27	14.3
3 visits	19	10.1
4 visits	11	5.8
5 visits	3	1.6
More than 5 visits	59	31.2
Number of companions		
Individuals or couples	58	30.7
Families (2-5 companions)	110	58.2
Groups (> 5 companions)	21	11.1
Year of the last visit		
2019	15	7.9
2020	12	6.3
2021	98	51.9
2022	64	33.9
Month of the last visit		
Dec-Feb	11	5.9
Mar-Apr	69	36.7
Jun-Aug	61	32.4
Sep-Nov	47	25.0

sample reported having visited the PLNP between March and August. Visitors who went to the PLNP only once represented the highest percentage of tourists in the sample. As concerns the number of companions, more than half of respondents declared they were accompanied by a few persons (i.e. between 2 and 5 companions).

As a first question, the respondents were asked to indicate which elements of the PLNP surprised them the most, both positively and negatively, in the last visit. As shown in Figure 4a, the natural landscape represents the most appreciated characteristic of the PLNP, followed by a much lower percentage of preferences for staff organisation. Instead, the main weaknesses (Figure 4b) are considered to be food services and the cost of the visit which is deemed too high. For the management of public transport and parking lots, both were assessed positively by a reduced number of visitors and negatively by a slightly higher percentage. Finally, the natural landscape is not listed as a negative; therefore, it is believed that it is a generally shared strength of the PLNP.

Actions Related to the Visitor Management System

The following sections of the questionnaire were devoted to the collection of visitor opinions. In particular, it analyses the level of priority deemed necessary for various macro-topics of actions within four different issues related to the management of visits (Table 3). The results show that visitors

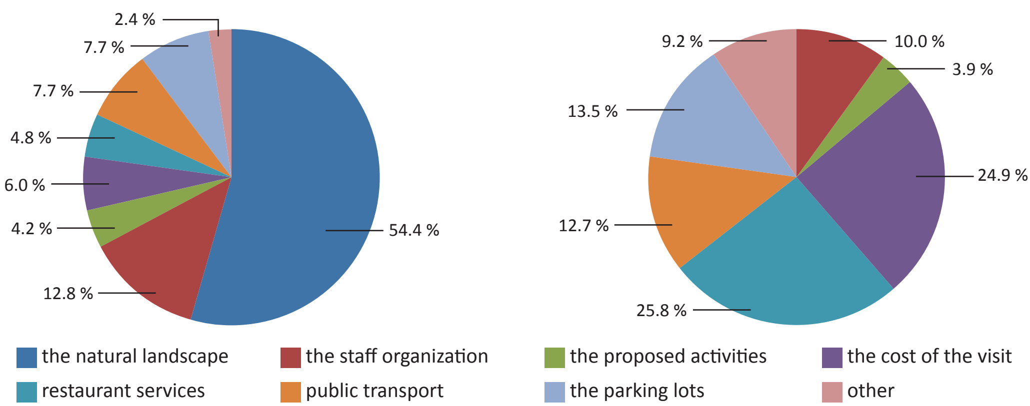

Figure 4. Plitvice Lakes National Park elements that surprised more positively **(a)** and negatively **(b)**.

tend to assign slightly higher priority levels for each macro-topic studied under the theme "Visitor use management system" (mean value: +0.28). The only exception is the need to install new signage to improve the safety of the paths (A.5), for which tourists roughly agree with the priority assigned within the current Management Plan. In particular, there are three macro-topics for which visitors recognize a half-point higher priority than that assigned by the managers: (A.1) actions aimed at increasing tourist information; (A.8) the monitoring of tourist satisfaction with regard to the system of visits and the infrastructure of the PLNP; (A.4) the definition of new visiting programs, useful for redistributing the presence of visitors even outside the crowded lakes area. Conversely, as regards the management of "Restaurant facilities" (B.a.1, and B.a.2), visitors recognize a lower priority than that envisaged in the Plan. For what concern the section on "Retail and souvenir shops", visitors expressed on all the macro-topics a priority of half a point more than that established in the Management Plan. In particular, the renovation of old structures and shops (B.b.2) recorded the higher difference, in positive terms, than that established by the managers. But it should also be said that this is the theme where, on average, the lowest priorities were assigned by tourists in relation to the other issues analysed in the questionnaire. With regard to the "Interpretation and education" segment, visitors on average agree with the priority assigned in the current Management Plan. The only exception concerns the macro-topic relating to the construction of a new visitor centre (C.5), for which they assigned a lower priority than that established by the managers.

For what concerned the characteristics and habits of visitors, a statistical analysis was performed using R software, in order to identify which are the variables that most influence the opinion of tourists. First of all, a Shapiro-Wilks test

Table 3. Comparison between priority scores assigned by visitors and those defined by the Plitvice Lakes National Park Management Plan 2019-2028 for the macro-topics of the theme C "Visitor management".

	Macro-topics	Visitors' score	Plan's score
	Visitor use management system		
A.1	INFORM VISITORS through the website, apps, social networks, etc. on: park rules; maximum daily number of visitors; presence of alternative tours in non-congested areas.	2.48	1.67
A.2	ENHANCE SURVEILLANCE: increasing the number of rangers to check the rules and report illegal acts.	2.49	2.00
A.3	AVOID OVERCROWDING by introducing new technologies and pricing policies.	2.18	1.67
A.4	OFFER NEW VISIT PROGRAMS for alternative areas to the Lakes area.	2.40	1.64
A.5	INCREASE the signage to ensure SAFE use of the itineraries.	2.16	2.20
A.6	MAINTAIN and ADAPT the different INFRASTRUCTURE, such as: bus stops, boat docks, parking areas and toilets.	2.24	1.84
A.7	INCREASE the capacity of the TOURIST MEANS OF TRANSPORT used during the visits.	2.07	1.67
A.8	Prepare a PERMANENT MONITORING SYSTEM on the visitors' satisfaction degree on: infrastructure and visits management system.	2.05	1.25
	Restaurant facilities		
B.a.1	IMPROVEMENT of the RESTAURANT STRUCTURES according to ecological standards.	2.25	2.86
B.a.2	Prepare a PERMANENT MONITORING SYSTEM on the visitors' satisfaction degree on restaurant facilities.	2.11	3.00
	Retail and souvenir shops		
B.b.1	EXPAND the range of PRODUCTS in souvenir shops to suit all visitor preferences.	1.77	1.00
B.b.2	RENOVATE the old STRUCTURES according to styles that are modern and well integrated with the landscape.	2.12	1.00
B.b.3	REALISE NEW STORES of souvenirs and local products and NEW EXHIBITION AREAS.	1.75	1.00
B.b.4	EXPAND THE OFFER of: local products; souvenirs; equipment for outdoor visits.	2.03	1.43
B.b.5	Prepare a PERMANENT MONITORING SYSTEM on the visitors' satisfaction degree on the offer of local products and souvenirs.	1.87	1.00
	Interpretation and education		
C.1	DEVELOP new programs for EDUCATIONAL VISITS and content adapted to people with disabilities.	2.53	2.67
C.2	Prepare: MONOGRAPHS on the park for both adults and children; MANUALS for tourist guides; WEB PLATFORM and MOBILE APPLICATIONS.	2.45	2.38
C.3	Create NEW EDUCATIONAL TOURS with informative signs.	2.45	2.30
C.4	Program GUIDED TOURS, LESSONS, WORKSHOPS, COURSES on: ecosystems and landscapes; cultural heritage, history and tradition; nature photography; recognition of plants and animals.	2.40	2.50
C.5	Design and build a new VISITOR CENTRE for shows and exhibitions.	2.01	2.75
C.6	Organise cultural and promotional EVENTS on the park's heritage.	2.15	2.29

(α=0.05) was conducted to verify whether the data for the 21 macro-topics were normally distributed or not. The Shapiro-Wilks test showed a non-normal distribution for all 21 macro-topics; therefore, non-parametric tests were used to identify statistically significant differences between the variables. The Mann-Whitney-Wilcox U test (α=0.05) was performed for the dichotomous variables (i.e. gender; country of origin; and number of visits, by dividing the sample into two classes: those that visited the PLNP once, and those that returned there more than once). For the variables where there were more than two independent groups (i.e. age; number of companions) the Kruskal-Wallis test (α=0.05) was performed. The results showed that for only two variables (i.e. Origin and Number of visits) there is a significant difference within the groups for most of the macro-topics analysed (Table 4). This means that the diverse visitor characteristics associated with these two variables tend to influence the opinions of the visitors themselves.

As regards the Origin variable (Table 5), Croatian visitors on average assigned higher priority to all the macro-topics than foreign tourists. In particular, the macro-topics with a higher priority difference of one point are the following: the monitoring of visitors' satisfaction with the management system (A.8) and the restaurant facilities (B.a.2); the renovation and expansion of restaurant facilities (B.a.1) and retail and souvenir shops (B.b.1÷B.b.5); the preparation of a new visitor centre (C.5); the organisation of events (C.6).

Regarding the Number of visits (Table 6), those who chose to return to the PLNP have expressed on average a higher priority for all macro-topics than tourists who have visited the PLNP only once. In particular, the macro-topics that reported a higher priority difference at one point are the following: increasing surveillance (A.2); monitoring visitor satisfaction (A.8, and B.a.2); the implementation of retail and souvenir shops (B.b.1, B.b.3, B.b.4, and B.b.5); the organisation of events (C.6).

Table 4. Statistically significant results of Mann-Whitney-Wilcox U test for variables: Origin and Number of visits.

Macro-topics	Origin	N of visits
	p-value	p-value
A.2	<0.01	< 0.001
A.4	0.04764	-
A.5	<0.01	-
A.7	0.02130	0.04579
A.8	< 0.001	< 0.01
B.a.1	< 0.001	< 0.01
B.a.2	< 0.001	< 0.001
B.b.1	< 0.001	< 0.001
B.b.2	< 0.001	0.01508
B.b.3	< 0.001	< 0.01
B.b.4	< 0.001	< 0.001
B.b.5	< 0.001	< 0.001
C.1	< 0.01	-
C.4	< 0.01	0.03153
C.5	0.00137	0.04712
C.6	< 0.001	< 0.001

Table 5. Mean and standard deviation of the priority for the macro-topics with statistically significant difference between national visitors and foreign visitors. (Δ Mean - the difference between the average values of national visitors and the average values of foreign visitors).

Macro-topics	National visitors	Foreign visitors	Δ Mean
	Mean±SD	Mean±SD	
A.2	6.92±2.19	6.10±2.16	0.82
A.4	7.16±2.07	6.64±2.11	0.51
A.5	6.86±2.17	6.02±2.07	0.84
A.7	6.58±2.35	5.78±2.46	0.80
A.8	6.87±1.98	5.29±2.29	1.58
B.a.1	7.36±1.88	6.07±2.13	1.29
B.a.2	7.25±1.91	5.28±2.27	1.98
B.b.1	6.13±2.33	4.38±2.45	1.75
B.b.2	6.99±2.36	5.63±2.37	1.36
B.b.3	5.91±2.45	4.48±2.65	1.43
B.b.4	6.87±2.44	5.19±2.33	1.69
B.b.5	6.66±2.28	4.40±2.37	2.26
C.1	7.88±1.68	7.26±1.74	0.63
C.4	7.52±1.81	6.81±2.07	0.71
C.5	6.53±2.52	5.45±2.40	1.08
C.6	7.07±2.23	5.76±2.52	1.31

Table 6. Mean and standard deviation of the priority for the macro-topics with statistically significant difference between visitors who went to the PLNP only once and visitors who returned more than once to the PLNP (Δ Mean - the difference between the average values of national visitors and the average values of foreign visitors).

Macro-topics	National visitors	Foreign visitors	Δ Mean
	Mean±SD	Mean±SD	
A.2	6.95±2.08	5.86±2.25	1.09
A.7	6.45±2.44	5.79±2.36	0.66
A.8	6.53±2.16	5.49±2.30	1.04
B.a.1	7.11±2.04	6.19±2.08	0.92
B.a.2	6.83±2.12	5.51±2.36	1.32
B.b.1	5.78±2.50	4.54±2.42	1.24
B.b.2	6.66±2.50	5.87±2.32	0.78
B.b.3	5.67±2.60	4.54±2.56	1.13
B.b.4	6.55±2.51	5.33±2.40	1.21
B.b.5	6.24±2.38	4.55±2.56	1.69
C.4	7.44±1.80	6.78±2.15	0.66
C.5	6.28±2.59	5.63±2.36	0.65
C.6	6.87±2.44	5.79±2.33	1.09

DISCUSSION

Natural landscapes are widely recognised as important reasons for choosing one tourist destination over another (Lončarić et al. 2021). For this reason, it is considered essential to examine in depth the preferences of tourists (Perera et al. 2015). Some studies have already investigated visitors' opinions on management issues, but with an exclusive focus on environmental and nature conservation aspects (Cihar and Stankova 2006, Arnberger et al. 2012, Belkayali and Kesimoğlu 2015, Abdullah et al. 2018). Whereas the present study goes even further: involving tourists in the evaluation of the adequacy of the actions related to the visitor management system of a NP, and thus giving voice to the opinions of the beneficiaries of such planning.

Besides, it is also important to point out that different types of tourists visit nature-based destinations, following a great variety of motivations, needs and expectations. Indeed, the outcomes of this study have revealed the existence of different types of visitors, also within the PLNP. For example, Croatian visitors gave a higher priority to the implementation of services and infrastructure, compared to tourists from other countries (Table 5). Approximately half of the sample is represented by Croatian visitors who are returned to the PLNP on more than one occasion. Only a small part of the sample consists of foreign vacationers who have visited the PLNP more than once. This means that the expectations that national visitors have by frequenting the PLNP many times are more related to the good maintenance of the services and infrastructure that the PLNP offers.

Another aspect found in the study is that which concerns the retention of visitors. In fact, it has proven that those who have repeatedly returned to the PLNP have higher safety expectations, and consider it important to taken into account the visitor opinion (i.e. through tourist satisfaction monitoring systems), both as regards the organisation of the visiting system and the improvement of the infrastructure. For this purpose, information panels with QR codes linked to a survey web page may be installed. This would ensure that a high percentage of visitors could easily accessed PLNP information services and express their preferences. These kinds of applications have been developed and refined in recent years, and prior to them it was considered extremely demanding to conduct multilingual surveys (Perera et al. 2015). Thanks to these new technologies, six versions of the questionnaire could be adopted in different languages to reach more international tourists, without creating data processing problems. In addition, the majority of questions were asked in such a way as to receive numerical answers that could easily converge in a single archive.

For those who chose to return to visit the PLNP, having travelled many times towards the same nature-based destination creates a desire to participate in new events or to benefit from a variety of facilities (e.g. the sale of products and restaurant services) that can diversify their experience (Lončarić et al. 2021). These aspects had already been identified among the strategies adopted in previous studies (McCool et al. 2021), in order to increase the duration of visits and the average expenditure of visitors. Higher expectations for infrastructure and services can also be viewed as advantage benefit. Services and facilities are actually a fundamental part of the physical infrastructure of a tourist destination, making a territory more attractive and competitive (Mandić et al. 2018). Furthermore, tourist attractions, events, local food and craft products can provide an excellent opportunity to experience the local culture (Lončarić et al. 2021), sensitising visitors to explore the various aspects that characterise a place. Finally, from an economic and market point of view, the range and quality of services greatly influence the success of a tourist destination (Radisic and Basan 2007). However, the results also demonstrated that visitors are generally inclined to set lower priorities for strategies related to retail and souvenir shops than those assigned to other management issues. In any case, they attribute greater importance to this macro-topic than that envisaged in the current Management Plan (Table 3). Therefore, it would be useful for PLNP managers to develop actions related to this theme in slightly shorter timeframes than those foreseen in the current Plan, to meet the expectations of a large number of visitors.

In addition, the Interpretation and education section received the highest priority from tourists (Table 3). Particularly, visitors showed interest in the development of new visit programs and educational materials and activities related to the natural and cultural heritage of the PLNP (see macro-topics C.1, C.2, C.3, and C.4, Table 3). So, in accordance with what has already been established in the current Management Plan, if these aspects were developed with a medium-high priority, it would increase the attractiveness of the PLNP, with tangible economic consequences (Wolf et al. 2015). Furthermore, this would redistribute visitors through a range of interesting alternative activities, which would decongest the most crowded area of the PLNP (i.e. the Lakes area). Finally, these initiatives would enhance visitors' awareness of the values and resources of the site. In this way, they would be more conscious of the environment, and therefore more respectful of the natural landscape and its ecosystems (Perera et al. 2015, Wolf et al. 2015). Among the new activities to be proposed, it would be important to involve local people, who are crucial stakeholders in the sustainable development of a PA (Marković et al. 2013). Private farms and villages can be interesting destinations to appreciate local traditions (McCool et al. 2021).

Regarding the Visitor use management system, tourists confirmed the need to intervene with almost the same level of medium-high priority already established in the current Management Plan. As stated in other studies (Radisic and Basan 2007, Lončarić et al. 2021), it is fundamental for managers of nature-based destinations to disseminate information on the various natural attractions and services available, using communications materials, web pages and social media. By being informed in advance, visitors would be facilitated in planning their trip, which would increase their satisfaction with the chosen destination. This is also confirmed by the results of this study. In fact, the survey sample gave a slightly higher priority to multiple actions related to this issue compared to the current Management Plan (see macro-topics A.1, A.4, and A.8 Table 3).

As PLNP tourism receipts represent approximately 98% of the total income (Mandić 2021), it is evident that any kind of action included in the management strategies could not be developed without visitors. Moreover, effective integration in the international tourism market requires specialised managerial skills and the provision of high quality tourism products, which can satisfy a wide range of visitors (Lundmark and Müller 2010). For this reason, the managers of the PLNP, as a nature-based tourist destination, must necessarily consider the satisfaction of their users.

CONCLUSIONS

In this study, a new research dimension concerning the investigation of visitors' perceptions of the management of an international nature-based destination - the Croatian Plitvice Lakes National Park - was experienced. This study builds on the findings of a previous research that used a methodology based on big data analysis to identify the topics of greatest interest to PLNP visitors (Sergiacomi et al. 2022). The results of this study may be useful to PLNP managers in formulating and promoting innovative experiences aimed at improving the aspects that the tourists themselves consider most relevant.

With respect to research questions, the survey identified management issues considered as priorities by PLNP visitors (RQ1). In particular, the actions strictly related to the issues of the "Visitor use management system" and "Interpretation and education" appear of greater interest to tourists. Furthermore, the study also identified the main discrepancies between the priorities expressed by visitors and those assigned by the managers (RQ2). Specifically, visitors gave a much higher priority than the current Management Plan on information and monitoring of tourist preferences. The theme of the renovation of the old souvenir shop structures reported the largest difference in positive terms on behalf of visitors, even if the absolute score they assigned to this topic is not one of the highest in the survey.

Although the online survey was released through the main social channels of the PLNP, this strategy collected only a small sample of respondents (214). Therefore, it would be useful to expand data collection by enabling an on-going monitoring system, for example using information panels with QR codes that are always connected to an online questionnaire on visitor preferences.

Nowadays, to achieve effective economic sustainability, PA managers are increasingly faced with a dual mission. On the one hand, the protection of natural and cultural resources, which makes the sector of interest a unique heritage. On the other hand, satisfying the expectations and needs of those who choose to use and enjoy these goods. To do this, visitors should be regularly included in the stakeholder categories to be involved in the decision-making process of managing the PLNP. In conclusion, all the results of this study are a confirmation of the fact that it is essential to involve tourists to management issues of a nature-based destination. In this way, it will be possible to turn them into visitors actively involved in the conservation of the resource, and attentive inspectors of the behaviour of the other users.

Author Contributions

CS, DV, AP and CF conceived and designed the research; CS carried out the data collection and processing; CS and AP performed the statistical analysis; DV, AP and CF supervised the research; CS prepared the original draft of the manuscript; CS, DV, AP and CF reviewed and edited the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Trends in the Phenological Pattern of Hybrid Plane Trees (*Platanus × acerifolia* (Ait) (Wild)) in Sarajevo Ecological Conditions

Mirzeta Memišević Hodžić[1,*], Dalibor Ballian[1,2]

(1) University of Sarajevo, Faculty of Forestry, Department of Cultivation of Forests and Urban Greens, Zagrebačka 20, BA-71000 Sarajevo, Bosnia and Herzegovina; **(2)** Slovenian Forestry Institute, Večna pot 2, SI-1000 Ljubljana, Slovenia

*** Correspondence:** e-mail: m.memisevic-hodzic@sfsa.unsa.ba

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ABSTRACT

Phenological research of plant species is of great importance in the context of adaptation to climate change and changing environmental factors, especially in dynamic urban environments, such as the area of Sarajevo. This research aims to determine trends in the phenological pattern of hybrid plane trees in the area of Sarajevo so that recommendations can be made for the use of plane trees in greening urban and suburban areas since they largely depend on microclimatic conditions. In this paper, the authors researched the variability of leafing phenology of maple (*Platanus × acerifolia* (Ait) (Wild)) at six different localities in the area of Sarajevo. Observations were made in the spring of 2009, 2014, 2016, and 2020. Six phenological phases in the spring aspect of leaf development were monitored (0 - dormant buds, 1 - beginning of bud opening, 2 - open buds, 3 - leaf opening, 4 - young leaves, 5 - fully developed leaves). The results showed differences in the beginning and end of phenological phases by years and localities. Analysis of variance showed statistically significant differences in the duration of leaf development phases caused by the year of observation, locality, and the interaction of locality and year, which indicates the influence of seasonal climatic elements and micro-location conditions, as well as their interaction on the occurrence of phenophases. The results of this research can be used to recommend the use of plane trees in selected locations, with the selection of appropriate provenances and respect for phenological characteristics. Research needs to be continued and extended to leaf rejection research, which is particularly significant given the frequent heavy snowfall during the winter months in the investigated area.

Keywords: *Platanus x acerifolia*; urban greening; leafing phenology

INTRODUCTION

Due to the increased need for climate research caused by various changes, plants can be used as indicators because each climatic change reflects in their rhythm and development. Significant climate change has occurred worldwide, including a rise in temperatures (Iglesias et al. 2007).

Urban greenery has an important role in shaping cities and settlements through its aesthetic and environmental functions. Trees located in urban areas are exposed to various biotic and abiotic factors which affect their development (Vukičević 1996).

Phenology studies the functional dependence of the annual development of the plant world on climatic conditions. Changes in the continuity of flowering and foliage over the years, for some tree species, show that plants can respond to different climate changes and can adapt to different conditions. Urban spaces affect plants and their phenological processes differently. They create a special microclimate, and one of the main factors influencing the greenery in the city is the effect of heat islands. Heat islands are created due to the lack of green areas and a higher presence of asphalt surfaces. Therefore, it is important to conduct phenological research in urban parts of cities because their warmer conditions can help to assess the potential effects of climate change on plants, as stated by many authors (Luo et al. 2007, Mimet et al. 2009, Richardson et al. 2013, Orzechowska-Szajda et al. 2020). There has been a small number of previous research on plane trees in Sarajevo. Hukić et al. (2008) performed DNA analysis of plane trees in the lined walkways of the city of Sarajevo, and the expected polymorphism was not obtained.

This research aims to determine the phenological variability of plane trees (*Platanus x acerifolia*) in the area of Sarajevo. The results will be used in future planning of the use of *Platanus x acerifolia* in urban greenery to make optimal use of the different dynamics of phenological phases of leafing and thus flowering in different localities.

MATERIALS AND METHODS

Research Area

The field research of this paper included six localities in the Sarajevo area. In the very center of the city, plane trees were observed in the Mirza Delibašić and Davorin Popović Park, in At-mejdan Park (only for 2009, 2014 & 2016) and in a tree-lined avenue that stretches from Alipaša's Mosque to Ciglane. Trees were also observed in Meša Selimović Boulevard and at the beginning and the end of Velika Aleja. The locations are shown in Table 1.

At the sites of Velika Aleja - beginning and Velika Aleja - end, and in the memorial park Mirza Delibašić and Davorin Popović and At-mejdan Park, there are large, old plane trees planted during the Austro-Hungarian rule in Bosnia and Herzegovina. These trees are still of good vitality, although the plane trees in the parks are surrounded by buildings and are shaded most days. The sites in Velika Aleja are important because they are located near the protected area, Vrelo Bosne, and because of the old trees that adorn this natural oasis. The height of the trees reaches an enviable 40 m, and diameter at breast height (DBH) of most trees is more than 1 m. Trees are vital and have minor damage having in mind their age. Velika Aleja is located in the southwestern part of the Sarajevo Field, at the foot of the mountain Igman, and it is therefore exposed to low temperatures, frost, and shorter daylight.

Plane trees in Meša Selimović Boulevard and Alipašina Street are located along the roads and are constantly exposed to dust and exhaust gases. In Alipašina Street, among other factors, electrical and trolleybus installations obstruct the normal development of the canopy. The trees also have very little space for the development of the root system. The plane trees in Meša Selimović Boulevard and Alipašina Street were planted in 1997. The trees were donated from Spain. However, bad planting material (or unsuitable for the conditions of the locations) has resulted in poor vitality, and these trees are often damaged by snow (Beus 2009).

Methods

Observations of phenological phases of leafing were made in the spring periods of 2009, 2014, 2016, and 2020. First observation every year took place on February 20, when the buds are in the winter dormancy phase, to register the beginning of the bud swelling phase. The last date when all trees were in Phase 0 was taken as the beginning of the observation. The date when all the trees in an individual locality were in Phase 5 were recorded as the end of the observation. The length of the observation by years and localities is shown in Table 2.

Field data collection was performed visually. The change of six different phenological phases in individual trees was monitored: 0 - dormant buds, 1 - beginning of bud opening, 2 - open buds, 3 - opening the leaves, 4 - young leaves, and 5 - fully developed leaves (Figure 1).

Table 1. Localities and number of observed trees per locality.

No	Locality	Number of trees observed	Average height of trees (m)	Average DBH (cm)	Year of planting	Height of surrounding buildings
1.	Mirza and Davorin Park	15	30-40	>100	End of XIX ct.	Up to 10 floors
2.	Alipašina Street	30	15	25	1997	Up to 10 floors
3.	Meša Selimović Boulevard	30	15	25	1997	Up to 20 floors
4.	At-mejdan	14	30-40	>100	End of XIX ct.	Up to 10 floors
5.	Velika Aleja - beginning	30	30-40	>100	1892	No buildings
6.	Velika Aleja - end	30	30-40	>100	1892	No buildings

Table 2. Length of observation of phenological phases of plane trees' leafing.

No	Locality	Number of observation days per year			
		2009	2014	2016	2020
1.	Mirza and Davorin Park	52	58	52	78
2.	Alipašina Street	41	77	89	69
3.	Meša Selimović Boulevard	39	61	78	61
4.	At-mejdan	50	69	83	-
5.	The beginning of Velika Aleja	42	48	74	92
6.	The end of Velika Aleja	41	42	91	80

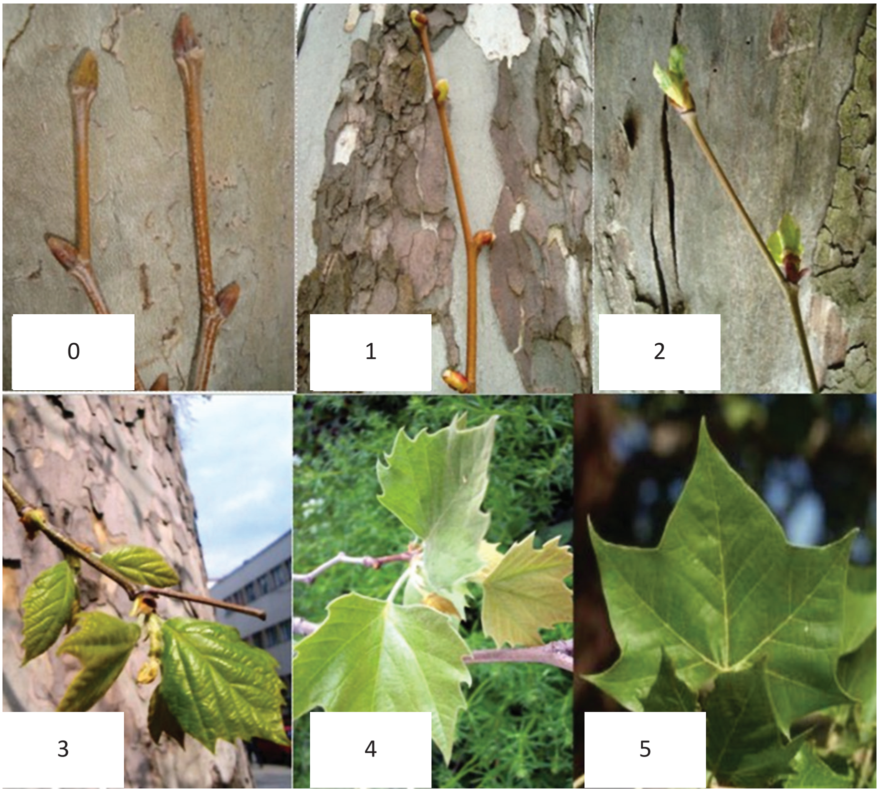

Figure 1. Observed phenological phases (Baručija 2015).

After monitoring the phenophases, the authors collected data on meteorological elements for the springs of 2009, 2014, 2016, and 2020. (Federalni hidrometeorološki zavod 2010, 2015, 2017, 2021).

Statistical Analysis

Data processing was done in Microsoft Office Excel 2016 and statistical program IBM SPSS 26.0 for Windows. Based on the collected data, the authors calculated the earliest and latest dates of the phases and the duration of phases by localities and years. Analysis of variance for the duration of phenophases was performed regarding the influence of locality, year of observation and interaction of locality and year. A multiple Duncan's test was also performed to determine the grouping of sites and years according to the common average lengths of phases.

RESULTS

Meteorological data for the months in which field research of plane tree phenology was conducted in the Sarajevo area (2nd-6th month) were collected from the report of the Federal Hydrometeorological Institute for 2009, 2014, 2016 and 2020 for Sarajevo (Federalni hidrometeorološki zavod 2010, 2015, 2017, 2021) and are shown in Table 3.

Table 3 shows that the meteorological elements in the research months were different by years. February had an average temperature ranging from 1.0ºC in 2009 to 7.8ºC in 2014. The amount of precipitation ranged from 19.9 $mm{\cdot}m^{-2}$ in 2014 to 25.5 $mm{\cdot}m^{-2}$ in 2020. March was the coldest on average in 2009, with an average temperature of 4.7ºC, and the warmest in 2014 with 8.1ºC. The lowest monthly amount of precipitation was recorded in 2020, 53.0 $mm{\cdot}m^{-2}$, and the highest in 2016, 131.7 $mm{\cdot}m^{-2}$. The average temperature in April ranged from 10.2ºC in 2014 to 12.9ºC in 2016, and the monthly amount of precipitation from 23.1 $mm{\cdot}m^{-2}$ (2020) to 148.5 $mm{\cdot}m^{-2}$ (2014). The average temperature in May ranged from 13.5ºC (2014) to 16.2ºC (2009), and the monthly amount of precipitation from 63.5 $mm{\cdot}m^{-2}$ (2009) to 186.2 $mm{\cdot}m^{-2}$ (2014). In June, average temperatures ranged from 17.5ºC (2014) to 19.5ºC (2016). The monthly amount of precipitation ranged from 92.1 $mm{\cdot}m^{-2}$ (2020) to 154.5 $mm{\cdot}m^{-2}$ (2009).

As stated in the materials and methods, observations were made for the first time each year on 20 February, when the buds were in the dormant phase, to register the beginning of the budding phase. The last date when all trees were in Phase 0 was recorded as the beginning of the phase. The date when all trees in an individual locality were in Phase 5 was recorded as the end of the phase. Durations of phases 0 and

Table 3. Basic meteorological data by years and months of observation.

Month	Year	Average temperature (°C)	Max temperature (°C)	Date	Min temperature (°C)	Date	Insolation (hours)	Monthly sum of precipitation (mm)	Max daily sum of precipitation (mm)	Date
II	2009	1.0	14.2	05	-11.6	23	76.5	53.7	15.9	19
	2014	7.8	19.8	16	-3.0	4	113.7	19.9	8.0	23
	2016	7.4	21.2	17	-5.7	6	80.7	87.0	17.6	26
	2020	5.0	21.6	17	-5.9	7	128.5	70.4	25.5	27
III	2009	4.7	20.0	30	-4.6	26	102.7	83.6	16.2	7 & 10
	2014	8.1	24.7	18	-0.7	12	169.5	67.3	24.1	6
	2016	6.1	24.0	31	-1.7	25	112.3	131.7	25.3	1
	2020	6.5	24.4	13	-4.8	24	141.2	53.0	17.8	4
IV	2009	12.1	23.4	1	3.5	15	181.7	61.3	17.1	4
	2014	10.2	24.3	8	-0.6	12	105.6	148.5	19.9	17
	2016	12.9	28.9	17	0.0	26	168.6	60.5	17.0	10
	2020	11.5	28.1	18	-5.0	2	239.0	23.1	7.6	22
V	2009	16.2	30.8	22	4.8	31	229.6	63.5	18.6	28
	2014	13.5	29.7	23	1.6	6	176.8	186.2	73.3	14
	2016	13.9	32.5	28	1.5	17	189.8	82.1	23.3	20
	2020	14.2	29.5	15	3.4	4	164.2	96.3	24.5	21
VI	2009	17.8	33.3	16	8.7	14	200.3	154.5	58.7	02
	2014	17.5	31.0	24	6.0	3	196.9	125.1	28.5	26
	2016	19.5	32.3	24	9.1	4	215.5	96.4	32.0	27
	2020	18.1	33.0	29	7.5	3	212.3	92.1	24.4	23

Table 4. Dates of the first and last occurrences of phenophases by years and localities.

Locality	Year	Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Park Mirza Delibašić and Davorin Popović	2009	27/3-7/4	30/3-19/4	7/4-9/5	19/4-15/5	9/5-18/5	15/5-30/5
	2014	21/3-27/3	24/.-17/4	14/4-20/4	20/4-5/5	5/5-30/5	17/5-30/5
	2016	27/3-1/4	29/3-29/4	20/4-29/4	29/4-27/5	23/5-6/6	23/5-10/6
	2020	18/3-18/4	18/3-24/4	11/4-29/4	18/4-9/5	4/5-4/6	17/5-4/6
Alipašina Street	2009	27/3-2/4	30/3-13/4	2/4-23/4	7/4-4/5	15/4-6/5	4/5-30/5
	2014	4/3-15/3	7/3-14.4	2/4-20/4	17/4-17/5	26/4-20/5	5/5-30/5
	2016	6/3-20/3	15/3-12/4	30/3-4/5	2/4-9/5	29/4-3/6	17/4-10/6
	2020	18/3-11/4	18/3-18/4	11/4-24/4	18/4-4/5	24/4-25/5	13/5-25/5
Meša Selimović Boulevard	2009	27/3-5/4	30/3-13/4	5/4-19/4	13/4-25/4	19/4-6/5	4/5-30/5
	2014	21/3-27/3	24/3-14/4	2/4-17/4	14/4-11/5	25/4-20/5	14/5-30/5
	2016	17/3-28/3	24/3-13/4	28/3-26/4	2/4-13/5	20/4-3/6	3/5-10/6
	2020	18/3-5/4	18/3-5/4	11/4-24/4	11/4-24/4	18/4-24/4	13/5-17/5
At-mejdan	2009	2/4-9/4	5/4-29/4	9/4-6/5	29/4-15/5	9/5-21/5	18/5-30/5
	2014	10/2-24/3	21/3-20/4	14/4-26/4	26/4-20/5	17/5-26/5	26/5-30/5
	2016	19/3-24/3	26/3-24/4	20/4-6/5	2/5-28/5	22/5-10/6	1/6-10/6
	2020	-	-	-	-	-	-
The beginning of Velika Aleja	2009	9/4-19/4	11/4-2/5	19/4-6/5	2/5-18/5	12/5-21/5	18/5-30/5
	2014	2/4-11/4	5/4-20/4	17/4-5/5	29/4-14/5	8/5-20/5	17/5-30/5
	2016	2/4-17/4	9/4-29/4	17/4-12/5	23/4-30/5	12/5-5/6	17/5-10/5
	2020	18/3-24/4	11/4-29/4	24/4-29/4	24/4-17/5	13/5-7/6	29/5-16/6
The end of Velika Aleja	2009	11/4-19/4	13/4-25/4	19/4-6/5	4/5-15/5	12/5-21/5	21/5-30/5
	2014	8/4-14/4	11/4-29/4	23/4-5/5	29/4-14/5	8/5-20/5	17/5-30/5
	2016	5/3-17/3	12/4-2/5	26/4-22/5	6/5-23/5	17/5-3/6	23/5-10/6
	2020	18/3-24/4	11/4-29/4	24/4-29/4	29/4-17/5	13/5-4/6	25/5-4/6

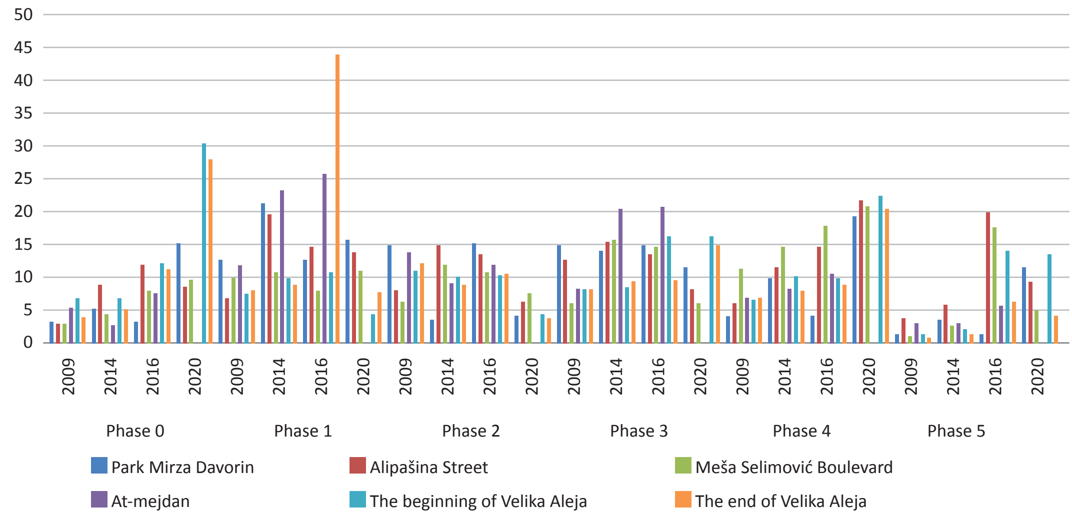

Figure 2. Duration of phases (in days) per localities and years.

5 were not complete because we did not observe autumn of the previous year and the following autumn (when trees entered Phase 0).

The length of observations by years and localities is given in Table 2. According to the duration of the observation period, which lasted 39 days at shortest and 94 days at longest, it can be concluded that the phases were of different lengths, i.e., started earlier/later depending on the location and annual, i.e., seasonal climate.

The dates of the first and last occurrences of the phases by years and localities are shown in Table 4. Phase 1 (beginning of bud opening) occurred at earliest on March 7, 2014. at the site of Alipašina Street, and at latest at the end of the Velika Aleja in 2009 (April 13).

The authors calculated the average durations of leafing phases per localities and years. Duration of phases per localities and years is shown in Figure 2.

The dormant buds phase (incomplete, from the last date when all the trees on the site were in that phase until the first appearance of Phase 1) of all observed years and localities lasted the shortest in 2016 on the site of Mirza Delibašić and Davorin Popović Park, and the longest in 2020 on the beginning of Velika Aleja. The bud swelling phase lasted the shortest in 2020 on the beginning of Velika Aleja (5 days) and the longest in 2016 on the end of Velika Aleja (44 days). The phase of open buds lasted the shortest in 2014 in the Mirza Delibašić and Davorin Popović Park (4 days) and the longest at the same location in 2016 (15 days). The phase of opening of leaves lasted the shortest in 2020 in Meša Selimović Boulevard (6 days), and the longest in 2016 in At-mejdan Park (21 days). The phase of young leaves lasted the shortest (4 days) at the Mirza and Davorin Park site in 2016 and the longest (23 days) in 2020 on the beginning of Velika Aleja. The phase of open leaves (incomplete, from the first appearance of this phase to the date when all trees on the observed site were in this phase) lasted the shortest in 2009 on the end of Velika Aleja (1 day), and the longest in 2016 in Alipašina Street.

Tests of between-subjects effects table (Table 5) for the duration of phenological phases of leafing showed statistically significant differences caused by year, locality, and interaction of the effects of the year of observation and locality (Fizr.>Ftab., Sig.<0.005).

As the results showed statistically significant differences in the duration of phases by years and localities, a multiple Duncan's test was performed for this trait to determine whether individual years/localities were grouped according to average values.

Duncan's test results by year showed no grouping for phases 0, 1, and 4. For Phase 2, 2009 and 2014, formed one group. For Phase 3, 2009 and 2020 formed one group, and for Phase 5, 2016 and 2020 formed one group.

The results of the Duncan's test for the phase duration by localities are shown in Table 6.

Duncan's test for Phase 0 (dormant buds) showed grouping into four groups. The beginning of Velika Aleja and the end of Velika Aleja formed separate groups with a longer average length, and the other four sites are divided into two groups that overlap. For Phase 1, bud swelling, Duncan's test showed grouping in five groups: Mirza and Davorin Park and the end of Velika Aleja formed one group, all other localities were not grouped. At-mejdan had the highest average value. For Phase 2, Alipašina Street and At-Mejdan were in one group, with higher average values of the phase duration, while all other localities were in the other group. For Phase 3 according to Duncan's test, At-mejdan site was in a separate group, with the highest average value, one group consisted of Meša Selimović Boulevard and the end of Velika Aleja, and the other group included the beginning of Velika Aleja, Alipašina Street and Mirza and Davorin Park. For Phase 4 Duncan's test showed grouping into 4 groups, Meša Selimović Boulevard was in a separate group with the longest average duration of the phase, while other localities were put into 3 groups. For Phase 5, Alipašina Street was in a separate group with the highest average duration, while other localities were divided into two groups.

Table 5. Tests of between-subjects effects for duration of phenological phases of leafing.

Phase	Source	Type III Sum of Squares	df	Mean Square	F	Sig.
0	Corrected Model	37110.700[a]	23	1613.509	62.714	0.000
	Intercept	51032.279	1	51032.279	1983.530	0.000
	Year of observation	14701.267	3	4900.422	190.470	0.000
	Locality	5632.288	6	938.715	36.486	0.000
	Year * Locality	9252.666	14	660.905	25.688	0.000
	Error	15179.528	590	25.728		
	Total	116604.000	614			
	Corrected Total	52290.228	613			
1	Corrected Model	43803.746[a]	23	1904.511	65.855	0.000
	Intercept	100552.565	1	100552.565	3476.973	0.000
	Year of observation	7483.963	3	2494.654	86.262	0.000
	Locality	8363.725	6	1393.954	48.201	0.000
	Year * Locality	25306.284	14	1807.592	62.504	0.000
	Error	17062.548	590	28.920		
	Total	167512.000	614			
	Corrected Total	60866.293	613			
2	Corrected Model	7391.858[a]	23	321.385	24.640	0.000
	Intercept	47077.617	1	47077.617	3609.286	0.000
	Year of observation	3194.972	3	1064.991	81.649	0.000
	Locality	318.033	6	53.005	4.064	0.001
	Year * Locality	3154.921	14	225.352	17.277	0.000
	Error	7695.647	590	13.043		
	Total	69838.000	614			
	Corrected Total	15087.505	613			
3	Corrected Model	11362.591[a]	23	494.026	23.201	0.000
	Intercept	74603.371	1	74603.371	3503.616	0.000
	Year of observation	2155.243	3	718.414	33.739	0.000
	Locality	2769.884	6	461.647	21.680	0.000
	Year * Locality	5624.909	14	401.779	18.869	0.000
	Error	12563.018	590	21.293		
	Total	110100.000	614			
	Corrected Total	23925.609	613			
4	Corrected Model	23214.267[a]	23	1009.316	50.445	0.000
	Intercept	84269.950	1	84269.950	4211.795	0.000
	Year of observation	13486.883	3	4495.628	224.691	0.000
	Locality	2853.380	6	475.563	23.769	0.000
	Year * Locality	1692.933	14	120.924	6.044	0.000
	Error	11804.771	590	20.008		
	Total	141375.000	614			
	Corrected Total	35019.037	613			
5	Corrected Model	31924.850[a]	23	1388.037	66.930	0.000
	Intercept	32550.464	1	32550.464	1569.548	0.000
	Year of observation	7232.896	3	2410.965	116.254	0.000
	Locality	11420.093	6	1903.349	91.777	0.000
	Year * Locality	5468.057	14	390.576	18.833	0.000
	Error	12235.862	590	20.739		
	Total	78369.000	614			
	Corrected Total	44160.712	613			

Table 6. Grouping of sites for the duration of phases according to the Duncan's test.

Phase	Locality	Subset				
		1	2	3	4	5
0	At-mejdan	5.36				
	Meša Selimović Boulevard	6.57	6.57			
	Park Mirza Davorin	6.85	6.85			
	Alipašina Street		8.19			
	The end of Velika Aleja			12.28		
	The beginning of Velika Aleja				14.15	
	Sig.	0.113	0.082	1.000	1.000	1.000
1	The beginning of Velika Aleja	8.17				
	Meša Selimović Boulevard		10.10			
	Alipašina Street			13.88		
	Park Mirza Davorin				15.75	
	The end of Velika Aleja				17.27	
	At-mejdan					20.50
	Sig.	1.000	0.644	1.000	0.106	1.000
2	The end of Velika Aleja		8.98			
	The beginning of Velika Aleja		9.06			
	Meša Selimović Boulevard		9.27			
	Park Mirza Davorin		9.55			
	Alipašina Street			10.85		
	At-mejdan			11.55		
	Sig.	1.000	0.412	0.269		
3	The end of Velika Aleja		10.67			
	Meša Selimović Boulevard		10.78			
	The beginning of Velika Aleja			12.42		
	Alipašina Street			12.63		
	Park Mirza Davorin			13.90		
	At-mejdan				16.82	
	Sig.	1.000	0.893	0.083	1.000	
4	At-mejdan	8.64				
	Park Mirza Davorin	9.48				
	The end of Velika Aleja		11.04			
	The beginning of Velika Aleja		12.38	12.38		
	Alipašina Street			13.67		
	Meša Selimović Boulevard				16.28	
	Sig.	0.277	0.085	0.100	1.000	1.000
5	The end of Velika Aleja	3.29				
	At-mejdan	3.95				
	Park Mirza Davorin	4.47				
	Meša Selimović Boulevard		6.74			
	The beginning of Velika Aleja		7.82			
	Alipašina Street			9.78		
	Sig.	0.163	0.176	1.000	1.000	

DISCUSSION

According to the beginnings of individual phases by years and localities (shown in Table 4), Alipašina Street and Meša Selimović Boulevard stand out with the earliest beginnings. Phase 1 started at earliest in Alipašina Street in 2014 (March 7), and Phase 2 in 2016 in Meša Selimović Boulevard (March 28). Phase 3 started at earliest in 2016 (April 2) at the locations of Alipašina Street and Meša Selimović Boulevard, and Phase 4 at Meša Selimović Boulevard (April 18). Phase 5 started at earliest in 2016 in Alipašina Street (April 17).

The latest start of Phase 1 occurred in 2009 on the end of Velika Aleja (April 13), Phase 2 at the same location in 2016 (April 26), Phase 3 on the end of Velika Aleja in 2016 (May 6), Phase 4 in 2016 at the location At-mejdan (22.5.) and Phase 5 at At-mejdan in 2016 (1.6.).

The year 2016 had the earliest beginnings of phases in some locations, and the latest beginnings of phases in other locations, which confirmed the influence of the micro-location and seasonal climate on the leafing phenology of plane trees.

Analysis of variance in this research showed statistically significant differences by localities, years, and according to the interaction of localities x years. Statistically significant differences by localities were obtained by Velić (2010), Baručija (2015), Drndo (2016).

Duncan's test showed different groupings per years and phases.

These results are important for understanding adaptation and response of plane trees to microclimatic conditions and changing seasonal climate. As a scientific discipline, phenology deals with the measurement and analysis of seasonal physiological processes and their relationship to the environment. The phenology of forest trees is important for discovering the enduring link between climate change and the physiological activity of trees (Ballian and Kajba, 2010). As phenology is temperature-dependent, accelerated climate change requires that monitoring of the impact of these changes on plants is carried out more frequently (Piao et al. 2019). As stated by Ducci et al. (2012), phenology is an important aspect of adaptation. Phenology traits are conditioned by several biological and environmental factors necessary for launching the processes, but they are also under strong genetic control (Ducci et al. 2012).

Phenological research in urban areas is important because warmer conditions of these areas can help to assess the potential effects of climate change on plants, as stated by many authors (Luo et al. 2007, Mimet et al. 2009, Richardson et al. 2013, Orzechowska-Szajda et al. 2020). Wohlfahrt et al. (2019) investigated changes in plant phenology caused by urbanization using publicly available pan-European data sets for 1981-2010 period. The authors found a significant advancement in leaf development, flowering and fruiting phenological phases, as well as higher air temperatures with higher degrees of urbanization.

Roetzer et el. (2000) researched effects of urbanization degree on flowering phenology on four species (*Galanthus nivalis*, *Forsythia* sp., *Prunus avium* and *Malus domestica*) in ten central European regions (Hamburg, Berlin, Cologne, Frankfurt, Munich, Prague, Vienna, Zurich, Basel and Chur). The results indicated that, despite regional differences, in nearly all cases, the studied species flowered earlier in urbanised areas than in the corresponding rural areas.

Jia et al. (2021) explored urbanization imprint on land surface phenology in 343 Chinese cities. They considered the urbanization intensity gradient ranging from 0% to 100%. The results showed that the growing season started on average 8.6 days earlier, and ended 1.3 days later in urban core areas (with urbanization intensity above 50%) relative to their rural counterparts (urbanization intensity lower than 1%).

Mimet et al. (2009) researched phenology of *Platanus acerifolia* and *Prunus cerasus* in relation to meteorological elements in the urban area (the city of Rennes, France). Their results showed the existence of both a climatic gradient and a developmental gradient corresponding to the type of urbanisation in the city. The town influenced plant phenology by reducing the diurnal temperature range and by increasing the minimum temperature as one approaches the town centre (Mimet et al. 2009). Increasing temperature can cause earlier occurrence of the phenological phases. It corresponds to the results of this research where all leafing phases in all observed years occurred later on the beginning and end of Velika Aleja, which are more distant from the city center, than in other localities, closer to the city center. Mimet et al. (2009) also confirmed the influence of ground cover type (plants or buildings) on the development of phenological phases (Mimet et al. 2009).

Mimet et al. (2009) found that the pre-flowering phases are best correlated with the mean of the minimum air temperature for the 15-day period before the observation, whereas flowering appears to be more dependent on the mean of the daily diurnal temperature range for the 8 days preceding the observation.

Orzechowska-Szajda et al. (2020) confirmed the extension of the period of vegetation in the city center in relation to its peripheries in research of phenology of *Aesculus hyppocastanum* carried out in 2017 in Wrocław, Poland. In the same research (Orzechowska-Szajda et al. 2020) the authors found that trees growing in road lanes entered the vegetation period later and defoliated faster, which confirms the negative impact of street conditions on the development of trees in urban space. Plane trees take a special place in green areas in Sarajevo, both because of their number and their visual dominance over many other species. During the war from 1992 to 1995, urban greenery in Sarajevo suffered heavy losses, according to Hadžidervišagić (2011). Plane trees are a very desirable species in our parks, and in planting them it is necessary to choose the best material, considering the origin of planting material and its phenological characteristics. According to Beus (2009), the introduction of inappropriate plane trees in Sarajevo (donated from Spain and France) often caused damage due to large amounts of snow.

CONCLUSIONS

When planning the greening of urban areas, special attention should be paid to the phenological characteristics of the species, hybrid, clone, and genotype and its interaction with environmental factors. Sometimes even minimal differences in some environmental factors can cause different reactions at the beginning of certain phenological phases.

One of the very important species for our urban areas is the plane tree, a tree of imposing appearance at any time of the year. Some of the trees observed in this study are over 100 years old, which implicates that the species is adapted to urban conditions.

The research results showed that the beginnings of plane tree leafing phases in Sarajevo were different both by years and by localities. It is not possible to say when the vegetation period begins. This points to the conclusion that the leafing of plane trees depends on the annual/seasonal climate, as well as on the microclimatic conditions of the locality, and certainly on the climate changes that cause differences in the seasonal climate.

Analysis of variance showed statistically significant differences caused by the years of observation (2009, 2014, 2016, and 2020), which shows that the influence of seasonal climate on plane tree leafing is significant. Analysis of variance showed statistically significant differences caused by observation sites, which proves that the influence of microclimatic conditions on the leafing of plane trees is significant.

In the observation areas, the plane tree has proven to be a species suitable for tree lines and its planting in parks. In that sense, it should continue to be used, considering the results of phenological observations and adaptation to microclimatic conditions. It is necessary to continue research on the phenology of leafing and undertake research on the phenology of flowering and leaf rejection to make recommendations for the use of this species on a particular locality.

Author Contributions

DB and MMH conceived and designed the research, DB carried out the field observations, MMH and DB processed the data and performed the statistical analysis, MMH and DB wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Chemical Composition and Energy Evaluation of *Abies* spp. and *Pinus* spp. Sawdust Collected as a Byproduct of the Primary Wood Sawing

Omar Martínez-Gómez[1], Luis Fernando Pintor-Ibarra[2], José Guadalupe Rutiaga-Quiñones[2], Jarinzi Corona-Terán[2,*]

(1) Tecnológico Nacional de México/Tecnológico de Estudios Superiores de Valle de Bravo, División de Ingeniería Forestal, Km 30 carretera Federal, Monumento-Valle de Bravo, 51200 Valle de Bravo, Mexico; **(2)** Universidad Michoacana de San Nicolás de Hidalgo, Facultad de Ingeniería en Tecnología de la Madera, Avenida Francisco J. Múgica S/N, 58040, Morelia, Mexico

*** Correspondence:** e-mail: cjarinzi@yahoo.com.mx

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ABSTRACT

The aim of this paper is to chemically evaluate the byproducts of the primary processing of genera *Abies* and *Pinus*, to determine the possibility of using them as solid biofuel. Ash percentage, volatile matter and fixed carbon values were determined by proximate analysis. The basic chemical composition includes the determination of extractives content, lignin and holocellulose. Ash microanalysis was performed with an X-ray spectrometer and the calorific value of the samples was determined by using an AC600 calorimeter. The results of this research varied as follows: the content of inorganic substances (0.33% to 0.41%), volatile matter (88.54% to 82.57%), fixed carbon (11.13% to 17.06%), extractives content (5.37% to 17.82%), Runkel lignin (27.33% to 30.97%), holocellulose content (58.53% to 69.56%) and calorific value (19.09 MJ·kg^{-1} to 20.42 MJ·kg^{-1}). According to the X-ray analysis, the most abundant elements were potassium, calcium and magnesium; whereas no heavy metals were found. The results of this research show that the two genera studied here are suitable for solid biofuel production.

Keywords: byproducts; sawmills; biofuel; chemical composition; calorific value

INTRODUCTION

During the last decades, atmosphere composition has been affected by the increasing emission of greenhouse gases produced by anthropogenic activities. In addition, activities such as the combustion of fossil fuels and the possible exhaustion of oil reserves, which are causing climate change, have also boosted a worldwide demand for renewable energy sources (Escorsim et al. 2018), such as biomass.

Biomass production is significant and stands in the fourth place in the global energy balance right after coal, oil and natural gas. Biofuels are considered better than fossil fuels, since their overall CO_2 emissions can be considered equal to zero. This is due to the fact that during its growth a plant can absorb the same amount of CO_2 and release oxygen through the photosynthetic process, as well as because plants have low sulfur and nitrogen contents (Di Blassi 2009). Furthermore, thanks to its abundance, wood is the lignocellulosic raw material most widely-used, namely, as construction material, for furniture production, and for charcoal and biofuel production (Karinkanta et al. 2018).

The mechanical forestry industries use wood primarily for sawmilling, which is one of the least complex activities. It consists of a certain number of operations, starting with log handling and transportation, wood drying, selection and classification. Several types of energy are needed to perform these operations (FAO 1991). Throughout this productive process, several byproducts are generated, such as sawdust, woodchips, shavings, and slabs (FAO 1991, Zavala-Zavala and Hernández-Cortés 2000), which might be incorporated into the production of pulp, paper, boards, and fertilizers (Kollman 2001). Nonetheless, the volume of generated byproducts places biomass as a source of energy that is economically competitive with fossil fuels (García et al. 2012).

In the interest of achieving both domestic and industrial uses of these byproducts, it is necessary to determine their properties and components (Mitchual et al. 2014). Properties of combustible materials include calorific value, density, moisture content, ash, mineral content, volatile matter, and fixed carbon content (Khan et al. 2009, Mediavilla et al. 2009, Telmo et al. 2010), while their structural analysis consists of determining the cellulose, hemicellulose and lignin content (Zhang et al. 2010) and extractive content (White 1987). Thus, the aim of this paper is to evaluate the byproducts of the primary processing of genera *Abies* and *Pinus* wood to determine the possibility of using them as solid biofuel.

MATERIALS AND METHODS

Study Area

The study was carried out in the municipality of San José del Rincón, Mexico. The study area is located between parallels 19°29' and 19°47' N; meridians 100°01' and 100°16' W; with altitude of 2500-3700 meters. The municipality´s climate is mild sub-humid with rains in the summer months and an average annual precipitation of 900 mm. The average temperature is 12°C (INEGI 2009). This area stands out for belonging to the Monarch Butterfly Biosphere Reserve. The byproducts of forest genera *Abies* and *Pinus* were collected from two private sawmills that process sawn lumber into commercially sized timber. The facilities are located on the periphery of San José del Rincón.

Samples Preparation

The samples were taken from the process machinery: the main saw, string trimmer and edging-saw. Then, sawdust samples were dried at room temperature and grounded in a Micron mill, model K20F, in accordance with standard T 257 om-85 (TAPPI 1985). After that, samples were sieved using stainless steel Montinox-sieves, and 40-mesh wood meal was stored in sealed plastic containers to avoid any contamination and moisture absorption. Each chemical determination was made out in triplicate.

Methods

Proximate Analysis: Ash Percentage, Volatile Substances and Fixed Carbon.

Inorganic material content was determined using the gravimetric method. One gram of the sample was first burnt over a Bunsen burner flame in nickel crucibles, and then heated in a Muffle furnace at 550±10°C during of 4 hours (UNE-EN 14775 2010).

Volatile matter was determined in accordance with ASTM E 872-82 (1985). 1 g of wood meal was heated in a capped nickel crucible, to avoid the entrance of environmental air.

The fixed carbon content of a char is the calculated value of the difference between 100 and the sum of ash and volatile matter, where all values are expressed on the same moisture reference base, according to Equation 1,

$$\%\ \text{fixed carbon} = 100 - \%\ \text{volatile matter} - \%\ \text{ash}$$

Characterization of the Basic Chemical Composition of Byproducts

Total amount of extractives was determined using 9.5 g of wood meal in a Soxhlet extraction sequence under 6 hours reflux cycles, using solvents in the order of increasing polarity: cyclohexane, acetone, methanol, and hot water (Mejía-Díaz and Rutiaga-Quiñones 2008). The resulting solvents were retrieved by applying vacuum in a rotatory evaporator. The extractive content for each solvent was calculated dividing the weight of the anhydrous extract by the weight of the anhydrous meal, expressed as the percentage. The total extractives were calculated as the sum of the percentages of all extractives of the sample. Once the extraction sequence was over, wood meal was considered to be extractive-free and used to determine lignin (Runkel and Wilke 1951) and holocellulose (Wise et al. 1946). The results are expressed as percentages.

Ash Microanalysis

Ash microanalysis was performed using an X-ray spectrometer, connected to a Jeol JSM - 6400 scanning electron microscope, with operating conditions of 20 kV and 8.5 s (Téllez-Sánchez et al. 2010).

Calorific Value

Pellets were formed from 0.1 g samples, on a dry basis, to determine the calorific value (MJ·kg^{-1}) in an AC600 bomb calorimeter, which was calibrated with benzoic acid (UNE-EN 14918: 2011).

Statistical Analysis

An analysis of variance was performed using a general linear model, with a randomized complete block design. Tukey's test was used to compare means. Both statistical analyses were processed using Minitab V. 17 (Minitab Inc. 2017), at a significance value of $P<0.05$ and a 95% confidence interval. Additionally, a multiple linear regression was performed to correlate calorific value of the byproducts with their lignin and extractive content and between the ash content and volatile matter against the calorific value.

RESULTS AND DISCUSSION

Proximate Analysis: Ash Percentage, Volatile Matter and Fixed Carbon

The ash content found ranged from 0.33% to 0.41% (Table 1) and no statistical difference was observed between the two genera studied here. This result agrees with the data reported by Bernabé-Santiago et al. (2013) for some other species of the genus *Pinus* (0.3%) and it is within the parameter (0.1-1.0%) reported by Fengel and Wegener (1989). Likewise, the inorganic content found in this study is lower than the permitted values for softwood pellets and briquettes, 0.4% and 0.8% (Obernberger and Thek 2004), and it complies with the standard UNE-EN 14961-2 (2012), which sets the requirement for high quality pellets (≤0.7%).

Ash composition and properties are determined by age, tree species, part of the tree, environmental conditions, cultivation, harvesting, harvesting time and technique, transportation, storage, pollution and processing (Vassilev et al. 2017). Ash content may cause operating problems during the combustion process, such as slag formation and reduction of the protective layer of oxide in the combustion chamber (Lehtikangas 2001), causing higher maintenance costs (Grover and Mishra 1996). Reported low ash content values are positively related to heating value, since the elements conforming to the ashes generally do not have heating value themselves (FAO 1997). Therefore, the risk of obstruction problems in the combustion equipment is also reduced.

The volatile matter content found is shown in Table 1, with a variation of 88.54%±0.7% to 82.57%±0.8%, the genus *Abies* being the one with the highest value. This value is higher than the one found in the byproducts of the primary transformation of *Pinus patula* (80.15%), reported by González-Martínez (2013); it is also higher than the ones reported for woody biomass, which vary from 76% to 86% (Van Loo and Koppejan 2002). Our result is also high compared to the value of 83.1% reported by García et al. (2012) for wood byproducts. Biomass generally contains high levels of volatile matter (64-98%) depending on plant origin, compared to fossil coal (40%) (Vassilev et al. 2010). Volatile matter refers to the part of the biomass that is released when the biomass is heated at 400°C to 500°C. A high volatile matter content indicates that during combustion, most of the biomass will volatilize and burn as gas (Mitchual et al. 2014). This content influences the thermal behavior of solid biofuels (Van Loo and Koppejan 2002), therefore, it can be stated that the higher volatile matter content, the lower ignition temperature of the fuel (Vamvuka et al. 2011). Thus, the quality of the fuel is related to the high content of volatile material.

Finally, fixed carbon, which is the solid combustible residue that remains after a char particle is heated and the volatile matter is expelled, varied from 11.13% to 17.06% (Table 1), which can be considered a low percentage. The genus *Pinus* showed the highest fixed carbon content. Yet, it is a value below the range of 20-25% reported in wood pellets (Stelte et al. 2013). The fixed carbon content is the percentage of carbon available for combustion, so it is desirable to get the lowest level of this parameter as it ensures a higher volatile content (Bandara and Kowshayini 2017).

Analysis of the Basic Chemical Composition

The results of the extractive substances are shown in Table 1. In this case, significant difference was presented for *Pinus* spp. when using cyclohexane as solvent (12.93%±1.39%), in the edging saw, which indicates that the test samples were very heterogenous. This result differs from Bernabé-Santiago et al. (2013), who reported the highest solubility in hot water for several species of the same genus (1.6-2.1%). The lowest value corresponded to *Abies* spp. with cyclohexane (0.43%±0.03%) for both the main saw and the string trimmer. Wood contains secondary metabolites such as terpenes, fats, waxes, phenols and sugars, among other compounds (Fengel and Wegener 1989). This chemical composition depends on various factors such as age, species, tree conditions, geographic location, environmental factors, genetic factors, available nutrients, and part of the tree used to get the sample (Vázquez et al. 1987, Fengel and Wegener 1989, Ramos-Pantaleón et al. 2011), which explains the yield difference found in this research work.

Furthermore, the methods applied influence the extractives yield (Rutiaga-Quiñones et al. 2000). Extractives content, in turn, influences physical and mechanical properties of wood (Poblete et al. 1991, Ávila and Herrera 2012). It has been determined that extractive content is a parameter directly affecting the heating value of biomass (Kataki and Konwer 2001, Demirbas 2002, Demirbas and Demirbas 2009). Therefore, the calorific value increases as the extractives content does (Sadiku et al. 2016). On the contrary, no interaction was found between the machinery and the extractives content.

Table 1. Physical and chemical properties of timber byproducts.

	***Abies* spp.**			***Pinus* spp.**		
	MS (%)	**ST** (%)	**ES** (%)	**MS** (%)	**ST** (%)	**ES** (%)
Ash	0.41±0.06a	0.33±0.002a	0.37±0.07a	0.33±0.00a	0.37±0.06a	0.33±0.01a
Volatile matter	87.83±0.35ab	88.54±0.77a	86.23±0.63ab	85.79±1.57b	82.57±0.86c	86.23±0.64ab
Fixed carbon	11.77±0.41bc	11.13±0.77c	13.4±0.56bc	13.88±1.56b	17.06±0.85a	13.45±0.64bc
Cyclohexane	0.43±0.03b	0.43±0.05b	0.60±0.26b	2.35±0.04b	2.03±0.05b	12.93±1.39a
Acetone	2.45±0.13a	1.82±0.13b	2.63±0.20a	0.83±0.02cd	0.69±0.01d	1.23±0.04c
Methanol	3.22±1.25a	1.72±0.14ab	2.77±0.40ab	0.75±0.03b	0.76±0.08b	0.84±0.01b
Hot water	1.15±0.13a	1.40±0.04a	2.08±0.48a	1.85±0.30a	1.97±0.08a	2.82±1.42a
Total extractives	7.25±1.28bc	5.37±0.11c	8.08±0.02b	5.78±0.39c	5.45±0.20c	17.82±0.07a
Runkel lignin	28.39±0.50a	27.33±0.66a	29.29±0.97a	27.55±0.45a	30.97±2.01a	27.26±0.65a
Holocellulose	69.56±0.71a	66.72±0.53b	66.44±0.41bc	65.56±0.49bc	64.40±0.37c	58.53±1.76d

MS – main saw; ST – string trimmer; ES – edging saw; % – percentage on a dry basis. Mean±standard error: same letters on the line indicate that there is no statistically significant difference (Tukey, P<0.05).

In woody plants, the content of lignin is about 15-40% (Gellerstedt and Henriksson 2008). The values of Runkel lignin varied from 27.26%±0.65% to 30.97%±2.01% for the genus *Pinus*, while for the genus *Abies* it ranged from 27.33%±0.66% to 29.29%±0.97%; with no statistical difference found (Table 1). The content of lignin is within the results reported by Lima-Rojas (2013) for sapwood and heartwood of *Pinus leiophylla* (29.1-29.8%), *Pinus montezumae* (28.3-28.4%) and *Pinus pseudostrobus* (26.9-29.2%). Pintor-Ibarra et al. (2017) reported similar values (29.57-32.52%) for the same species. Lignin contents found in this study are close to the Klason lignin values obtained in *Pinus patula* (31.0%) (González-Martínez 2013), and to those reported by Rowell et al. (2005) for other pine species (25-30%) and by Berrocal-Jiménez et al. (2012) for *Pinus radiata* at the age of 16-20 years (29.4%). No reports were found for the genus *Abies*. The calorific value of softwoods depends on lignin content, since lignin has a low oxygen content. Other intervening factors to determine this value are species, age, and growth conditions (Bajpai 2018). In addition to the lignin content, softwoods are considered to have a high calorific value due to their high extractives content (White 1987). Lignin is the main component that acts as a binder, essential for forming a good pellet (Stelte et al. 2011), and it has an important influence on durability (Lehtikangas 2001). The economic advantage is that binding additives costs are cut down in pellet production.

Holocellulose content is also shown in Table 1. Statistical differences were found in the two studied genera. The content ranges from 58.53%±1.76% (for *Pin*us spp.) to 69.56%±0.71% (for *Abies* spp.). This content is within the reported values for coniferous woods (65-75%) (Rowell et al. 2005). Holocellulose is made up of cellulose and hemicellulose (Fengel and Wegener 1989). It is known that the main components of wood have different calorific value. In a research, heating value values for holocellulose (15.9 to 16.3 MJ·kg^{-1}) and for lignin (22.5 to 23.5 MJ·kg^{-1}), isolated from oak wood, have been reported (Herrera-Fernández et al. 2017). It is clear that high lignin values are desired in the biomass used for making solid biofuels; however, for good pellet formation for example, the moisture content plays an important role (Samuelsson et al. 2009).

Ash Microanalysis

The byproducts' relative percentage of ash, expressed as an atomic percentage, is shown in Table 2. The most abundant elements were potassium, calcium and magnesium, which coincides with previous reports (Fengel and Wegener 1989, Martínez-Pérez et al. 2012, Correa-Méndez et al. 2014, Pintor-Ibarra et al. 2017). In the case of potassium, a significant difference was found in both genera, corresponding to the genus *Abies* a higher value (60.88%±0.83%), which coincides with the average value reported by Lima-Rojas (2013) for the *Abies religiosa* species in sapwood and heartwood (60.21%) under the same conditions of analysis. For calcium, the highest content was found in the genus *Pinus* with a value of 41.63%±0.03%, as well as in the case of magnesium (19.59%±0.72%), these values coincide with previous studies for *Pinus* woods (Bernabé-Santiago et al. 2013, Lima-Rojas 2013, Correa-Méndez et al. 2014). These elements can be found in wood as oxalates, carbonates, sulfates, silicates and phosphates (Ragland and Aerts 1991, Hon and Shiraishi 1991), resulting in the risk of corrosion and slag (Vassilev et al. 2014). Inorganic elements are highly variable between and within species and they can vary with soil and growth rate (Young and Guinn 1966, Ragland and Aerts 1991, Fernandez et al. 2020). Other elements are also present in smaller amounts: manganese, sulphur, silicon, aluminium, phosphorus; while iron was only detected in the genus *Pinus* (0.96%±0.03%), in concordance with the results of Ragland and Aerts (1991) for wood species. During combustion, mineral ions oxidize and volatilize, or form particles (Ragland and Aerts 1991). Knowledge of mineral composition is needed for analysis of ash deposition, erosion and corrosion in combustion systems, as well as for understanding stack gas opacity (Ragland and Aerts 1991, Jenkins et al. 1998). Moreover, potassium plays a key role in ash fusion and deposition (Díaz-Ramírez et al. 2014). During the combustion process mineral matter vaporizes and, when the temperature decreases, it condenses on heating surfaces and forms a sticky slagging layer (Wei et al. 2005). A high potassium content, by nucleation and condensation, increases ash-related issues, including alkali and silicate-induced slagging formation, as well as agglomeration (Niu et al. 2016). Silicon and phosphorus increase ash fusion (Mu et al. 2012); whereas potassium, magnesium, calcium and manganese decrease it (Liu et al. 2018). The presence of silicon and aluminium reduces fouling and increases ash fusion temperature. Also, aluminium may reduce the risk of corrosion during the combustion process (Vargas et al. 2001). As mentioned before, iron was detected only in the case of the genus *Pinus*. These two latter elements could be related to contaminants in wood machinery (Correa-Méndez et al. 2014). However, the presence of these two elements is characteristic in wood (Fengel and Wegener 1989).

Calorific Value

The results for heating value are shown in Table 3. The results for heating value ranged in from 19.09 MJ·kg^{-1} to 20.42 MJ·kg^{-1}, with the genus *Pinus* being the one with the highest value. The two studied genera turned out to be statistically different. The values found in this study are higher than those reported for maritime pine (17-18 MJ·kg^{-1}) (Vassilev et al. 2013) and for *Pinus patula* (18.6-18.9 MJ·kg^{-1}) (González-Martínez 2013). A study of different agricultural and forestry species reported a calorific value between 16.18-21.23 MJ·kg^{-1} (Özyuguran and Yaman 2017). The obtained values are within the ranges for wood, between 19.8 MJ·kg^{-1} and 20.7 MJ·kg^{-1} (Obernberger and Thek 2004). The variability of such results indicates that calorific value depends on the tree species, and therefore, on its chemical characteristics. Previous research has reported a direct and positive relationship between calorific value and lignin and extractive concentrations (White 1987, Lethikangas 2001).

Multiple Linear Regression Analysis Between the Total Removable Content and Lignin Against Calorific Value

According to the multiple linear regression analysis between the byproducts, calorific value and lignin and extractive content, it was observed that calorific value tends to increase as the total extracts do. This is consistent with previous studies (Martínez-Pérez et al. 2012, Ngangyo-Heya et al. 2016), with a correlation coefficient R^2=0.774. No correlation was shown between lignin and calorific value

Table 2. Ash microanalysis of timber byproducts.

Element	*Abies* spp.			*Pinus* spp.		
	MS (%)	ST (%)	ES (%)	MS (%)	ST (%)	ES (%)
K	57.32±0.95ab	56.60±0.62b	60.88±0.83a	29.13±1.75cd	32.74±0.8c	27.65±0.91d
Ca	31.18±0.71c	32.41±0.40c	21.56±1.78d	38.56±2.08ab	34.57±1.48bc	41.63±0.03a
Mg	8.90±0.86d	9.59±0.30d	7.42±0.74d	19.59±0.72a	12.85±0.70b	16.30±0.12c
Mn	0.64±0.08a	1.04±0.12ab	1.03±0.33ab	1.76±0.14c	1.98±0.51bc	1.77±0.15c
S	0.20±0.04a	0.36±0.09b	0.05±0.04b	1.52±0.18c	3.88±0.66c	2.21±0.14c
Si	0.61±0.20a	0.60±0.12ab	1.23±1.04ab	2.70±0.51b	5.11±0.04b	2.67±1.11b
Al	0.25±0.21a	0.19±0.04a	0.27±0.33a	2.56±0.18b	3.47±0.38b	3.51±0.48b
P	0.05±0.01a	0.31±0.07b	0.05±0.03b	2.85±0.16c	4.91±0.57c	3.30±0.47c
Fe	Nd	Nd	Nd	0.96±0.03a	Nd	Nd

MS – main saw; ST – string trimmer; ES – edging saw; % – percentage on a dry basis; Nd – not detected. Mean±standard error: same letters on the line indicate that there is no statistically significant difference (Tukey, P<0.05).

Table 3. Calorific value of timber byproducts.

	Abies spp.			*Pinus* spp.		
	MS ($MJ \cdot kg^{-1}$)	ST ($MJ \cdot kg^{-1}$)	ES ($MJ \cdot kg^{-1}$)	MS ($MJ \cdot kg^{-1}$)	ST ($MJ \cdot kg^{-1}$)	ES ($MJ \cdot kg^{-1}$)
Calorific value	19.12±024b	19.15±0.13b	19.09±0.26b	19.54±0.27ab	19.71±0.67ab	20.42±0.24a

MS – main saw; ST – string trimmer; ES – edging saw. Mean±standard error: same letters on the line indicate that there is no statistically significant difference (Tukey, P<0.05).

(R^2=-0.142), which differs from literature data (Tillman 1978, Jara 1989, Cunha et al. 1989), and which is consistent with previous reports (Avelin et al. 2014, Sadiku et al. 2016), which reported that a higher value is not correlated with lignin content.

A negative linear relationship was observed between the calorific value and the volatile matter, and also between the calorific value and the ash content. A correlation coefficient R^2=-0.450 was obtained between the calorific value and the volatile matter, indicating that the calorific value values decreased with the increase in volatile matter. In this regard, Kataki and Konwer (2001), and Demirbas and Demirbas (2009) mention that the high calorific value may be due to the presence of extractives and lignin. White (1987) and Guadalfajara (2015) suggest that coniferous species have a higher calorific value due to the presence of resins. While for the calorific value and ash content it was R^2=-0.147, showing a tendency to decrease with a higher value of ash content, which is consistent with the literature (Márquez-Montesinos et al. 2001, Martínez-Pérez et al. 2012) and is an indicative factor of fuel quality (Kumar et al. 2009, Kumar et al. 2010, Meetei et al. 2015).

CONCLUSIONS

Chemical and physical properties of byproducts generated from the primary processing of wood were analyzed in order to determine whether they might be incorporated into the production chain of solid biofuels. Both genera, *Pinus* spp. and *Abies* spp., presented low ash content values, indicating a low risk of slag production. Also, volatile matter content was high, which will require a low ignition temperature to burn in combustion. As for the genus *Pinus,* it presented the highest extractives content, as well as the lowest content of lignin, which is associated with higher calorific value. These results suggest that both genera are suitable to be used in the production of solid biofuels.

Author Contributions

OMG: formal analysis, writing, investigation. LFPI: formal analysis, validation. JGRQ: conceptualization, formal analysis, funding acquisition, project administration, resources, review and editing. JCT: formal analysis, data curation, validation, writing, review and editing.

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Conflicts of Interest

The authors declare no conflict of interest.

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Investment Analysis of a Joint Forest and Game Management – A Case Study from Croatian Dinarides

Karlo Beljan[1,*], Marija Pokupić[2], Hrvoje Mataković[3], Stefano Bruzzese[4]

(1) University of Zagreb, Faculty of Forestry and Wood Technology, Department of Forest Inventory and Management, Svetošimunska 25, 10000 Zagreb, Croatia; **(2)** Ive Marinkovića 79, Lozan, 33404 Špišić Bukovica, Croatia; **(3)** Institute for Tourism, Vrhovec 5, 10000 Zagreb, Croatia; **(4)** University of Turin, Department of Agricultural, Forest and Food Sciences (DISAFA), Largo Paolo Braccini, 2, 10095 Grugliasco, Italy

*** Correspondence:** e-mail: kbeljan@sumfak.unizg.hr

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ABSTRACT

Wildlife-based tourism, including hunting, is attracting interest from governments, the tourism industry, and researchers. Capital investment in renewable resources, like forests, represents spatial and temporal management, which is significantly limited by the natural potential of a particular habitat (e.g., volume increment, the quantity of food for wildlife, etc.). Therefore, the return rate expected by the investor is quite fixed and the only tool by which the investor can increase it is by adding further business activities and/or expanding the existing value chain. In the Republic of Croatia, the only forests which can be purchased by individual or institutional investors, and in which it is possible to establish both active forest management and commercial hunting, are private forests. Based on these insights, we analysed characteristics of capital invested in a large-scale private forest, where game management is carried out in addition to extensive forest management. Of the 1,104 hunting grounds in Croatia, the one with the largest percentage of forest cover (92%) and privately owned (61%) was taken as the subject of this case study (name of the hunting ground: VIII/120 "Permani" (10,017 ha)). A theoretical approach was used in which the investor buys all private forests (predominantly consisting of common beech), conducts forest management activities, and makes a profit by selling timber (30-year period). Furthermore, the hunting segment consisting of game management for red deer, roe deer, wild boar and brown bear is evaluated. At the lowest cost of capital (5.41%), the results of the separate forest management revealed an Internal Rate of Return (IRR) of 5.10%, a negative Net Present Value (NPV) (-760,000 €) and a 30-year discount payback period. Joint forest and game management resulted in an IRR of 5.69%, a positive NPV (680,000 €), and the same length of a discount payback period.

Keywords: game management; capital budgeting; private forests; forest management planning; hunting tourism; Croatia

INTRODUCTION

Forestry is an economic branch and also a science that deals with the cultivation, care, protection and exploitation of forests (LzMK 2021a). Game management (hunting) is an economic branch and science and it includes the management, protection, hunting and use of game (LzMK 2021b). What is in common to these two branches is the land, i.e. land management. To be more precise, they overlap in their competence over forest land (since game management includes both forests, agricultural land, and other types of land use, like wetlands, rangelands, deserts, etc.). In other words, one particular activity cannot stand for itself due to the complexity of the natural forest ecosystem (processes and management approaches). While planning forest management activities, i.e., creating Forest Management Plans, the forest management attributes are partially incorporated into it, and vice-versa, when creating Game Management Plans. This interconnection is more informative and has almost no impact on the other one. This leads us to the idea that the overall insight would be essential for better understanding of the forests' potential. Since one of the major drivers for managing forests and game are the economic outcomes and benefits, the most significant impulse for this research is exactly the economic potential of joint management (forestry + game management).

A similar approach to that used in private forestry, which is based on sustainable and allowable cuts (more on this principle in Bettinger et al. (2008), Čavlović (2013) and Beljan et al. (2018a)), can be applied for game management. In fact, only a surplus above the optimal stock for each species should be bagged during a season (Hasenkamp 1995). To properly distinguish the term bagging (Pang 2017), it is necessary to say that there are regular, sanitary, and trophy bagging (shooting the game). With the latter, one tries to achieve the optimal and best possible ratio between natural and economic results. Each bagging is represented differently by the amount of game that is hunted and, of course, is variously valued from an economic point of view. Hunting can be described as a livelihood (subsistence), recreational, management, and commercial activity, where the last one is the most important from an economic point of view (Middleton 2014). Hunting is not just bagging but instead has multiple aspects of satisfaction (Pang 2017). This concept recognises factors such as enjoyment of nature, exploration of the outdoors, adventure and companionship (Hammitt et al. 1990). But the success in hunt and hunting the most precious trophies, regardless of wild meat (Gigliotti 2000, Naevdal et al. 2012, Sánchez-García et al. 2021), are the top-rated reasons for commercial hunting.

Game management is a source of both costs and benefits to the society (Gren et al. 2018). Costs occur from wildlife predation on livestock, damages in forest stands (browsing, bark striping, and frying) and in agriculture (crops), traffic collisions, and transmission of diseases to animals and humans. These negative interactions between game and land users should also be calculated as costs. Benefits accrue from hunting and recreational activities such as hunting tourism, food, and other ecosystem services (Middleton 2014, Arnett and Southwick 2015).

Hunting in the European Union approximately contributes to the management of over 65% of rural areas (Kupren and Hakuć-Błażowska 2021). It involves landowners, farmers, foresters, and other stakeholders and by that creates an extensive social network involved in nature and landscape management (Middleton 2014). According to Massei et al. (2015) and Sánchez-García et al. (2021), there are about 8–9 million hunters in Europe, which makes it the second-largest formally organised hunting population, after the one in the United States of America (Kupren and Hakuć-Błażowska 2021). In the EU hunting as a commercial branch is an important economic subject, approximately worth 16 billion € (Middleton 2014, Arnett and Southwick 2015). It should be emphasized that in all European countries there is a legal framework which regulates the harvest of wild natural resources, i.e. the game (Kupren and Hakuć-Błażowska 2021). The European Union's legal framework regarding hunting is rather complex. There are several legal documents which emerged as the result of international agreements that affect the internal law of each EU country (the so-called "Birds" and "Habitat" Directives).

Hunting tourism can be defined as a "special form of a selective tourist offer, based on sustainable tourism, while creating synergy between postulates of eco, rural and sport tourism, and it was developed thanks to hunters' passion for hunting outside of their own hunting grounds, for which they set aside significant funding" (Milojica et al. 2014). Except for the fact that hunting and hunting tourism has a long tradition, Croatia has excellent prerequisites for the development of hunting tourism (Kovačević and Kovačević 2006). Some of the prerequisites are relatively huge agricultural areas, a high stock of wild animals, geographical biodiversity (Sudarić et al. 2022), a preserved environment, and a pleasant climate (Milojica et al. 2014). Interest in hunting in Croatia is raising. According to the Croatian Bureau of Statistics, in 2020 in Croatia there were 64,394 registered hunters, representing an increase of 3.2% compared to 2019 (DZS 2021). The ratio between the inhabitants and hunters in Croatia is 1:65, which is the highest among the countries of Central and Eastern Europe (Deutscher Jagdverband 2021). Most Croatian hunters hunt quite intensively - according to a research conducted by Sudarić et al. (2022) in eastern Croatia, 78.6% of respondents go hunting once a week and 9.3% every day. These data indicate that many people are actively involved in hunting, which presents the potential for the development of hunting tourism. The potential of attracting foreign tourists should also be considered: out of approximately 7 million hunters in the European Union, about 1.5 million of them travel abroad once or twice a year to hunt, spending at the same time about 10 million € (Ružić et al. 2016). This group thus represents the strong potential for Croatian tourism, especially if one considers the high number of hunters in neighbouring countries such as Italy with 533,000 hunters, Austria with 118,000 hunters, and Hungary with 55,000 hunters (Deutscher Jagdverband 2021). The increased interest of foreign hunters in hunting in Croatia could also be seen from the fact that in the Osijek-Baranja County, in the period from 2008 to 2018, the average annual growth rate of permits issued to foreign hunters was 7.8% (Tolušić et al. 2020). When speaking about the economic effects of hunting tourism, it should also be taken into account that hunters are mainly people with higher purchasing power who spend up to three times more than regular tourists (Milojica et al. 2014).

Since the majority of the forests, globally looking, are owned by governments and are not profit-oriented (Palo and Lehto 2012), the only possible area for investment and economic analyses are private forests. Private forestland can generate an income for its owner from two basic inputs: forestry and game management. In the ideal case, sustainable development motives will come first, i.e., allowable cut is defined and equals the increment, and the economic motives will come second, exclusively as a result of the utilization of the allowable cut. The investment potential of privately owned forests has been analysed in many previous studies, such on a local scale (Krajter et al. 2015, Posavec et al. 2017, Beljan et al. 2018b, Beljan et al. 2020), in Croatia (Pukkala et al. 2003), Finland (Sharp et al. 2004), Australia (Schiberna et al. 2011), Hungary (Moss and Hedderick 2012), USA (Toscani and Secot 2015) and on a global scale (Beljan et al. 2022a). There is extensive literature on the market and non-market values in hunting demand using different methods and approaches, such as the Travel Cost Method (Knoche and Lupi 2007, Fagarazzi et al. 2021), Hedonic Pricing (Hussain et al. 2007, Martinez-Jauregui et al. 2015, Lozano et al. 2021), Contingent Valuation (Boman et al. 2011, Donnelly et al. 2019), Discrete Choice Models (Delibes-Mateos et al. 2014, Davis et al. 2022). However, game management, which is acknowledged to generate a large set of values in all sectors of the economy both through direct and indirect effects (Lindsey et al. 2007, Samuelsson and Stage 2007, Munn et al. 2010, Middleton 2014, Arnett and Southwick 2015, Kupren and Hakuć-Błażowska 2021), lacks its economics evaluation in the context of joint management with forestry. However, it is proper to say that we have found one study which incorporates forestry and game management in economic terms. It is by Zhou (2007) who investigated two optimisation models (one for timber harvest, the other for reindeer harvest) in Sweden.

The above-elaborated issues regarding the lack of economic evaluation of the joint management brought us to the aim of this paper. From the potential investor's standpoint, an investment analysis on purchasing the private forest land, on which both forest and game management are maintained, will be conducted. By this concept, the forest's economic potential will be investigated closer to its Total Economic Value (Venkatachalam and Jayanthi 2016, Roy 2022).

MATERIALS AND METHODS

Research Area

For this research, the experiment area has been selected in the Croatian part of Dinarides. In the Republic of Croatia, there are 1,104 Hunting Grounds (HG) that are defined according to the property (state, county, and private). The boundaries of those areas are fixed. For this research, the experiment area has been selected in the Croatian part of the west Dinaric Alps – HG "Permani". The HG "Permani" has an area of 10,017 ha, where the most dominant land use category are forests (92.21%), and those are mostly privately-owned forests (61.18%). The amount of agricultural land is 6.04% (Table 1).

Since in Croatia the boundary of the HG does not correspond with Forest Management Units (FMU) or private forests, we had a case where five different FMUs, to a greater or lesser extent, are present in the experiment area. The first step was to collect all the data relevant for privately owned FMUs areas which spatially overlap with the HG "Permani" (HLS 2017). Here should be stressed that state-owned forests, apropos the FMUs of those, are not the subject of this research. The private FMUs in the HG have validity from 2018 to 2027 and take the surface shares as followers: "Mune" takes 43%, FMU "Brgud" 32%, FMU "Žejane" 24%, FMU "Kastavske šume" 1%, and FMU 0.4% "Lipa". The initial data is recalculated and now represents forest characteristics of all private forests in the HG (Table 2), which is a starting point for creating a new forest management plan unique for investigating joint forest and game management.

Private forests in this HG take a significant share of its surface (Table 1) and can be classified into five types (Table 2). High forests of beech are the most prevalent, followed by beech coppice and high forests of black pine with black hornbeam. The rest of the private forest types are represented in a minor share. It is important to emphasize that a larger forest surface does not necessarily mean larger economic potential, so characteristics such as silvicultural type (high forest or coppice), increment, and monetary value of cut, should be taken into account.

According to central hunting evidence (CHE 2022), four species of big game are present in the HG "Permani". Those are red deer *(Cervus elaphus* L.*)*, roe deer *(Capreolus capreolus* L.*)*, wild boar *(Sus scrofa* L.*),* and brown bear *(Ursus arctos* L.*)*. The basic population quantities are stable from year to year since the harvesting is limited to the amount of yearly population increment (Table 3). Other big game species which are present in the HG, but are not managed actively, are brown bear, European badger, wild cat, rabbit, fox. Further, about twenty species of small game like birds, small rodents and small mammals can be found sporadically.

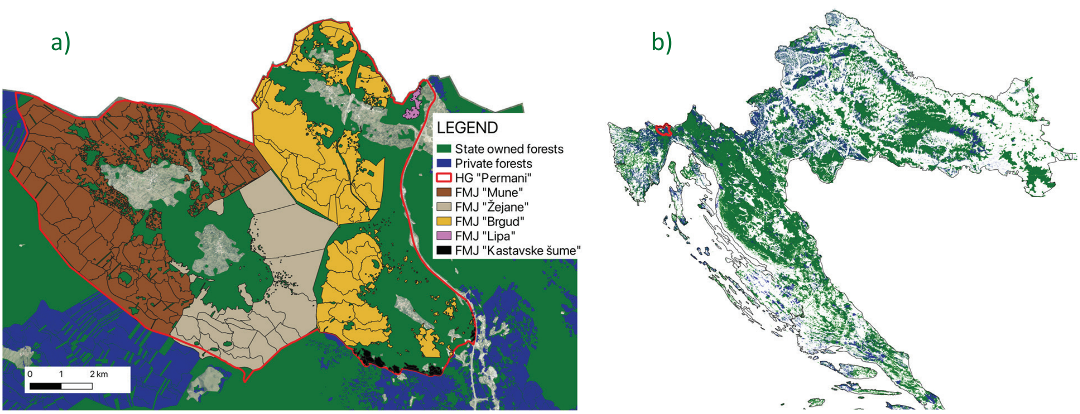


Figure 1. Research area defined by the boundaries of Hunting Ground "Permani" and belonging inner parts of privately possessed Forest Management Units (FMU) **(a)**. Total forest cover including state-owned and privately-owned forests at the national level **(b)**.

Table 1. Land use classes within the experiment area HG "Permani".

Land classification	Total forests	Private forests	State forests	Agricultural land	Other
Area (ha)	9,237	6,129	3,008	606	174
Share in total of 10,017 ha (%)	92.21	61.18	31.00	6.04	1.73

Notes: data source: HLS 2017

Table 2. Basic forest characteristics of private forests.

Forest type	Area (ha)	Average stock (m³·ha⁻¹)	Annual increment (m³·ha⁻¹)	Stock share per tree species (%)							
				Beech[1]	Oak[2]	Pine[3]	Hornbeam[4]	Maple[5]	Ash[6]	Spruce[7]	Other[8]
Beech high forest	3,313	175.49	4.15	71.9	13.2	1.0	5.8	2.7	0.3	4.8	0.1
Beech coppice	2,233	224.25	4.38	77.4	4.6	0.3	6.6	1.4	2.1	0.7	6.7
Black pine high forest	376	164.82	3.80	6.1	4.5	50.6	11.5	0.0	5.4	1.0	19.6
Turkey oak high forest	92	126.88	2.81	20.8	47.1	0.2	15.3	1.5	3.5	1.3	10.2
Shrub/bushes	115	-	-	-	-	-	-	-	-	-	-

Notes: table data recalculated from five different FMU so it can present unique forest area within the HG ; Tree species are as follows: [1] – *Fagus sylvatica* L. [2] – *Quercus petrea* (Matt.) Liebl. and *Quercus cerris* L.; [3] – *Pinus nigra* J.F.Arnold; [4] – *Carpinus betulus* L.; [5] – *Acer pseudoplatanus* L.; [6] – *Fraxinus ornus* L.; [7] – *Picea abies* (L.) H.Karst.; [8] – other broadleaved species.

Within the HG “Permani” there are 17 feeding stations for the big game, 50 salt stations, 32 watering holes and 18 high sits. Annual food intake is mostly constant and equals 18,000 kg of concentrate fodder (mostly corn), 6,000 kg of dry voluminous fodder, 5,000 kg of fruits and 1,000 kg of salt. Furthermore, annual game crops (1.5 ha), perennial game crops (0.5 ha) and grasslands (3.0 ha) are maintained as an additional source of food for game.

Simulation of Forest and Game Management

The following research phases from the perspective of potential investor were assumed: (1) purchase all private forest land (Table 2) at the average price of 0.26 €·m⁻² (2 HRK·m⁻² in local currency) and establishment of a limited liability company with only one employee, i.e. licensed forest officer (both for forestry and game management activities), who deals with the entire management of (2) forest management activities, (3) game management activities, (4) timber selling on forest site, and (5) commercial game hunting. A list of activities with belonging unit prices is given in Beljan et al. 2020, while the ones related to game management are presented here in Table 4. Here it is important to stress that forest management in the sense of this paper consists just of making trees for cutting and their selling as standing timber.

Separately for each forest type (except scrublands, see Table 2), the theoretical forest management plan has been created for the next 30 years. The idea behind that plan is to perform (1) uneven-aged management using the area control method with natural regeneration and (2) coppice management using the allowable cut principle (Čavlović 2013). The management plan was created specifically for a particular forest type where 10-year cutting cycles are assumed, and those plans are based on the forest type starting characteristics, as shown in Table 2. Both aim to direct the forest towards achieving a theoretically balanced structure in the long run, i.e., a normal forest. The primer outcome of the forest management simulation is the annual quantity and assortment quality of a cut timber which generates profit for the investor. The source of all input data on economic calculations (selling prices) is the price list of Croatian Forests Ltd. (HŠ 2022a), while the only fixed cost is the salary for one employee (2,000 €/month gross).

Game management simulation is actually an application (i.e. implementation) of a real hunting management plan for the HG “Permani” (HLS 2017). Costs are the result of yearly facility maintenance, food intake and plantation maintenance whose unit processes are collected on the free market (presented in Table 4). On the other hand, revenues are an outcome of commercial hunting. Big game hunting quantities regarding species, gender and age classes are presented in Table 3, for which all related summed revenues are assumed in Table 4.

Table 3. Data on big game quantities.

Game	Quantity	Game structure per age classes and related annual quantities for hunt				
		Calves	Young	Subadult	Adult	Total
Red deer	Basic population*	16	30	20	14	80
	For hunt	2	6	2	6	16
Roe deer	Basic population*	66	108	84	72	330
	For hunt	6	14	10	36	66
Wild boar	Basic population*	48	26	26	20	120
	For hunt	22	10	6	10	60

Note: data source: HLS 2017; Brown bear is not included in the table because of occasional hunting quotas; *Gender ratio (M:F) is 1:1.

Table 4. Costs and revenues of game management.

Hunting ground maintenance						Commercial hunting[1]	
Facility repairs	**Costs (€·year^{-1})**	**Fodder**	**Costs (€·year^{-1})**	**Plantation**	**Costs (€·year^{-1})**	**Game species**	**Revenue (€·year^{-1})**
Feeding stations	500	Concentrate	6,600	Annual	800	Red deer	18,000
Salt station	100	Dry voluminous	2,000	Perennial	2,000	Roe deer	33,000
Watering hole	1,000	Fruits	1,500	Pastures	3,000	Wild boar	33,000
Hunting hide	1,000	Salt	1,500	-	-	Other[2]	6,000
TOTAL			20,000				90,000

Notes: [1]- according to the price list of commercial hunt in Croatian forests Ltd. (HŠ 2022b) and meat prices as follows: 4.5 €·kg^{-1} for red deer, 5 €·kg^{-1} for roe deer and 3 €·kg^{-1} for wild boar; [2]- game which is commercially hunted sporadically. Only fixed cost is the salary for one employee (2,000 € /month gross).

Economics Valuation

Within the time frame of the next 30 years the comprehensive investment analysis has been conducted using the following tools according to Orsag and Dedi (2011): Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP) and Discounted Payback Period (DPP). Corporate income tax in Croatian equals 18% and has been is used in this research accordingly. The cost of capital is set at minimum of 5.41% representing the investor with a well-diversified portfolio (Beljan et al. 2022b). Regarding the terminal value of the project at the end of the investment horizon conservative approach was taken. Terminal value is assumed to be equal to the initial purchase (i.e., current market) value of the estate.

RESULTS

As a result of land management, two separate scenarios have been conducted: a forest management scenario and an additional one that includes game management (i.e., joint management of forest and game). Forest management starts with all private forest land purchases which take into account 6,129 ha (Table 1) and the initial cost of about 17.5 Mil € (Table 5). Furthermore, separate forest management plans were created for a specific forest type and resulted in timber sold on the free market. The total annual cut differs from type to type and in the sum, it equals about 25,000 m^3 per year. The amount of annual cut is actually equal to the annual increment by which the sustainable forest management approach for a specific forest type is accomplished (varies from 2.81 m^3·ha^{-1} to 4.38 m^3·ha^{-1}). Annual income varies from 95 €·ha^{-1} to 181 €·ha^{-1} (Table 5) and it is constant for the entire project duration.

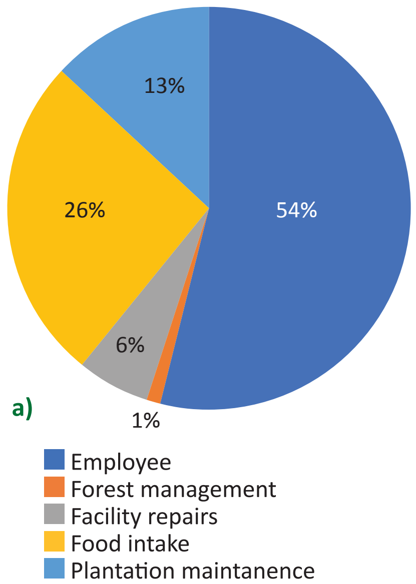
Game management includes all essential segments of HG maintenance: that involves costs for facility repairs, food intake and plantation maintenance (Table 4, left section), and income from commercial hunting (Table 4, right section). In total, all annual costs equal 20,000 €, while all annual incomes are about 90,000 €.

Results on cost and revenue structure (Figure 2) reveal segments that the potential investor should pay attention to. About 54% of all annual costs is the employee's gross salary (highest share in total cost structure), while the share of costs related to forest management is minimal. This is so because the fact that all the timber is sold as standing timber and natural regeneration is assumed. Also, forest management activities exclusively refer to the employee's domain (like marking trees that will be cut). On the other hand, game management-related costs take up all the rest of the cost structure (Figure 2). The revenue structure reveals a predominance of forest/timber related origin (about 90%) (Figure 2). The actual size of a certain forest type (ha) determines the share in revenue structure. Beech high forests, which are predominant by the surface, also prevail in the revenue structure followed by other forest types according to their surface significance (Figure 2). Revenues from commercial hunting result in a share lower than 10%.

Table 5. Investment cost and annual income of active forest management.

Forest type	Investment (€)	Total annual cut (m^3)	Annual income before taxes (€)	Average amount of cut (m^3·ha^{-1})		Average income before taxes (€·ha^{-1})	
Beech high forest	9,941,419	13,760	600,715	4.15		181.28	
Beech coppice	6,503,708	9,620	380,077	4.38		175.32	
Black pine high forest	750,322	1,420	60,550	3.80		161.40	
Turkey oak high forest	184,817	260	8,849	2.81		95.75	
Shrub/bushes	115,000	0	0	0		0	
TOTAL	17,495,268	25,000	1,050,190	4.12[1]	2.49[2]	172.18[1]	104.84[2]

Notes: [1]- average on total forest area (6,129 ha); [2] – average on total hunting ground area (10,017 ha).



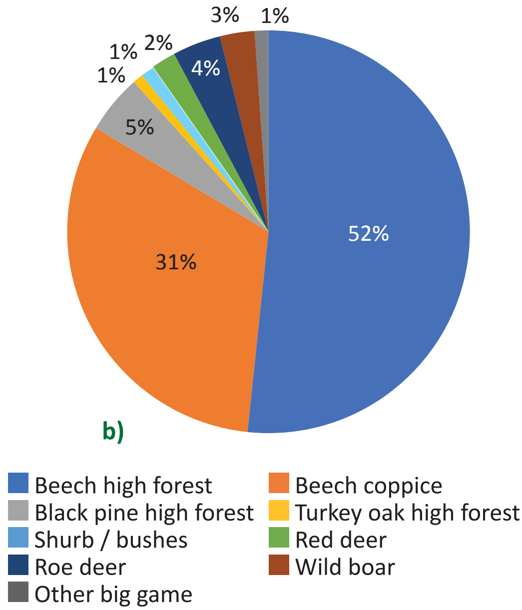


Figure 2. Structure of annual costs **(a)** and revenues **(b)** of the joint land management (both forest and game management).

Overall, forest management alone, after 30 years, would end in negative figures (Table 6, left section). The payback period (which neglects the time preference of future incomes) equals a reasonable period of 20 years, i.e. a 5% annual payback (100/20=5%). However, the discounted payback period (the tool which better evaluates the project's characteristics) is 10 years longer (3.3% of linear annual payback). As previously shown in Table 6, the project's NPV is negative (-767,800 €). So, even when a minimal discount rate of 5.41% is applied, it is not advisable to invest in this project. Only an investor who, for some reason, would be ready to accept a lower cost of capital could consider investing. To be more precise, only costs of capital lower than 5.10% will result in a positive NPV (see IRR in Table 6, left part).

However, joint forest and game management will achieve positive economic results. The payback period is 2 years shorter; the discounted payback period is the same, NPV is higher for 1,450,300 € and IRR is higher for 0.59% (Table 6, right section). In the case study of this HG only joint management has its economic justification.

DISCUSSION

Metaphorically speaking, the game (wildlife for commercial hunting) can be considered as a by-product when managing land. A landowner or a company that manages both forest and agricultural land can also make a business from commercial hunting affairs. The accent is here put on the "can" since it is possible to manage the land without game management activities. If the landowner decides to get involved with commercial hunting but does not invest in the HG maintenance, the landowner can even then expect to have the game on their land. The characteristic of game management is such that the management can be done by nature (biotic) or humans (anthropogenic). In the case when human's presence is absent, natural mortalities will reduce a part of the game population (predators, diseases, starvation, etc.). The idea behind game management by humans is to anticipate natural processes and to monetise them, to commercialise the hunt itself. By that, the natural process is replaced by human interventions which are called commercial hunting. Furthermore, game management by

Table 6. Investment analysis.

Financial measure	Forest management scenario	Forest and game management scenario	Difference
Payback Period (years)	20	18	+2
Discounted Payback Period (years)	30	30	0
Net Present Value at 5,41% (€)	-767,800	682,500	+1,450,300
Internal Rate of Return (%)	5.10	5.69	+0.59

humans must in a shorter period and on a smaller surface result in a larger number of high-ranked and monetary appreciated hunting trophies. Because of all of this stated above, a landowner (or investor) can make a profit without investing in HG maintenance (Rasker et al. 1992). This is one of the important reasons why determining the price for commercial hunting based on a free-market principle can be questionable.

Furthermore, the “optimal stock” for a species of the game must be at least the survival size (due to the winter, predators, etc.). This means that the capital is natural, not economically based. Also, regarding the rate of reproduction apropos allowable commercialisation of a forest resource, Rasker et al. (1992) give rise to the concern about the usage of neoclassical economic theory when the economic valuation is used for natural resources. Utilisation, both for forest and belonging wildlife, is possible only above the level of “optimal stock” (i.e., utilisation of the increment), which means that only the utilised part can be found on the free market and be appraised by neoclassical/supply-demand theory.

Another issue that arises when it comes to the economics of game management is the pricing of commercial hunting. As it is well-known, in Croatia the majority of the forest land is state-owned and the State defines prices both for forests (Posavec and Beljan 2013, Beljan et al. 2022c) and game products. Since prices are set too low, a competitive market does not exist, the supply of forest and game products is artificially limited, and the space for a private investor who expects positive returns on his investment is rather small. It should be emphasised that long-year contracts for a lease over an HG (10-year period defined by Hunting Law, Official Gazette No. 99/2018) are almost regularly extended to the benefit of the former purchaser, leaving practically no chance for a “new” investor who is willing to bid at a higher price.

Hunting tourism can be an additional source of income for the investor. Resources necessary for hunting tourism are game species and their habitats (Tolušić et al. 2020). The analysis carried out at the HG “Permani” showed that this hunting ground has enough high populations of game species. This composition of the game may be interesting for hunters-tourists, considering that in 2020, according to the data of the Croatian Bureau of Statistics (DZS 2021), the most numerous animals shot for the big game were wild boar with 39,778 heads, roe deer with 17,789 heads and deer with 5,654 heads (the same species that can be found in the HG “Permani”). At a national level, compared to 2019, hunting bags for these game species increased: red deer by 8%, roe deer by 6.6% and wild boar by 0.2%, while at the same time, waterfowl decreased by 10%. HG “Permani” is located closer to the Adriatic part of Croatia, which is much more intensively engaged in tourism than continental Croatia. Hence, hunting tourism can enrich the tourist offer of this region and extend the tourist season, which mostly lasts from June to September, and in most part overlaps with the hunting season for red deer, roe deer and wild boar (all year long for wild boar). In this way, the number of tourist arrivals and overnight stays can be increased during autumn, winter, and early spring, when “usual” tourist activities in Adriatic Croatia are quite modest.

The incomes of hunting grounds could be increased by hunting tourism. Regardless of the excellent natural prerequisites necessary for the development of hunting tourism, at this moment, “Croatia lacks a richer and more diverse offer of hunting tourism facilities” (Milojica et al. 2014). Public authorities, such as the Ministry of Tourism and Sports and the Ministry of Agriculture, but also the local community and the hunting societies, are not sufficiently aware of the existing potential for the development of hunting tourism (including the meat preparation for the food market) (Kovačević and Kovačević 2006), and thus the promotion of hunting tourism is mainly based on the enthusiasm of individual hunting societies or county hunting associations. Therefore, more intensive cooperation of all stakeholders is necessary (Ružić et al. 2016), but also better education of both people from the hunting sector and potential tourism entrepreneurs (Milojica et al. 2014, Tolušić 2017).

Within this research, deviations in economic calculations can occur and affect results to some extent. Within the boundaries of this case study (the HG), there is also agricultural land whose costs and benefits in the context of game management are neglected. Agricultural land is owned by third persons who should receive annual payments regarding the fact that their land is used for game management (Gren et al. 2018). This specific segment in Croatia is regulated by the Hunting Law (Official Gazette No. 99/2018). Furthermore, input values regarding the price of commercial trophy hunting and the monetary value of wild meat are collected from a conditionally speaking “free market” whose veracity can be doubted because of widespread tax avoidance and other grey economy issues.

CONCLUSIONS

This analysis has shown that only joint management of forests and game has its economic justification. The forestry business alone (including the selling of standing timber) cannot fulfil the basic economic criteria of NPV at the minimal level of cost of capital. However, investors who can try to lower the cost of capital beyond the investigated minimum (5.41%) should use the cost of capital not higher than 5.10% (in nominal terms). However, joint management ensures a positive NPV and IRR of 5.69% which exceeds the cost of capital. This is supported by the cognition that game management if evaluated as a self-standing business activity, and a lucrative natural-based economic branch.

Profitability can be increased not by cutting costs but by increasing revenues instead. With better management, forests can produce highly valuable timber, and HG big game management can result in a higher share of valuable hunting trophies. Also, the land itself offers the possibility of non-wood forest products commercialisation (e.g., mushrooms, nuts, and berries).

On the basis of this analysis, it can be concluded that the forest management plan and the game management plan should be better interconnected. Therefore, administrative boundaries should overlap, a 10-year plan for both should start in the same year, and elements of both plans should be spatially and temporally connected.

The future management perspective should take into account this interconnection from the perspective of an added value chain that starts with the land and continues with all possible outcomes which can generate revenue for the investor. Here it is important to note that Croatian Hunting Law (Official Gazette No. 99/2018) allows private hunting grounds, but only in situations when the landowner possesses a minimum of 500 ha of land in one piece (all land parcels must lean each other continuously without gaps of land parcel of another landowner). Furthermore, according to the Croatian Forest Law (Official Gazette No. 145/2020), only privately owned forest properties which exceed 20 ha can have an autonomous management plan. In the end, we can conclude that the interconnection mentioned above is possible in properties with a size of 500 ha and more.

Author Contributions

KB conceived and designed the research, KB and MP carried out the data collection, KB and MP processed the data and performed the analysis, KB, HM and SB wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Energy Properties of 22 Timber Species from Oaxaca, Mexico

Faustino Ruiz-Aquino[1], María Elena Jiménez-Mendoza[1], Mario Enrique Fuente-Carrasco[1], Wenceslao Santiago-García[1], Mario Ernesto Suárez-Mota[1], Ciro Aquino-Vásquez[1], José Guadalupe Rutiaga-Quiñones[2,*]

(1) Instituto de Estudios Ambientales, Universidad de la Sierra Juárez, Avenida Universidad S/N, Ixtlán de Juárez, Oaxaca C.P. 68725, México; **(2)** Facultad de Ingeniería en Tecnología de la Madera, Universidad Michoacana de San Nicolás de Hidalgo, Av. Fco. J. Múgica S/N, Col. Felicitas del Rio, Morelia, Michoacán C. P. 58040, México

*** Correspondence:** e-mail: rutiaga@umich.mx

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ABSTRACT

The potential use of forest species as fuels depends on their energy quality. However, in rural communities in developing countries, fuelwood is still an energy source without any technical study evaluating its energetic characteristics. Therefore, this study aimed to analyze the energetic characteristics of 22 forest species from four communities in the state of Oaxaca, Mexico. The basic wood density, proximal analysis, and high heating value were evaluated. As a result of the analysis, the fuel number (FN) is proposed as a measure of the energy quality of biomass fuels in the form of firewood. FN considers the basic wood density, the fixed carbon, and the high heating value of each species. Wood basic density ranged from 0.472 $g \cdot cm^{-3}$ for *Pinus pseudostrobus* to 0.814 $g \cdot cm^{-3}$ for *Dodonaea viscosa*, fixed carbon ranged from 4.74% to 21.27% for *Liquidambar styraciflua* and *Quercus rugosa*, respectively, and high heating value from 18.33 $MJ \cdot kg^{-1}$ to 22.07 $MJ \cdot kg^{-1}$ for *Liquidambar styraciflua* and *Pinus leiophylla*, respectively. Classifying wood according to FN, in decreasing order, *Quercus rugosa* stands out as the best wood (66.97%), followed by *Liquidambar styraciflua* (39.52%). Regarding the fuel value index, the nine pine species showed the highest values (27.32 to 77.76). The FN provides a measure of the quality of biomass fuels in the form of firewood, and can be evaluated by easily measured variables.

Keywords: basic wood density; proximate analysis; high heating value; fuel number; fuel value index

INTRODUCTION

The use of wood as fuel started when humanity discovered how to make fire for cooking or heating (Ramos et al. 2016). Currently, wood is an essential raw material in the energy supply for many sectors in the world, such as industrial, commercial, transportation, and household. In rural communities in developing countries, biomass from forests is used as an energy source for cooking, both due to economic and cultural conditions (Sierra-Vargas et al. 2014). In addition, its use contributes significantly to climate change mitigation (de Oliveira et al. 2022).

Despite efforts to control biomass energy use, biomass remains the most attractive resource for local populations and, therefore, continues to be of great importance (Massuque et al. 2021). Globally, it is estimated that about half of the population uses plant or animal biomass as the primary source of energy for domestic use, where firewood is the primary fuel (Aguirre-Cortés et al. 2018, CONABIO 2020). The global consumption of firewood is estimated at over 1.5 billion m^3 per year. Europe uses more than 90 million m^3 of fuelwood per year (Parikka 2004), with an increase between 1992 and 2006 of 39 million m^3 (Buongiorno et al. 2012). In Mexico, in 2018, 1,069,380 m^3 of timber production was designated for energy use (SEMARNAT 2018). In addition, 11% of households use firewood or charcoal, which represents 40% of the total energy used (INEGI 2018).

The wood used as fuel must be evaluated to determine its suitability for bioenergy production (Lachowicz et al. 2018). The most important parameters to evaluate include volatile matter, ash content, fixed carbon, calorific value, moisture content, basic density, and chemical composition (Choi et al. 2014, de Paula Protásio et al. 2019). This study mainly evaluates the energetic wood characteristics from 22 species collected in the forests of Oaxaca, Mexico, and proposes a number to rank the quality of biomass fuels.

MATERIALS AND METHODS

Study Area

Woody biomass was collected in different areas of forest communities in the state of Oaxaca, Mexico: Ixtlán de Juárez, Oaxaca (17°20' N and 96°29' W), San Sebastián Coatlán, Miahutlán, Oaxaca (16°12'41.6" N and 96°49'15.9" W), Santa María Tlahuitoltepec, Mixe, Oaxaca (17°03' N and 95°58' W) and San Juan Metaltepec, Mixe, Oaxaca (17°10' N and 95°54' W).

Tree Selection and Sample Preparation

Two trees per species, healthy, without bifurcation, and representative of the study area, were selected and harvested. A directional felling was applied to the trees with an Oleo-Mac GS 370® chainsaw. A 1 m long log close to the root was taken from each tree, and a 2 cm slice was cut from each side (Ruiz-Aquino et al. 2019). To determine the energetic characteristics, the material was chipped, and ground in a Wiley-type mill; the material that was retained in the 40 mesh was used (Rutiaga-Quiñones et al. 2020).

Determining the Basic Wood Density

From each slice, cubes of 2 cm per side were cut with a KNOVA KN SCM-10A® band saw. The fresh volume of each cube was determined by the immersion method, determining the mass of water displaced by a wooden cube when immersed in water (Figure 1), the mass in grams being numerically equal to the volume in centimeters (Test method B- Volume by Water Immersion (ASTM 2007a)). Subsequently, once the cubes were in their anhydrous state, their basic wood density (BWD) was calculated as the ratio of the anhydrous weight and the fresh green volume (ASTM 2007a).

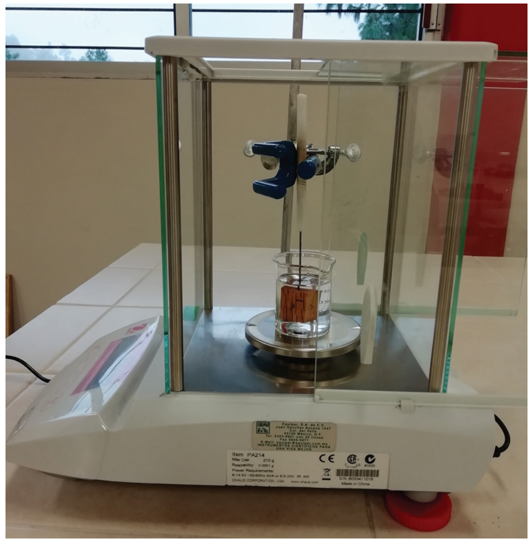

Figure 1. Determination of fresh volume by the immersion method.

Proximal Analysis

Ash content and volatile matter (VM) content were calculated using ASTM D1102-84 (2007b), and ASTM E872-82 (2013), respectively. Additionally, fixed carbon (FC) was calculated as the sum of ash and volatile matter subtracted from 100 (ASTM 2006). All percentages were calculated taking as reference the anhydrous weight of the samples.

High Heating Value

A 1341 flat jacket calorimeter (Parr, USA), equipped with a digital thermometer (Parr, 6775), ignition unit (Parr, 2901), and calorimetric pump (Parr, 1108) was used to calculate the high heating value (HHV), in accordance with ASTM E 711-87 (2004).

Fuel Number

The use of a number is proposed to rank the quality of biomass fuels. As independent variables, three parameters are considered as good indicators of energy quality: BWD, FC, and HHV (Demirbaş and Demirbaş 2009). For the development of the Fuel Number (FN), maximum values of each of the independent variables were taken. In the case of basic density, the cell wall density of 1.53 g·cm^{-3} is practically constant for all woods (Desch and Dinwoodie 1981, Usta 2003). For fixed carbon, it is considered that the higher it is, the better the fuel quality is. In addition, fixed carbon is an important generator of heat during combustion (Kongprasert et al. 2019); different studies agree that the value of fixed carbon in biomass fuels in the form of firewood or densified, does not exceed 30% (Uceda 1984, Vassilev et al. 2010, Ruiz-Aquino et al. 2019, Ramírez-Ramírez et al. 2021, 2022). In the HHV, lignin (25.58 MJ·kg^{-1}) was taken as the maximum value because, in general, the HHV of biomass fuels increases with lignin content and is highly correlated (Demirbaş 2001, 2002, 2003). If we consider hypothetical data for fuel with the best characteristics outlined above, then FN takes a maximum value of 100%. Under this premise, it is relatively simple to rank the quality of biomass fuels, considering that the higher the FN, the better the fuel quality.

Fuel Value Index

In the present study, a comparison has also been made with the Fuel Value Index (FVI) proposed by Bhatt and Todaria (1992), where calorific value and density are considered positive characters and ash content is a negative parameter (Equation 1):

$$FVI = \frac{(HHV)(BD)}{A} \quad (1)$$

where HHV is high heating value (MJ·kg^{-1}), BD is basic wood density (g·cm^{-3}), and A is ash content (%).

All analyses were performed with five replicates, and the mean value and standard deviation have been reported. No software was used to calculate these values.

RESULTS AND DISCUSSION

Basic Density

Table 1 summarizes the mean values and standard deviation in parentheses for the 22 studied tree species in the study; thirteen belong to the broadleaved hardwood and nine to the conifer group. In the broadleaved hardwoods group, the basic wood density varies from 0.475 g·cm^{-3} for *Liquidambar styraciflua* to 0.814 g·cm^{-3} for *Dodonaea viscosa*. Concerning oaks, the results are within the defined interval (0.543 to 0.889 g·cm^{-3}) reported by different authors (De la Paz Pérez-Olvera and Dávalos-Sotelo 2008, Herrera-Fernández 2013, Ruiz-Aquino et al. 2015, Herrera-Fernández et al. 2017). Based on the classification by Sotomayor (2005), *Dodonaea viscosa* is classified as very high-density wood, while the five oak species are classified in the category of high density. In the case of conifers, the obtained values ranged from 0.472 g·cm^{-3} (*Pinus pseudostrobus*) to 0.600 g·cm^{-3} (*P. patula*), the nine species were classified as medium density woods (0.401 to 0.600 g·cm^{-3}) proposed by Sotomayor (2005). In general, the BWD values for pine wood are in accordance with data previously reported by Peña and Rojas (2006) and Sotomayor (2005). The basic density of wood is a physical property that influences biomass combustion processes (Demirbaş and Demirbaş 2009). Kumar et al. (2010) found that higher basic density increases the calorific value of wood due to the energy contained per unit of volume. This coincides with findings by Ruiz-Aquino et al. (2015), who mention that high-density woods are preferred as fuels in a rural community in Oaxaca, Mexico. BWD and extractives content are characteristics responsible for providing high energy density, longer duration, and intensity of combustion, which are important characteristics for choosing the type of fuelwood (Massuque et al. 2020).

Proximal Analysis

Fuel's volatile matter is the portion of condensable and non-condensable gases and vapors which are released when the fuel is heated for a specific time and at specific temperature (Basu 2018). Volatile matter levels are inversely proportional to fixed carbon content (Pereira et al. 2012). According to Ragland et al. (1991), the volatile content for wood ranges from 70% to 90%, relative to the anhydrous weight of the sample, and can be subdivided into light

Table 1. Basic wood density, proximate analysis, and high heating value of 22 tree species.

Species	BWD (g·cm^{-3})	VM (%)	Ash (%)	FC (%)	HHV (MJ·kg^{-1})
Dodonaea viscosa Jacq.	0.814 (0.01)	82.04 (2.27)	0.81 (0.01)	17.15 (2.26)	21.06 (0.12)
Quercus rugosa Née.	0.797 (0.02)	76.60 (3.90)	2.12 (0.04)	21.27 (3.92)	19.91 (0.10)
Q. glaucoides M. Martens & Galeotti.	0.786 (0.01)	78.12 (1.82)	3.42 (0.04)	18.46 (1.82)	20.20 (0.15)
Q. resinosa Liebm.	0.777 (0.01)	80.13 (1.58)	1.12 (0.03)	18.74 (1.58)	20.28 (0.17)
Q. laurina Humb. & Bonpl.	0.720 (0.03)	79.45 (2.11)	3.03 (0.08)	17.51 (2.13)	19.93 (0.51)
Leucaena diversifolia (Schltdl.) Benth.	0.709 (0.02)	82.45 (0.75)	1.45 (0.03)	16.09 (0.77)	20.85 (0.13)
Q. candicans Née.	0.704 (0.02)	86.16 (1.78)	1.35 (0.04)	12.48 (1.79)	20.88 (0.19)
Acacia pennatula Schltdl. & Cham.	0.608 (0.02)	78.04 (4.27)	4.51 (0.01)	17.44 (4.27)	19.54 (0.30)
Arbutus xalapensis Kunth.	0.601 (0.03)	81.24 (1.32)	1.54 (0.03)	17.21 (1.32)	21.05 (0.36)
Montanoa leucantha subsp. arborescens (DC.) V. A. Funk.	0.548 (0.02)	82.95 (2.18)	1.19 (0.32)	15.86 (2.33)	20.11 (0.52)
Alnus jorullensis Kunth.	0.525 (0.03)	82.76 (2.76)	0.49 (0.00)	16.74 (2.76)	21.04 (0.24)
Lippia myriocephala Schltdl. & Cham.	0.504 (0.04)	83.69 (2.02)	1.11 (0.02)	15.20 (2.01)	20.53 (0.21)
Liquidambar styraciflua L.	0.475 (0.01)	94.70 (1.01)	0.54 (0.01)	4.74 (1.04)	18.33 (0.97)
Pinus patula Schiede ex Schltdl. et Cham.	0.600 (0.01)	92.81 (1.11)	0.39 (0.03)	9.28 (0.37)	19.86 (0.17)
P. rudis Endl.	0.580 (0.01)	94.82 (1.01)	0.30 (0.01)	4.88 (0.25)	19.08 (0.19)
P. douglasiana Martínez.	0.540 (0.01)	92.84 (2.05)	0.28 (0.02)	6.88 (0.46)	19.45 (0.27)
P. devoniana Lindley	0.572 (0.03)	84.96 (1.33)	0.16 (0.03)	21.75 (0.35)	14.87 (0.58)
P. lawsonii Roezl ex Gordon	0.556 (0.02)	84.56 (1.15)	0.17 (0.03)	18.83 (0.11)	15.27 (1.15)
P. hartwegii Lindley	0.526 (0.03)	86.12 (1.29)	0.21 (0.06)	21.40 (0.33)	13.67 (0.28)
P. leiophylla Schiede ex Schltdl. et Cham.	0.523 (0.02)	84.61 (1.20)	0.17 (0.01)	22.07 (0.22)	15.22 (1.21)
P. ayacahuite Enhrenb ex Schltdl.	0.480 (0.01)	93.04 (3.25)	0.37 (0.01)	21.06 (0.24)	6.59 (0.17)
P. pseudostrobus Lindl.	0.472 (0.03)	86.03 (0.56)	0.17 (0.05)	21.53 (0.18)	13.79 (0.57)

BWD = Basic Wood Density, VM = Volatile Matter, FC = Fixed Carbon, HHV = High Heating Value hydrocarbons, tar, carbon monoxide, carbon dioxide, hydrogen, and moisture.

The volatile material content in broadleaves varied from 76.60% for *Quercus rugosa* to 94.70% for *Liquidambar styraciflua* (Table 1), while in the conifer group, the variation was from 84.56% to 94.82% for *Pinus lawsonii* and *P. rudis*, respectively. In general, the values found for hardwoods coincide with those reported by different authors. For acacia species, a range of 75.30% to 86.50% has been reported (Agostinho-Da Silva et al. 2014, Eloy et al. 2015, Apolinar et al. 2016). *Alnus jorullensis* presented 82.767 %, like that reported by Ruiz-Aquino et al. (2019), and 82.61% was reported for *Alnus acuminata*. The results for conifers are close to values reported for pine wood (78.9% to 89.8%) (Rutiaga-Quiñones et al. 2020).

Ash content in hardwoods varied from 0.49% for *Alnus jorullensis* to 4.51% for *Acacia pennatula*, and in conifers from 0.16% for *Pinus devoniana* to 0.39% for *P. patula*. Out of the 13 hardwoods species in the present study, 12 were in the content range (1% to 3.4%) according to Gutiérrez-Acosta et al. (2021), except *Acacia pennatula*, which presented the highest ash content (4.51%). Regarding the four pine species (*P. patula*, *P. rudis*, *P. douglasiana* and *P. ayacahuite*), they were within the ash range (0.27% to 0.95%) referred by Rutiaga Quiñones et al. (2020). On the other hand, *Pinus pseudostrobus*, *P. leiophylla*, *P. hartwegii*, *P. lawsonii*, and *P. devoniana* were positioned within the range (0.13% to 0.23%) for bioenergy use reported by Pintor-Ibarra et al. (2017). All conifers in this study were within the range (0.1% to 1.1%) reported for pine sawdust (Ramírez-Ramírez et al. 2021). In general, ash content in conifers is lower than in broadleaved hardwoods, which coincides with the study by Gutiérrez-Acosta et al. (2021). The ash content in biomass influences fuel quality and higher content decreases the calorific value (Demirbaş and Demirbaş 2009, Klašnja et al. 2013, Martínez-Pérez et al. 2015, Ngangyo-Heya et al. 2016, Ruiz-Aquino et al. 2019). In combustion equipment (for example, stoves, ovens, furnaces, boilers, among others), it is preferable to use firewood with lower ash content because the containing minerals cause corrosion and potential problems to the equipment (Massuque et al. 2020).

Fixed carbon is the solid carbonaceous residue from the release of volatiles from biomass (McKendry 2002). It is related to the amount of ash and volatiles; thus, a higher amount of these components is reflected in a lower concentration of fixed carbon (Ruiz-Aquino et al. 2019). The fixed carbon content in the wood of the species studied (Table 1) ranged from 4.74% (*Liquidambar styraciflua*) to 21.27% (*Quercus rugosa*), and in conifer species from 4.88% (*Pinus rudis*) to 15.27% (*P. lawsonii*). All 22 tree species in the present study suit well within the range (6.5% to 26.3%), as reported for 28 wood and woody biomass samples by Vassilev et al. (2010). In our study, *Liquidambar styraciflua* has the highest volatile matter, and, therefore, it is considered the species that shows the lowest amount of fixed carbon.

High Heating Value

The HHV in hardwoods ranged from 18.33 MJ·kg^{-1} for *Liquidambar styraciflua* to 21.06 MJ·kg^{-1} for *Dodonaea viscosa*, and in conifers from 18.83 MJ·kg^{-1} for *Pinus lawsonii* to 22.07 MJ·kg^{-1} for *P. leiophylla*. The HHV of 12 studied hardwoods was within the range (19 to 21 MJ·kg^{-1}) as reported for hardwoods by Mark et al. (1985), while only four conifers were below the mentioned range (20-22 MJ·kg^{-1}). The slightly higher HHV values of conifers can be explained by the higher extractive contents and lignin in conifer wood (Ragland et al. 1991).

Fuel Number

Taking the values considered as the maximum for the parameters: basic density (BWD = 1.53 g·cm^{3}), fixed carbon (FC = 30%), and higher calorific value of lignin (HHV = 25.58 MJ·kg^{-1}), the FN was calculated as the average of the mentioned parameters (Equation 2):

$$FN = \frac{76.74\ BD + 3.91\ FC + 4.59\ HHV}{3.52} \qquad (2)$$

where BD is basic density (g·cm^{-3}) BWD, FC is Fixed carbon content (%), and HHV is high heating value (MJ·kg^{-1}).

Table 2 presents a comparison between the fuel number (FN) calculated and proposed in the study, and the fuel value index (FVI) proposed by Bhatt and Todaria (1992).

Classifying the tree species' wood based on FN in decreasing order, *Quercus rugosa* stands out as the best wood (66.97%), followed by *Liquidambar styraciflua* (39.52%). It can be observed that except for *Quercus candicans*, which may be due to its low fixed carbon content (Table 1), oak species are considered as most important. This hierarchy is congruent with the findings by Ramírez-López et al. (2012), who found that, in eight social communities in Chiapas, Mexico, oak firewood is preferred due to its heating quality. Similarly, Soares (2006) and Ruiz-Aquino et al. (2015) indicate that the most preferred fuel species belong to the *Quercus* genus. The preference for the use of oak wood as fuel lies in the high basic density of the wood, high fixed carbon content, high calorific value, and low ash content, characteristics that influence energy quality the most (Abbot et al. 1997). On the contrary, the low FN of *Liquidambar styraciflua* is explained by the high amount of volatiles (94.7%), its medium basic density (0.475 g·cm^{-3}), and low fixed carbon content (4.74%), being the species with the lowest calorific value (18.33 MJ·kg^{-1}), in comparison with the other studied species. The second most important species is *Dodonaea viscosa*, also preferred as a fuelwood in an indigenous community in Oaxaca due to its high BWD, high fixed carbon content, high calorific value, and low ash content coupled with easy ignition properties (Silva-Aparicio et al. 2018).

Fuel Value Index

Regarding the FVI, the highest value was found in *Pinus devoniana* (77.76) and the lowest in *Acacia pennatula* (2.63). The nine pine species showed the highest FVI values (27.32 to 77.76). However, in practice, this fuelwood is quickly consumed, and is not preferred as a good material for certain uses, such as cooking food (Ramírez-López et al. 2012, Morales-Máximo et al. 2019). The high FVI values in pine wood are more influenced by how it is calculated, i.e., the product of the calorific value and BWD is more significant, while fixed carbon is not considered. Conifers

Table 2. Fuel number (FN) and fuel value index (FVI)* for 22 timber species.

Species	FN (%)	FVI
Quercus rugose Née.	66.97	7.49
Dodonaea viscosa Jacq.	64.25	21.16
Quercus resinosa Liebm.	64.21	14.07
Q. glaucoides M. Martens & Galeotti.	63.98	4.64
Q. laurina Humb. & Bonpl.	61.14	4.74
Leucaena diversifolia (Schltdl.) Benth.	60.51	10.19
Arbutus xalapensis Kunth.	59.67	8.21
Acacia pennatula Schltdl. & Cham.	58.10	2.63
Alnus jorullensis Kunth.	57.47	22.54
Pinus devoniana Lindley	57.35	77.76
P. leiophylla Schiede ex Schltdl. et Cham.	57.09	67.90
P. rudis Endl.	56.61	36.89
Quercus candicans Née.	56.44	10.89
Montanoa leucantha subsp.arborescens (DC.) V. A. Funk.	55.78	9.26
Lippia myriocephala Schltdl. & Cham.	54.64	9.32
Pinus hartwegii Lindley	54.55	53.60
P. pseudostrobus Lindl.	53.68	59.78
P. lawsonii Roezl ex Gordon	53.63	61.59
P. ayacahuite Enhrenb ex Schltdl.	52.26	27.32
P. patula Schiede ex Schltdl. et Cham.	51.99	30.55
P. douglasiana Martínez.	50.36	37.51
Liquidambar styraciflua L.	39.52	16.12

* FVI calculated by the equation proposed by Bhatt and Todaria (1992).

have a higher calorific value than hardwoods due to the higher amount of lignin; however, the quality of fuelwood should not be ranked based on HHV alone. In the RFN, the three parameters (HHV, BWD and FC) have the same importance and the ranking results are congruent with the preference of users (Ramírez-López et al. 2012, Ruiz-Aquino et al. 2015).

The FN provides a measure of the quality of biomass fuels in the form of firewood. However, fuel quality is currently taking a back seat due to deforestation and land-use change, causing primary fuelwood users to use species that are closer in proximity to decrease transportation costs (Deka et al. 2002, Ramírez-López et al. 2012).

CONCLUSION

The basic wood density varied in a range from 0.475 g·cm^{-3} for *Liquidambar styraciflua* to 0.814 g·cm^{-3} for *Dodonaea viscosa*. Within this range, the five species of oaks are classified as having high wood density, ideal for their use as fuels. On average, coniferous firewood presented lower ash content, an indispensable attribute for its use as densified fuel. The high heating value of conifers was, on average, higher than that of hardwoods. Good fuel quality was verified with the FN, given the combination of wood density, high calorific value, and fixed carbon content. Based on the FN, four *Quercus* species indicate better fuel quality. The nine pine species showed the highest values for FVI (27.32 to 77.76), but in practice, they are not favorable for use by the local communities.

Author Contributions

FRA, MEJM, JGRQ conceived and designed the research; FRA, MEJM carried out the field and laboratory measurements; MEFC, WSG, MESM, CAV processed the data; FRA, MEJM, JGRQ, MEFC, WSG, MESM, CAV drafted the manuscript, and wrote the manuscript. All authors read and approved the final manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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REVIEW PAPER

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Analysis of the Fire Season of 2020 in the Mediterranean Bioclimatic Zone of Croatian Adriatic

Damir Barčić[1], Tomislav Dubravac[2,*], Mario Ančić[3], Roman Rosavec[1]

(1) University of Zagreb, Faculty of Forestry and Wood Technology, Institute of Ecology and Silviculture, Svetošimunska 23, HR-10000 Zagreb, Croatia; **(2)** Croatian Forest Research Institute, Division for Silviculture, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia; **(3)** University of Zagreb, Faculty of Forestry and Wood Technology, Institute of Forest Inventory and Management, Svetošimunska 23, HR-10000 Zagreb, Croatia

*** Correspondence:** e-mail: dbarcic@sumfak.hr

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ABSTRACT

Fire season in the Mediterranean bioclimatic area is most associated with the period from June to late October. Despite this, a large number of fires occur in February and March due to the intentional burning of agricultural lands. A characteristic of the Mediterranean region is the strong adaptation of vegetation to fire, though this adaptation also depends on the frequency and intensity of fires. This frequency is shown on satellite images via MODIS. This paper provides an overview of indicators of vegetation fires in the Croatian coast and karst coastal belt in the 2020 fire season. The 2020 fire season was above average in comparison with the period 2010 to 2019, with more fires than average and more burnt area. A specificity of the 2020 season is seen in the large number of fires in February and March. Fire protection in Croatia is facilitated by the use of new remote sensing technologies, in combination with the existing surveillance and monitoring methods, and organised protection systems to prevent open fires.

Keywords: open space fire; fire activity; distribution; mapping of burnt areas; prevention

INTRODUCTION

Wildfires significantly disturb terrestrial ecosystems. Large-scale fires inflict immeasurable ecological damage and commercial loss in forestry, agriculture and to the infrastructure. Direct consequences of wildfires are related with polluted air; smoke and soot in the atmosphere, residue from burning contaminates the soil and groundwater (Delač et al. 2021, 2022) destroys biomass, affecting, in ecological sense, both aboveground and belowground biotic communities (Bond and Keeley 2005, Dove and Hart 2017). Fire is more common in certain parts of the globe due to the local climatic factors. One such region is the Mediterranean basin, which is specific since most of the vegetation is partly adapted to fire, which is also partly due to the frequency and intensity of fires. Some authors claim that fire is a natural element in Mediterranean ecosystems (Keeley et al. 2011, Moreira et al. 2020), which needs to be considered when analysing the impacts of fire on vegetation. In Southern European Mediterranean countries, change in the fire regime are land abandonment and afforestation of former agricultural land, leading to fuel accumulation and landscape-level connectivity of flammable patches (Moreira et al. 2012). Pausas et al. (2008) state that fire is both an integral part of many terrestrial biomes including Mediterranean ones, and a major factor of disturbance. In that sense, it is necessary to list very specific and important information about the scale and causes of open fires. Approximately 80-86% of the global burnt area occurs in grassland and savannas, primarily in Africa and Australia (Mouillot and Field 2005, van der Werf et al. 2006), while the remainder occurs in forested regions of the world (Flannigan et al. 2009). Most open fires are caused by humans, intentionally or unintentionally, with less than 4% caused naturally, i.e., by lighting (Martinez et al. 2009). The number of naturally caused fires is also very low due to the development of fire prevention and protection technology in recent decades (Viegas 1998, Koo et al. 2010), and more intensive surveillance and monitoring of meteorological parameters. According to some research in the western Mediterranean, increased negative ecological impacts of fires on habitat, in the sense of diminished biodiversity and increased erosion, are due to pine plantations (Gomez-Gonzalez et al. 2018, Ojeda 2020). However, fire occurrence is most highly correlated with climate factors (temperature and drought).

In that sense, fire regimes can be analysed, and some studies have highlighted the variations in the relationship between climate and fire among regions, primarily based on the differences in the effects of human and biophysical drivers on fire initiation and behaviour (Littell et al. 2009, Keeley and Syphard 2017, Syphard et al. 2017). In Croatia, fire severity has been monitored for many years, and in some cases also the connection with vegetation from a bioclimatic point of view (Barčić et al. 2020). A key issue in the Mediterranean climate conditions in Croatia is whether new technologies in fire protection offer an opportunity to reduce the number of fires and burnt areas. The cumulative impact of burnt areas in the European Mediterranean region (Ayanz et al. 2012), as mapped in the European Forest Fire Information System (EFFIS) from 2000 to 2009, is presented in Figure 1.

In the context of climate change projections, the poten-tial for wildfires will only increase in southern Europe, which can significantly reduce the resilience of Mediterranean ecosystems to fire (Vallejo et al. 2012).

MATERIALS AND METHODS

The most common index, the Canadian Fire Weather Index (FWI), was used to assess fire severity and to assess fire risk based on meteorological conditions. This index is a numerical assessment of the potential intensity of fire for a standard fuel type and is a relative measure of the expected fire behaviour and a daily requirement for fire supervision (van Wagner and Pickett 1985, van Wagner 1987, 1993). The mean seasonal FWI can successfully explain most of the year-to-year variation in burnt areas in European countries. Burnt area index (BAI) was used for the interpretation of wildfires (BAI = area affected by fire / number of fires).

Maps were developed using MODIS (Moderate Resolution Imaging Spectroradiometer) on board the Terra and Aqua satellites over a 10-day period. Each coloured dot indicates a location where MODIS detected at least one fire during the compositing period. Colours range from red where the fire count is low to yellow where number of fires is high.

The temporal resolution of MODIS is one to two days, and the radiometric resolution is 12 bits per pixel. Various channels of MODIS have various purposes, of which the most interesting to us are channels 17-19 (monitoring of vapor in the atmosphere), channels 20-23 (determining the temperature of the Earth's surface and clouds), channels 24 and 25 (determining the temperature of the atmosphere) and finally channels 31 and 32 (determining the temperature of the Earth's surface and clouds).

RESULTS

According to the data collected and kept by the Operational Fire Centre of the Croatian Firefighting Association, a total of 3906 vegetation fires were recorded in the coastal belt and coastal areas of the Mediterranean karst in 2020. This figure is 20.78% higher than the previous five-year average (Tables 1 and 3). In these fires, the total burnt area (according to field estimates and georeferencing calculations based on maps) was 35,168 ha, or 14.72% more than in the previous five-year period (Tables 2 and 3), thereby resulting in a 5.02% reduction in the burnt area index (BAI).

The distribution of the number of fires by burnt area size during the main fire season and for the whole fire season in 2020 in shown in Table 4. The size of the burnt area in most wildfires during the fire season (June – October) was less than 5 ha, while only one fire had a burnt area of over 100 ha, accounting for just 0.09% of the number of fires in that period. The number of fires that had burnt an area between 10 and 100 ha (24 fires) was nearly the same number of fires that burnt an area between

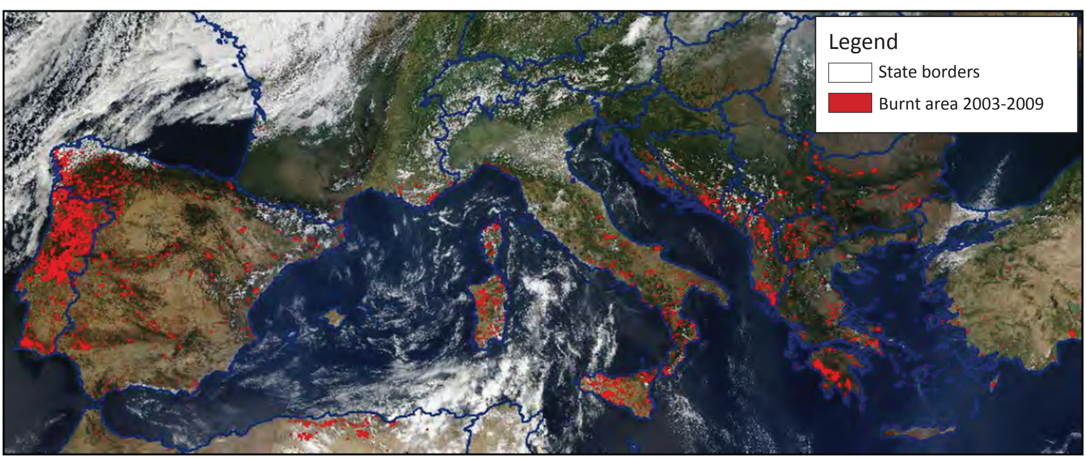


Figure 1. Cumulative impact of forest fires in the 2000-2009 period marked with red.

5 and 10 ha (25 fires). This is a characteristic recorded for the fourth year in a row (where the ratio is nearly the same or is larger), indicating that, unless controlled, fires spread very quickly to areas of over 10 ha. Taking the entire year into account (data analysed at the Croatian Operational Fire Control Centre), 25 fires spread to an area greater than 100 ha (0.67%) and 167 fires were contained within an area of 10 and 100 ha (4.28%), while 110 affected an area of 5 to 10 ha (2.82%) and the vast majority of 3604 fires (92.27%) burnt an area of less than 5 ha.

The severity of the global fire seasons in 2019, 2020 and 2021 is shown in Figures 2,3 and 4, in a ten-day period in the month of January and in the month of August. Mouillot and Field (2005) estimate that the global average burnt area decreased from 535 to 500 Mha per year during the first half of the 20th century. Meanwhile, in recent decades, certain regions have shown evidence of a strong threat of the trend towards more fires affecting a larger area, and burning with greater severity (FAO 2007).

Figure 7 shows that the 2020 fire season was above average in comparison with the period of 2010 to 2019 (Figure 5), indicating that there were more fires and more area burnt than during the ten-year average. The specificity of 2020 is seen in the larger number of fires in February and March (during cleaning weeds on agricultural area), primarily due to weather conditions (reduced precipitation and a higher number of days with strong to gale force winds), with the frequent, irresponsible burning of agricultural lands that went out of control. The deviation for the year 2020 is also clearly shown by the burnt area index (9.00 ha), which is still significantly less compared to the extremely dry and warm year of 2017, when the index was 20.86 ha per one fire.

Table 1. Number and surface of open fires in the coastal areas of Croatia.

Observed period	2015		2016		2017		2018		2019		2020	
	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)	Number of fires	Surface (ha)
01/01-31/12	3382	23909	2913	19773	4150	86576	1875	3891	3850	19129	3906	35168
01/06-31/10	1317	10265	1407	7415	1574	59770	1330	3160	1090	2643	1059	1695

Table 2. Five-year average of the number of fires and their area, and the burnt area index (BAI).

Observed period	2015-2019			2020
	Number of fires	Surface (ha)	BAI (ha·fire^{-1})	BAI (ha·fire^{-1})
01/01-31/12	3234	30655,6	9.48	9.00
01/06-31/10	1343,6	16650,6	12.39	1.60

Table 3. Comparison of the 2020 fire season and the five-year average.

Observed period	Ratio of the number of fires (%)	Ratio of the burnt area (%)	Ratio of the burnt area index - BAI (%)
01/01-31/12	20.78	14.72	-5.02
01/06-31/10	-0.21	-89.82	-87.08

Table 4. Distribution of open fires by burnt area size in coastal part of the Republic of Croatia in 2020.

Month	<=5 ha		>5 <=10 ha		>10 <=100 ha		>100 ha		Total fires
	Number	%	Number	%	Number	%	Number	%	
VI	156	98.11	1	0.63	2	1.26	0	0.00	159
VII	259	96.09	6	1.95	6	1.95	0	0.00	307
VIII	305	91.59	14	4.20	13	3.90	1	0.30	333
IX	207	97.64	4	1.89	1	0.47	0	0.00	212
X	47	95.92	0	0.00	2	4.08	0	0.00	49
VI-X	974	95.28	25	2.36	24	2.26	1	0.09	1060
I-XII	3604	92.27	110	2.82	167	4.28	25	0.64	3906

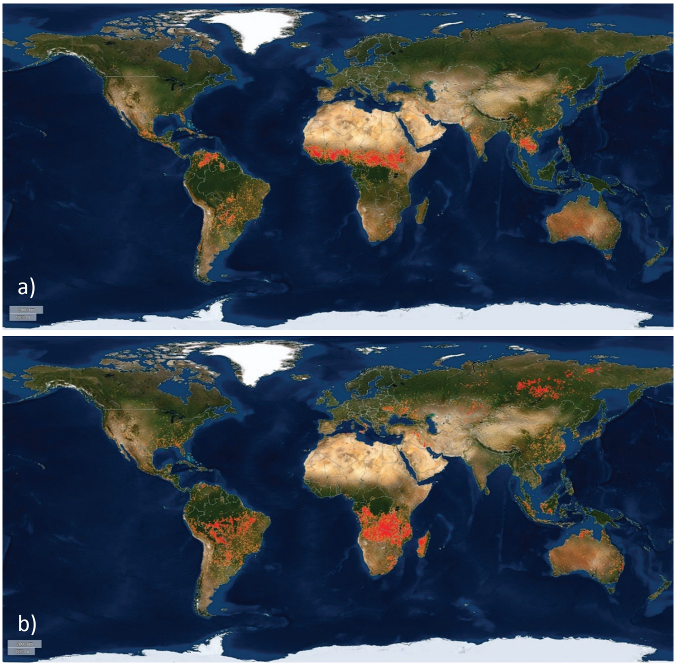
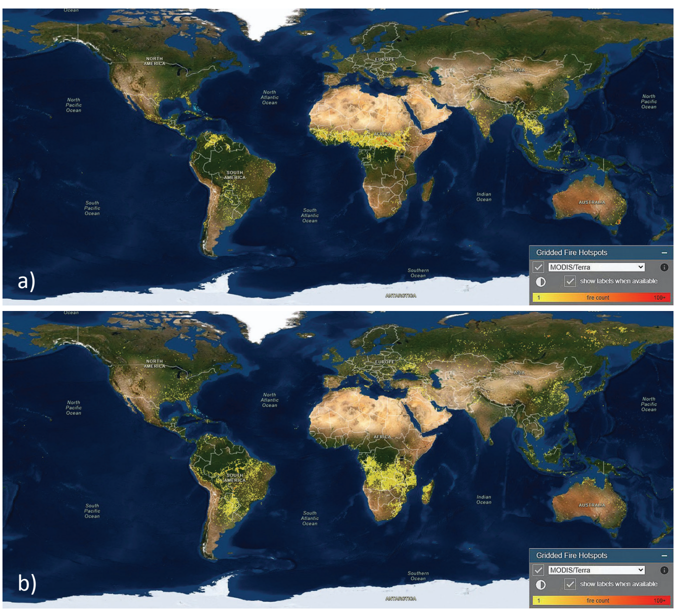


Figure 2. Examples of recent global fire activity (Modis/Terra Gridded Fire Hotspots) for: **(a)** 21–30 January 2019 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2019-01-21..2019-01-30;l:grids,countries;@-1.5,-1.7,3z), and **(b)** 05–14 August 2019 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2019-08-05..2019-08-14;l:modis_t,grids,country-outline;@1.7,3.4,3z). Each of these fire maps accumulates the locations of the fires detected by MODIS and images provided by the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2008011-2008020; accessed 25 October 2021).



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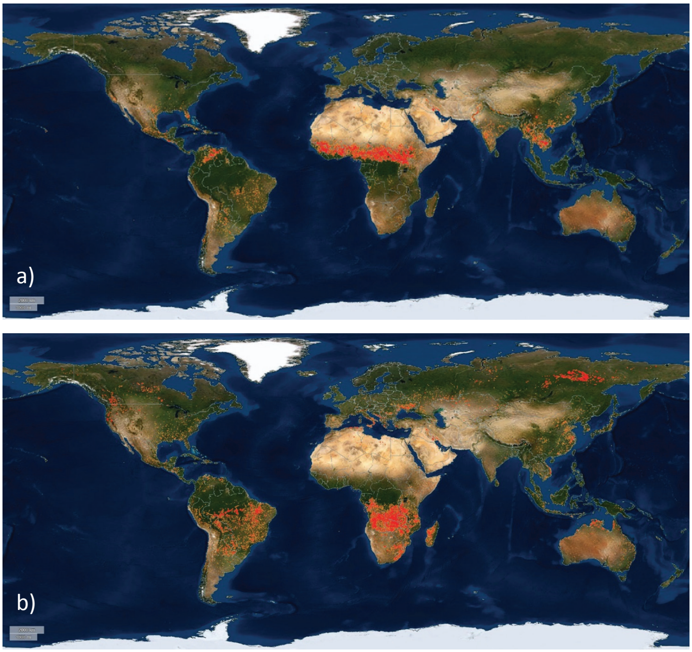

Figure 4. Examples of recent global fire activity (Modis/Terra Gridded Fire Hotspots) for: **(a)** 21–30 January 2021 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2021-01-21..2021-01-30;l:modis_t,grids,country-outline;@1.7,3.4,3z); and **(b)** 05–14 August 2021 (https://firms.modaps.eosdis.nasa.gov/map/#t:adv;m:advanced;d:2021-08-05..2021-08-14;l:modis_t,grids,country-outline;@1.7,3.4,3z). Each of these fire maps accumulates the locations of the fires detected by MODIS and images provided by the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/firemaps/?2008011-2008020; accessed 25 October 2021).

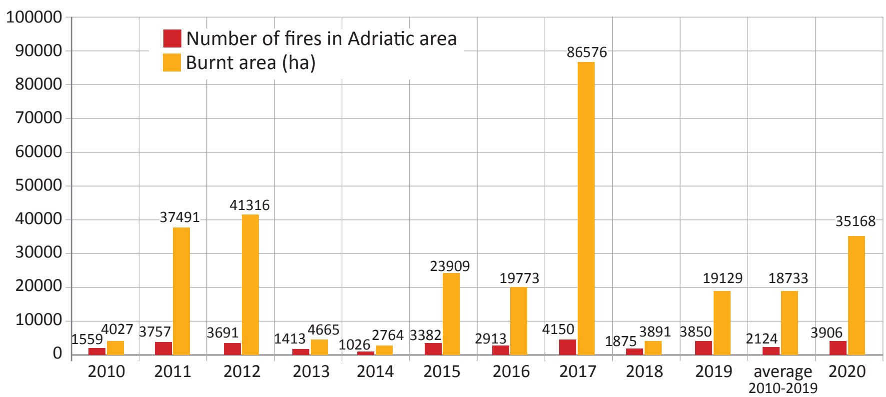

Figure 5. Croatia's coastal belt with the annual number of fires and affected land area in the period from 2010 to 2020. Source: Croatian Firefighting Association (2020).

DISCUSSION

The summer of 2020 fire season can be characterised by having a mean monthly air temperature equal to or higher than the multiyear average (1981 – 2010). In June, the temperature was lower in the southern Adriatic and northern Adriatic, while August was the hottest month. Precipitation was unevenly distributed, higher than average in some places, while others were marked by a precipitation deficit. This indicates the localised and torrential character of precipitation that is not uncommon in the summer months, when vertical cloud development is typical and can result in heavy rains. In September, a period of above average temperatures was recorded, with rain at the start and end of the month, while in October rain was frequent and even heavy (Mokorić et al. 2020). Following such weather conditions, that year's summer fire season was not extreme, given the lack of pronounced, long-term heat waves that cause the drying of the deepest soil layers. However, relatively unfavourable weather conditions in that season were seen in the occasional occurrence of strong winds, such as on 7 July when the Adriatic was affected by strong to gale-force Bora (northeasterly) wind with gale gusts, which is an extraordinary occurrence in the summer (Mokorić et al. 2020). Figure 6 shows the fire threat conditions in the Croatian bioclimatic area in 2020, while Figure 7 shows the deviations from the ten-year mean of the monthly threat class of vegetation fires according to Mokorić et al. (2020). An analysis of the fire weather index (FWI) for the start and spread of vegetation fires categorised into a threat class by colour shows that the seasonal threat class for summer was moderate (June, July, August) in the northern Adriatic and continental Croatia in Figure 2. A high threat (red) was present for the central and southern Adriatic areas. If these data are compared with trends in Europe, the situation cannot be considered favourable, as over the period 1980–2012, the FWI significantly increased for southern and eastern Europe, and for Europe as a whole (European Commission 2018, 2020).

Comparison of the monthly mean vegetation fire threat class for the 2020 summer season (June – August) with the ten-year average (2003 – 2012) in Figure 7 shows that the mean class was significantly lower than average in the northern Adriatic and mountainous Croatia, and slightly higher than average for most of southern Croatia. Several synoptic situations were detected in the 2020 fire season that could negatively influence a vegetation fire, since in addition to the associated strong winds with changing

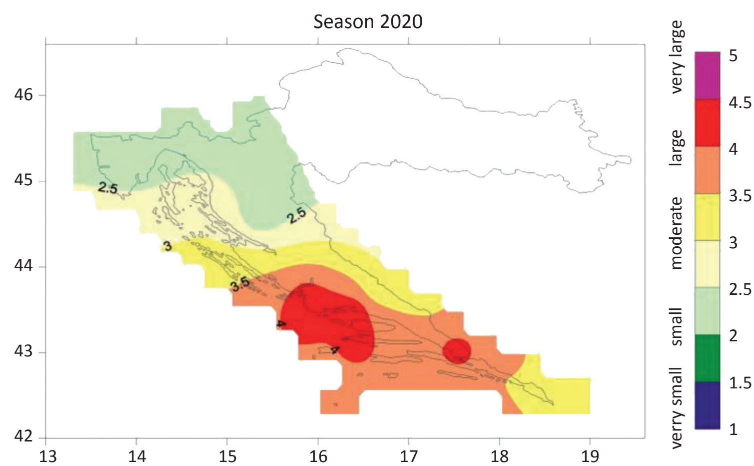

Figure 6. Mean monthly vegetation fire threat class for the 2020 fire season by Mokorić et al. (2020).

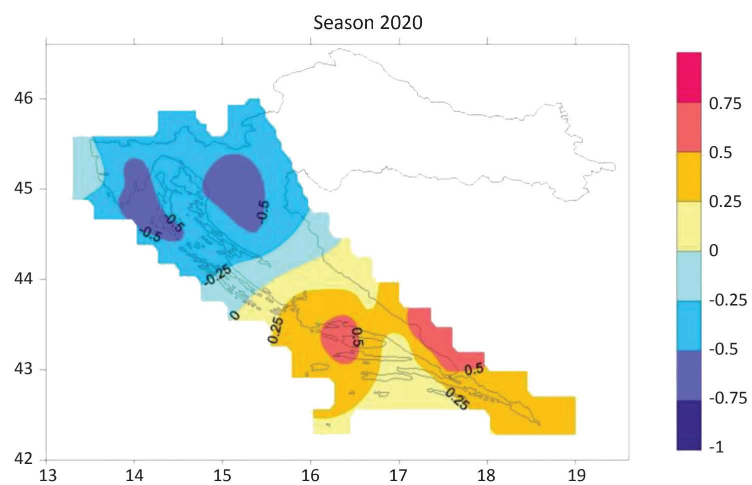

Figure 7. Deviations from the monthly mean vegetation fire threat class for the 2020 fire season, in comparison with the ten-year average (period 2003–2012) by Mokorić et al. (2020).

direction and the sparse and non-uniform distribution of precipitation, there were also appearances of instabilities within the relatively dry air mass. When the threat class was high or very high in combination with this described synoptic situation, then warnings were issued based on specific criteria with regard to the speed and direction of wind shifts, and the values of the Haines index as an indicator of dry air instability.

From 1980 to 2012, the FWI increased for Europe as a whole particularly in southern and eastern Europe (Venäläinen et al. 2014). The fact that the burnt area of the Mediterranean decreased over the same period suggests that fire management and suppression efforts in this region had some effect (Turco 2016). This is also seen in the data for Croatia, particularly for the 2020 fire season. Figure 8 shows the average burnt area, where the trends are positive in the sense of a reduction of the average burnt area over the past decade, with one prominent deviation in 2017, which was an above-average warm and dry year.

Figure 9 shows the clear influence of humans, regarding the intentional burning, with the aim of improving soil fertility. This is performed outside the fire season, usually in February and especially in March. These fires are associated with agricultural areas or on lands with non-forest vegetation. In some isolated cases, these fires can burn for days. From the aspect of combustible materials, these fires do not have a strong potential to spread, nor are they characterised by the same intensity as forest fires during the forest season. However, the practice of burning these fires has remained a common practice in the Mediterranean bioclimatic area. For example, most of the damage in Bosnia and Herzegovina occurred early in the 2019 season, between February and April. In total there were 144 fires over 30 ha mapped in the year, which burnt a total of 28,937 ha. The distribution of burnt area by land cover shows that most of the land was forest/wooded land (60%), followed by natural land (27%) and agricultural land (13%) (European Commission 2020). These trends can be a serious threat to fire spreading during the warmer part of the year, and to the further use of the agricultural land in the intended way. Under controlled conditions, these fires undoubtedly have a positive effect on arable lands, though it is important that they are not burnt during the fire season (Eales et al. 2018). New agricultural policies should be better aligned with forest and fire policies, promoting, for instance, livestock grazing and agroforestry whenever possible with other efficient tools to reduce fuel

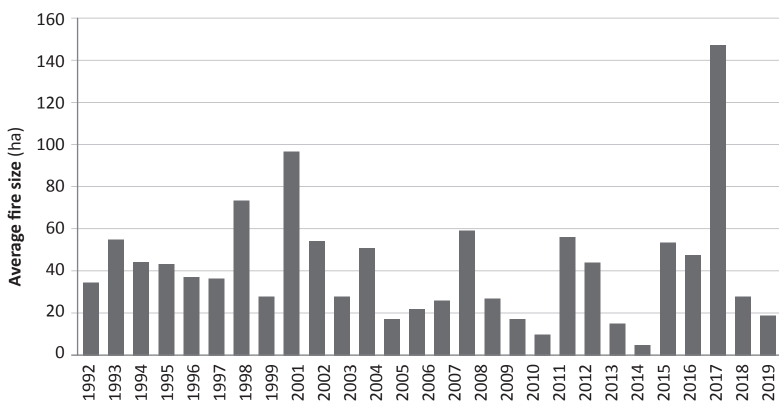

Figure 8. Average fire size in Croatia from 1992 to 2019 (Source: Directorate for Forestry, Hunting and Wood Industry, Ministry of Agriculture, Croatia; National Protection and Rescue Directorate, Croatia).

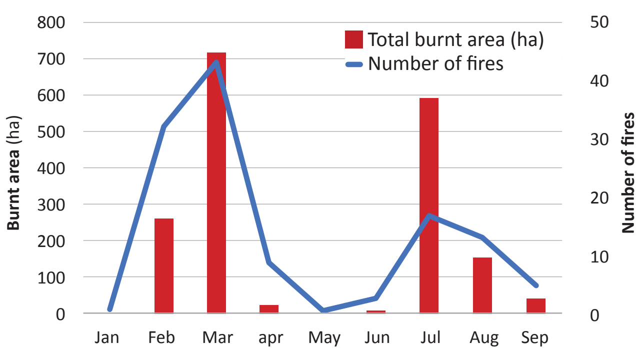

Figure 9. Monthly distribution of fires in 2019 (Source: Directorate for Forestry, Hunting and Wood Industry, Ministry of Agriculture, Croatia; National Protection and Rescue Directorate, Croatia).

biomass, such as prescribed burning (Ganteaume et al. 2021). Some authors have explained this technique in the following way. Prescribed burning is a land management technique that uses fire in a planned and supervised way over a predefined zone, without endangering adjacent areas. This ancient practice, often employed to clear land for agricultural and pastoral use, has become a modern tool for wildfire prevention by controlling the level of combustible materials on the ground. Prescribed burning is also used to maintain landscapes and open environments, to improve the habitat of fauna (particularly hunted species), to regenerate land in the aftermath of farming and to carry out thinning operations (Delattre 1993, Goldammer 1994). In Croatian Adriatic coast there are still problems with abandoned terraces as fuel storage of forest fuel.

Prescribed burning for wildlife in southern Europe is far less developed than in other areas of the world, and the environmental implications remain poorly understood (Fernandes et al. 2013).

Almost all Mediterranean countries have adopted measures to increase public awareness of forest fires, and the focus is nearly always put on accidentally caused fires. The target is the adult public - residents or tourists - located in areas of risk. School children are also the target of specific programmes (Calabri 1986); in Croatia there is a very useful programme of Croatian Agrometeorological Society called Agrometeorological mosaic for youth (2016 – until nowadays): "The fire, fierce enemy of the forest", including an animated film and a comic "The fire is not a joke" (https://www.hagmd.hr/projekti/2016/94).

According to Alexandrian et al. (2000), the management of forests for the prevention of fires is carried out in a very similar way throughout the Mediterranean basin. It is based on the creation of tracks, firebreaks and water reserves. The estimated social and economic costs of wildland fire are known to be huge, but are largely unquantified (FAO 2007 in Flannigan et al. 2009). Direct suppression costs would easily be in the many billions of dollars. Wildland fires can have many serious negative impacts on human safety (Viegas 2002).

Furthermore, for the countries in southern Europe, particularly Mediterranean countries, it is necessary to note the climate factor that is critical for the fire regime. According to some authors (Moreira et al. 2012), abandoned lands and forestation of former agricultural lands are the main reason for the accumulation of combustible materials, and a potential connection of larger areas in the landscape to create fires of greater dimensions. This claim, however, is only partly justified, since it only pertains to abandoned and overgrown agricultural lands. For forest lands or agricultural lands that have been directly planted or have indirectly become forested (through succession), there is an important difference. Forest plantations, most often pine plantations, just as perennial agricultural crops, contain higher quantities of combustible materials. However, it is key whether or not those forest plantations have an intended goal, as prescribed in the forest management plan. With a specific goal and management in those plantations, forestry silvicultural works (cleaning and thinning) must be performed. These works ensure high quality stands, with lower quantities of dry dead fuel. When these forest stands are further opened with forest roads and trails, this can mean an important difference in relation to those areas that are left to natural succession and to overgrown agricultural lands.

Adequate fire protection requires measures of surveillance and monitoring using new technologies, including remote sensing (satellite monitoring, video surveillance, thermal cameras, unmanned aerial vehicles, e.g., drones). The use of other new technology, such as geographic information system (GIS) and remote sensing have largely facilitated the monitoring and supervision of fires. GIS is a computer system that combines geographic data with other types of data and displays them on maps. The use of GIS increases the speed and quantity of data processing and display. Remote sensing is a method of collecting and interpreting information on distant areas without the need for any physical contact. Aircraft, satellites and space probes are typical platforms for observation in remote sensing.

Operational methods of mapping burnt areas include ground-based or airborne global positioning system (GPS) surveys and interpretation of post-fire aerial photography or satellite imagery (Kolden and Weisberg 2007, Zell and Kafka 2012). According to Thomas and McAlpine (2010), fire detection could be established by passive detection (based on the random travels of the public over the area of interest), organised detection (systematic detection designed by fire-management organisations to locate fires where they occur), fixed detection (takes the form of fire towers or lookouts strategically positioned across a landscape) and aerial detection (involves flying aircraft along set lines across a landscape searching for fires, where planes fly at altitudes of 600–1500 m at specific times of the day to maximise detection probability).

MODIS (Moderate Resolution Imaging Spectrometer) is a highly sensitive instrument carried on the Terra and Aqua satellites. This instrument records the Earth's surface in a range of wavelengths from 0.4 to 14.4 µm in 36 channels, with a spatial resolution of 250, 500 or 1000 m. MODIS detects fires based on an algorithm that uses radiation data in the 11 µm (precisely 11.03 µm) wavelength channel and the T11 temperature channel (Figure 2, 3, 4), and the 4 µm (precisely 3.959 µm) wavelength channel with accompanying T4 temperature channel. The use of new technology is desirable in all cases, even though it is unable to influence the number of fires, because the dominant factors continue to be climate and human activity. The justification of their use is seen in the rapid detection of fires, enabling a quick setting up of fire protection systems, a rapid response and arrival to the site and localisation of the fire, which ensures minimal burnt area. According to the data of the Croatian Firefighting Association (for 2020), the average fire-fighting session for vegetation fires in the Mediterranean part of Croatia is approximately 3 hours and 37 minutes, and for Croatia as a whole it is approximately 2 hours and 33 minutes. It is also important to state that this includes the time until the complete extinguishing of the fire, which also includes the time of guarding the entire fire area after localisation, when the majority of the fire-fighting personnel have returned to the station or rerouted to other fire sites. In a preventive sense, fire modeling and the development and integration of fire behavior, fuel treatment and fire suppression strategies into one model have recently been present (Konoshima et al. 2008, Bettinger 2010).

CONCLUSIONS

In the Mediterranean bioclimatic area, wildfires are primarily caused by human activities and climatic conditions. In years marked with extreme drought or extremely hot summers, these conditions are correlated with a high number of fires and large areas affected by the fire. In Croatian Adriatic 2020 fire season was above average in comparison with the period of 2010 to 2019, indicating that there were more fires and more area burnt than during the ten-year average. However, burnt area index (BAI) is less than five-year average (2015-2019). The key point was probably the year 2017. with the extremely hot summer and drought.

Even under such conditions, the fire season can be well organised with systematic reaction to fire. This is primarily facilitated by the use of new remote sensing technology with the existing systems of surveillance and monitoring, and the application of technical works in agriculture and forestry that enable openness and access to large complexes, and reduce the quantity of dry combustible matter. Forest fires are essential for many global ecosystems, and a smaller part of the forest ecosystem needs fire for forest renewal, and in the control of insect infestation and disease. In fire prevention, prescribed burning is a method used by firefighters to reduce the build-up of fuel to reduce future fire intensity. However, frequent and large-scale fires have negative impacts on air quality and water quality, biodiversity, soil and landscape aesthetics. Forest fires also threaten the attempts to mitigate climate change, due to the release of large amounts of greenhouse gases, and they can also cause economic damage and loss of human life in populated areas. Fire risk depends on many factors including climatic conditions, which is particularly significant in the Mediterranean region. Climate change is expected to have a strong impact on forest fire risk in Europe, as recognised by the EU strategy on adaptation to climate change (European Commission 2021).

Author Contributions

Conceptualization, DB; methodology,TD and DB; validation RR and DB; formal analysis, MA and DB; investigation, DB; resources, DB and TD; writing—original draft preparation, DB; writing—review and editing, DB and MA; visualization, MA; supervision, TD and RR. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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The Most Important Parasitic and Saprophytic Fungi on Flowering Ash (*Fraxinus ornus*) in Parks of Serbia and Montenegro

Aleksandar Vemić[1,*]

(1) University of Belgrade, Faculty of Forestry, Department of Forest Protection, Kneza Višeslava 1, RS-11030 Belgrade, Serbia

*** Correspondence:** e-mail: aleksandar.vemic2@gmail.com

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ABSTRACT

In order to fulfil the gap in domestic literature about biotic causes of flowering ash (*Fraxinus ornus*) decline in urban conditions, this paper presents the results of a five-year investigation of the most important parasitic and saprophytic fungi on this tree species in parks of Serbia and Montenegro. In total, 21 fungal taxa were recorded. Within recorded taxa, 2 taxa were found on leaves, 1 taxon was found on root, thin branches and bark, while 16 taxa were found on the trunk. On leaves *Ascochyta* spp. was recorded. The most significant fungi were *Armillaria mellea*, *Phellinus igniarius* aff. and *Inonotus hispidus*. Species *Meripilus giganteus* and *Schizophyllum commune* were the main successive fungi and were often found on substrate damaged by the most significant fungi or abiotic disorders. Species *Hymenoscyphus fraxineus* was recorded on single trees, as well as taxon *Neonectria* spp. The majority of recorded taxa, including invasive pathogen *Hymenoscyphus fraxineus* were for the first time found on flowering ash (*Fraxinus ornus*) in Serbia and Montenegro, especially in urban conditions of these countries. Better protection strategies of flowering ash (*Fraxinus ornus*) in this part of the region could be achieved based on these results.

Keywords: decline of park trees; manna ash; mycoses; distribution

INTRODUCTION

Genus ash (*Fraxinus*) contains about 60 species of broadleaved trees and shrubs and it is divided into 7 subsections (Cvjetićanin et al. 2016). Flowering ash (*Fraxinus ornus*) belongs to subsection *Ornus* and represents its typical species with flowers terminally or laterally in paniculate inflorescences on young twigs (Cvjetićanin et al. 2016). The species is autochthonous and a heliophyte; it belongs to sub-Mediterranean flora, grows in thermophilic oak forests, thermophilic bushes and occurs on dry, shallow soils (Cvjetićanin et al. 2016, Šeho et al. 2019). Also, flowering ash (*Fraxinus ornus*) is a bio-meliorative and decorative species (Jovanović 2007).

In domestic literature, there is almost no data about fungal causes of decline for this ecologically important tree species. Also, research that investigates mycoflora of this tree species is rare even in foreign literature (Farr and Rossman 2016). So far, new research about the occurrence of parasitic and saprophytic species on genus ash (*Fraxinus*) in this part of the region has mostly been directed to common ash (*Fraxinus excelsior* L.) (Vemić and Milenković 2018, Karadžić et al. 2019, Vemić 2020) and narrow-leaved ash (*Fraxinus angustifolia* Vahl) (Keča et al. 2017, Karadžić et al. 2019). Besides multiple benefits of flowering ash (*Fraxinus ornus*), there is a need for investigation of its mycoses because the other two autochthonous ash species in Europe are endangered by fungus *Hymenoscyphus fraxineus* (Kowalski) Baral, Queloz & Hosoya (Bakys et al. 2009, Gross et al. 2014), which causes greater ecological pressure to this tree species.

The main purpose of the research was to identify the most important parasitic and saprophytic species associated with the decline of flowering ash (*Fraxinus ornus*) trees in parks of Serbia and Montenegro. This way, knowledge about the decline of flowering ash (*Fraxinus ornus*) in urban areas is gained and can serve later as a basis for investigation of this tree species' mortality in natural stands, especially due to climate change or intensive urbanization. Obtained results enable creating new or the improvement of the existing protection strategies for flowering ash (*Fraxinus ornus*) in this part of the region based on knowledge about fungal diversity colonizing this tree species.

MATERIALS AND METHODS

Field Methods

Field methods included the examination of terrain and taking samples for laboratory analyses. Terrain examination and taking samples was performed in the period of 2017-2022, 2-3 times a year in a range of 3 months. Terrain examination covered all larger cities in Serbia and Montenegro in search for flowering ash (*Fraxinus ornus*) trees. Special emphasis was put on the cities of Belgrade, Danilovgrad and Cetinje due to a significant number of flowering ash (*Fraxinus ornus*) trees. All trees with visible changes that can resemble mycosis symptoms or on whom visible fruit bodies of fungi were found were used as a sample for determination of fungi. Samples of symptomatic tissues including leaves, bark and branches were taken from symptomatic trees. Optionally, from these trees, fragments of wood or fruit bodies of macrofungi were collected. For taking samples from trees, a knife sterilized in 96% alcohol was used.

Laboratory Methods

Laboratory methods included determination of fungal species from the collected material. Conventional methods of identification based on morphological characteristics were used for the identification of fungi. Observation of fungal morphology was under enlargement of 400x using Am Scope B120 C E1 microscope. Preparation of temporary histological sections and isolation of mycelium from symptomatic tissues for microscopic analyses were conducted according to Muntanola-Cvetković (1990).

For identification of microfungi, descriptions by Ellis and Ellis (1985), Mel'nik (2000) and Kowalski (2006) were used. Some macrofungi were identified based on the morphology of carpophores according to Karadžić (2010). Microscopic identification of macrofungi was made using descriptions by Nobles (1948, 1965) and Stalpers (1978).

RESULTS

Diversity of recorded fungi on flowering ash (*Fraxinus ornus*) trees in Serbia and Montenegro is presented in Table 1.

On flowering ash (*Fraxinus ornus*) trees 21 taxa of parasitic and saprophytic fungi were recorded (Table 1). Whereby, 2 taxa were recorded on leaves, 1 taxon was recorded on root, thin branches and bark, while the remaining 16 taxa of fungi were recorded on the trunk. The most significant fungal taxa found on flowering ash (*Fraxinus ornus*) in parks of Serbia and Montenegro were *Armillaria mellea*, *Phellinus igniarius* aff. and *Inonotus hispidus* (Table 1, Figure 1, Figure 2). The other taxa that colonized the trunk represented successive species, mostly occurring on trees previously affected with the most significant fungi. The most significant was *Schizophyllum commune* and somewhat less significant was *Meripilus giganteus* of these successive species. Succession of fungal occurrence was also expressed on trees damaged by abiotic disorders. Table 2 shows the occurrence of successive fungi according to the condition of substrate.

All taxa of fungi were found in both investigated countries except the species *Hymenoscyphus fraxineus*, which was found only in Montenegro. *Hymenoscyphus fraxineus* was recorded only on one tree and it was isolated from necrotic leaf rachis (Figure 3). Also, necrosis was visible on one young green twig, but it was not isolated (Figure 3). Taxon *Neonectria* spp. caused more damage (Figure 3). Based on symptoms and laboratory analyses the fungus was identified up to the genus level.

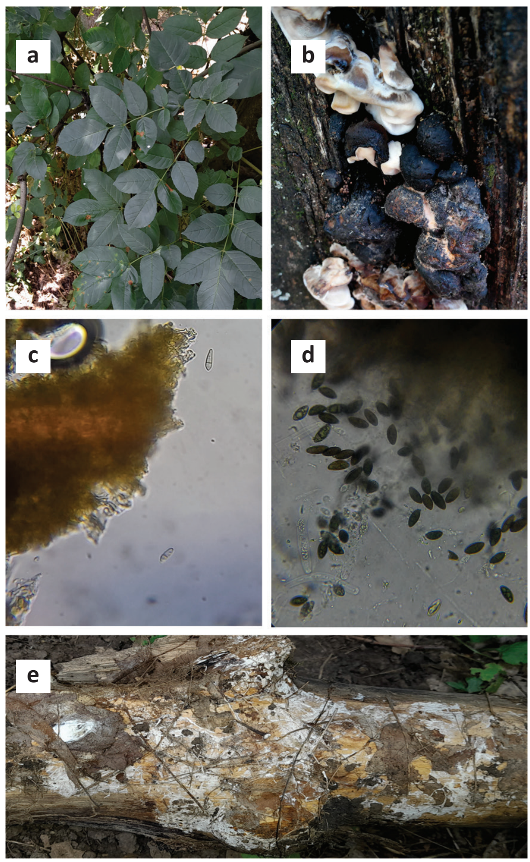

Figure 1. Fungi recorded on flowering ash (*Fraxinus ornus*): **(a)** *Ascochyta* spp. Symptoms; **(b)** *Bjerkandera adusta* and *Hypoxylon* spp. (old fruit body); **(c)** *Ascochyta* spp. part of pycnidium and conidia (pycnospores); **(d)** - *Hypoxylon* spp. ascospores; **(e)** *Armillaria mellea*.

Table 1. Fungi recorded on flowering ash (*Fraxinus ornus*) in Serbia and Montenegro.

Taxon of fungus	Part of tree	Recorded morphological characteristics
Ascochyta spp.	Leaves	Pycnidia 120 µm, epiphyllous, light brown Conidia hyaline, septate, ellipsoid, ends round, 6-10 x 2-3 µm
Armillaria mellea (Vahl. ex Fr.) Kummer	Root	Pileus 2-11.5 cm, stipe 5-1.5 cm, anulus 3-9 mm, hymenophore lamelloid Basidia 30 x 6.5 µm, cystidia 15 x 8 µm, spores hyaline 7 x 6.5 µm, Marginal and aerial hyphae 1-4 µm
Bjerkandera adusta (Willd.) P. Karst.	Trunk	Basidiocarps 3-4 cm, grey, hymenophore poroid Basidia 9-13 x 2-3 µm, Cystidia absent, Spores hyaline 4-5 x 3 µm, Marginal hyphae 2-5 µm, Aerial hyphae 2-5 µm
Botrytis cinerea Pers.	Little twigs	Conidiophores hyaline, spherically, up to 2 mm Conidia in clusters, hyaline, round 8-14 x 7-9 µm
Exidia spp.	Trunk	Basidiocarps 5-50 cm, black, soft, resupinate, hymenophore poroid Basidia septate, 16 x 9 µm, Cystidia absent, Spores hyaline 14 x 5 µm
Fomes fomentarius (L.) Fr.	Trunk	Basidiocarps 10-50 cm, grey, zonate, hard, hymenophore poroid Basidia 20-30 x 10 µm, Cystidia absent, Spores hyaline 19 x 6-7 µm, Marginal hyphae 1.5-5 µm, Aerial hyphae 2-3 µm
Ganoderma applanatum (Pers.) Pat.	Trunk	Basidiocarps 20-40 cm, dark brown, upper surface dull, hard, hymenophore poroid, dark zones between layers Basidia 11-15 x 6-8 µm, Cystidia absent, Basidiospores 7-9 x 5-6 µm, brown, Marginal hyphae 2-9 µm, Aerial hyphae 1-2 µm
Hymenoscyphus fraxineus Baral, Queloz, Hosoya	Leaves	Apothecia were not recorded. Phialides dark, up to 24 µm, phialoconidia 3-4 x 2-2.5 µm, first forming conidium was clavate 7 x 2.5 µm
Hypoxylon spp.	Trunk	Stromata grey, black when old, hemispherical. Ascospores dark brown, 15 x 7 µm
Ischnoderma spp.	Trunk	Basidiocarps 12-15 cm, fleshy, concentric, brown and black Basidia 12-18 x 6 µm, Cistidia absent, Spores hyaline 6 x 2 µm, Marginal and aerial hyphae 2-5 µm
Inonotus hispidus (Bull.) Karst.	Trunk	Basidiocarps 10-16 cm, hirsute, reddish-orange to reddish-black, hymenophore poroid, yellowish-brown Basidia 20-27 x 9-11 µm, Cistidia absent, Setae 24 x 8 µm, Spores brown 8-10 x 6-8 µm, Marginal hyphae 1-9 µm
Meripilus giganteus (Pers.) P.Karst	Trunk	Basidiocarps 6-30 cm, circular, young fleshy and hard when old, grey to ochraceous Basidia 25-40 x 7-8 µm, Cistidia 20-40 x 6-8 µm, Spores hyaline 6-7 x 5-6 µm, Marginal and aerial hyphae 2.5-7 µm
Neonectria spp.	Bark	Stromata red, perithecia 300 µm, spores hyaline, septate 9-18 x 4-7 µm
Omphalotus olearius (DC.) Singer	Trunk	Basidiocarps flashy, yellow to orange, pileus 5-10 cm, stipe 4-10 x 1-3 cm, anulus absent, Spores hyaline 5-7 x 5-7 µm
Polyporus squamosus (Huds.) Fr.	Trunk	Basidiocarps 10-30 cm, laterally stipitate, reniform and circular, azonate, flaky, hymenophore poroid, white Basidia 40-70 x 9-12 µm, Cystidioles 20-35 x 6-8 µm, Spores hyaline 14-17 x 5-6 µm, Marginal hyphae 2-6 µm, Aerial hyphae 3-6 µm
Pleurotus spp.	Trunk	Basidiocarps 9-10 cm, pileus brown-grey, soft, hymenophore lamelloid Basidia 50 x 8 µm, Cystidia absent, Spores hyaline 10 x 4 µm
Phellinus igniarius aff.	Trunk	Basidiocarps 8-20 cm, sessile, grey, hard, margin concolorous, hymenophore porid, pale brown Basidia 9-13 x 6-7 µm, Cistidia absent, Setae 14-17 x 4-6 µm, Spores hyaline 5-6.5 x 4-6 µm, Marginal hyphae 2-6 µm, Aerial hyphae 1-3 µm
Schizophyllum commune Fr.	Trunk	Basidiocarps 3-5 cm, semi-sessile, shelly, curved rim, grey, hirsute, hymenophore lamelloid, brown Basidia 40-55 x 7-10 µm, Cistidia absent, Spores hyaline 6-7 x 2 µm, Marginal hyphae 2-4 µm, Aerial hyphae 1.5-6 µm
Stereum hirsutum (Willd.) Pers.	Trunk	Basidiocarps resupinate or semi-resupinate, zonate, ash grey, slightly hirsute, hymenophore poroid, yellow Basidia 30-45 x 3.5-4.5 µm, Cistidia absent, Spores hyaline 6 x 2.5 µm
Trametes hirsuta (Wulf.) Pil.	Trunk	Basidiocarps 4-7 cm, effused, hirsute, white or light grey, zonate, hymenophore poroid, white or grey Basidia 15-22 x 5-7 µm, Cystidioles 12-18 x 3-5 µm, Spores hyaline 6-9 x 2-2.5 µm, Marginal hyphae 2-4 µm, Aerial hyphae 3-9 µm
Trametes versicolor (L.) Lloyd	Trunk	Basidiocarps 4-7 cm, sessile, in clusters, concentric, motley, hymenophore poroid, pores angular Basidia 15-20 x 5-6, Cistidia absent, Spores hyaline 5-6 x 2 µm, Marginal hyphae 3-4 µm, Aerial hyphae 2-3 µm

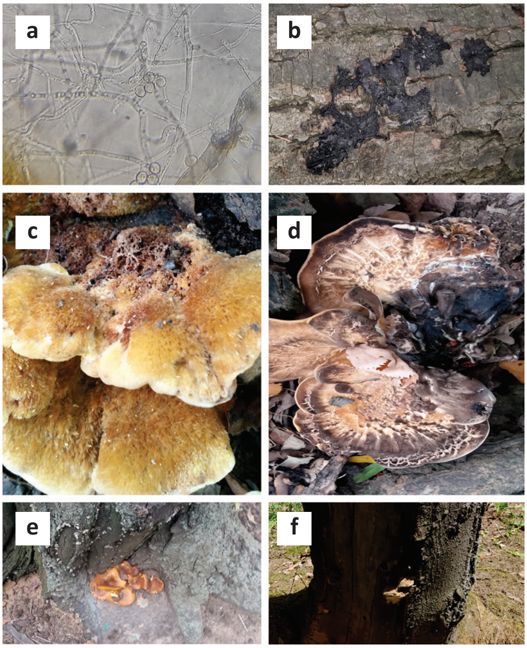

Figure 2. Fungi recorded on flowering ash (*Fraxinus ornus*): **(a)** *Botrytis cinerea*; **(b)** *Exidia* spp.; **(c)** *Inonotus hispidus*; **(d)** *Meripilus giganteus*; **(e)** *Omphalotus olearius* and *Schizophyllum commune*; **(f)** *Phellinus igniarius* aff.

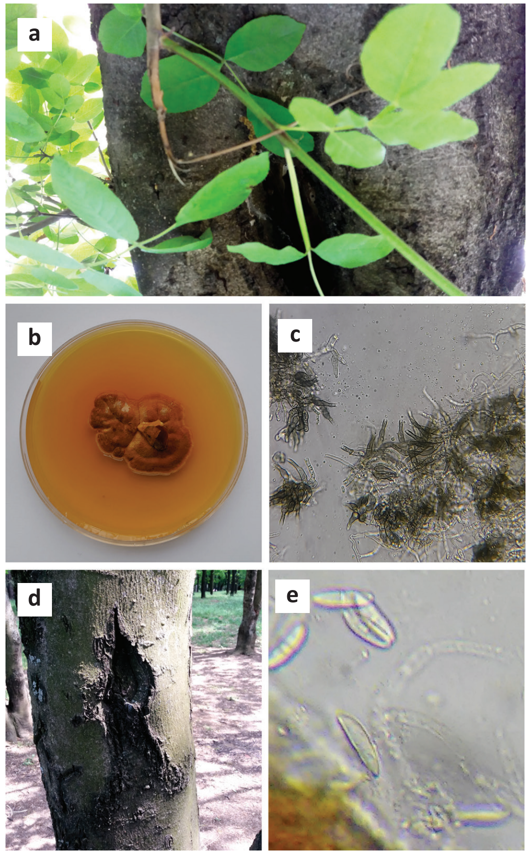

Figure 3. Fungi recorded on flowering ash (*Fraxinus ornus*): **(a)** *Hymenoscyphus fraxineus* symptoms; **(b)** *Hymenoscyphus fraxineus* culture; **(c)** *Hymenoscyphus fraxineus* phialides and phialoconidia; **(d)** *Neonectria* spp. symptoms; **(e)** *Neonectria* spp. ascospores (mature and immature).

Table 2. Occurrence of successive fungi according to the condition of substrate.

Damaging cause	Condition of substrate	Recorded fungal taxon
Snow	Breakage	*Exidia* spp. *Pleurotus* spp.
Wind		*Schizophyllum commune* *Stereum hirsutum*
Unknown	Stumps	*Ischnoderma* spp. *Meripilus giganteus* *Omphalotus olearius*

DISCUSSION

This research showed in detail the diversity of parasitic and saprophytic fungi on flowering ash (*Fraxinus ornus*) trees in urban conditions of Serbia and Montenegro. The majority of found taxa were recorded for the first time on flowering ash (*Fraxinus ornus*) in this part of the region. Further molecular analyses are needed to closely identify and confirm all recorded fungal taxa in this study, particularly *Ascomycota* and *Basidiomycota* fungi within certain species complexes or those fungi that were impossible to identify to the species level based on morphological characteristics due to old, dry and damaged fruit bodies.

Problems regarding the decline of trees species from genus *Fraxinus* in Europe culminated through the occurrence of fungus *Hymenoscyphus fraxineus*. Flowering ash (*Fraxinus ornus*) can also be affected with this fungus (Kirisits and Schwanda 2015), although damaging consequences are much less frequent because the fungus is limited to leaves and surrounding tissues (Kirisits 2017). Confirmed presence of fungus *Hymenoscyphus fraxineus* on flowering ash (*Fraxinus ornus*) in this part of the region has great importance for understanding the distribution and ecology of this pathogen.

Considering that fungus *Hymenoscyphus fraxineus* causes the decline of leaves on flowering ash (*Fraxinus ornus*) (Kirisits 2017), being familiar with the diversity of other fungi occurring on them has significant importance in defining decline progress. Spots on the leaves of flowering ash (*Fraxinus ornus*) in this part of the region were possibly caused by *Ascochyta* spp. The presence of *Venturia fraxini* Aderh. which also has two-celled spores, but which are bigger and light brown instead of hyaline spores of *Ascochyta* spp. (Ellis and Ellis 1985), has not been confirmed for now. Also, fruit bodies of *Venturia fraxini* are perithecia (pseudothecia), unlike pycnidia of *Ascochyta* spp., and only the anamorph of this fungus colonizes living leaves (Ellis and Ellis 1985). Fungus *Venturia orni* Ibrahim, Schlegel & Sieber morphologically similar to *Venturia fraxini* (Ibrahim et al. 2016) also was not found. This points to further investigation of fungal diversity in natural stands in order to confirm the presence of these species, especially using molecular methods. It is assumed that air pollution in urban areas influenced the absence or markedly reduced presence of these species considering susceptibility of leaf pathogens to the external environment (Kowalski 2013).

Bark necrosis and further damages as a consequence of their development have great significance in urban conditions in reducing ornamental value of trees (Tello et al. 2005). This research showed the presence of *Neonectria* spp. on the bark of flowering ash (*Fraxinus ornus*) trees. Difficulties in sampling tissues due to tree cutting and age of necrosis excluded more detailed analyses. Previous research demonstrated that species *Neonectria punicea* (J.C.) Schmidt Castl. & Rossman caused bark necrosis on common ash (*Fraxinus excelsior*) in cases where bark had been previously damaged (Karadžić et al. 2020). Since bark damages in urban conditions are frequent due to different causes, it is assumed that this species was also present on flowering ash (*Fraxinus ornus*) trees in parks of Serbia and Montenegro.

Decay of trees also has great importance in urban conditions (Tello et al. 2005). However, due to their different bioecological characteristics in urban conditions, lignicolous fungi that cause heart rot and have hard fruit bodies are less frequently distributed (Vasaitis 2013). This theory was confirmed by this research, but also, at some level, there were exceptions from this rule. This can be explained due to the proximity of typical forest ecosystems near the investigated park trees.

Finally, pathogenicity tests are recommended for certain *Ascomycota* fungi recorded in this study, primarily *Ascochyta* spp. and *Neonectria* spp. to evaluate their role in flowering ash (*Fraxinus ornus*) trees' decline in urban conditions.

The obtained results enable adequate protection strategies in parks with flowering ash (*Fraxinus ornus*) trees in this part of the region. Identification of the most important fungal species associated with diseases of trees potentiate taking such protection measures that will decrease or eliminate their presence.

CONCLUSIONS

This study identified 21 taxa of parasitic and saprophytic fungi on flowering ash (*Fraxinus ornus*) trees in parks of Serbia and Montenegro. Results and conclusions that follow from them can be presented as following:

- On flowering ash (Fraxinus ornus) trees 21 taxa of parasitic and saprophytic fungi were recorded. On leaves 2 taxa were found, 1 taxon was found on the root, thin branches and bark, while 16 taxa were found on the trunk. The majority of taxa were found for the first time on flowering ash (Fraxinus ornus) trees in Serbia and Montenegro, especially in urban areas.
- Invasive pathogen *Hymenoscyphus fraxineus* was for the first time recorded on flowering ash (*Fraxinus ornus*) in Montenegro. This represents one of the southernmost findings of this fungus and has great significance in studying ecology of this fungus. It is considered that *Hymenoscyphus fraxineus* is also present on flowering ash (*Fraxinus ornus*) in Serbia due to more favorable ecological conditions for this fungus.
- The most significant species were *Armillaria mellea*, *Phellinus igniarius* aff. and *Inonotus hispidus*. The other taxa occurred less frequently or successively, causing smaller damages to trees.
- Recommended protection strategies are focused on regulating a mixture of tree species in parks and local forest stands as well as lowering damages of trees because many fungal species found in this research also colonize other tree hosts.

Author Contributions

Author AV designed the research, performed field investigations, laboratory analyses and wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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A Conceptual Framework for Conservation and Management of Moroccan Forest Genetic Resources Using Biogeography-Based Approach

Kamal Laabou[1,2*], Mohammed Fekhaoui[1], Laila Saafadi[3]

(1) Mohammed V University in Rabat, Scientific Institute of Rabat, Geophysics, Natural Patrimony and Green Chemistry Research Center, Geo-Biodiversity and Natural Patrimony Laboratory, Avenue Ibn Batouta, PB 703, 10106, Rabat, Morocco; **(2)** National Agency for Water and Forests, 3 Rue Harroun Errachid, Rabat, Morocco; **(3)** University Hassan II of Casablanca, Faculty of Science and technology of Mohammedia, Laboratory of Process Engineering and Environment, Mohammedia, PB 164, Morocco

*** Correspondence:** e-mail: laaboukamal@gmail.com; kamal_laabou@um5.ac.ma

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ABSTRACT

The introduction of mal-adapted genotype is a major concern in conservation and management of forest genetic resources. This is risky because it potentially threatens the integrity of the natural genetic structure of populations. Therefore, it is necessary to provide guidance on the choice of appropriate germplasm and determine how far it can be moved from its native environment. The most basic guidelines for germplasm movement involve the use of Regions of Provenance (RoP). The RoP for a forest species or sub-species is the area or group of areas subject to sufficiently uniform ecological conditions in which stands or seed sources showing similar phenotypic or genetic characters are found, taking into account altitudinal boundaries where appropriate. However, there is little information concerning Regions of Provenance and limited knowledge about safe limits to the movement of seed, cuttings and planting stock in Morocco. This paper establishes a conceptual framework based on Regions of Provenance that is designed to better understand, protect and use forest genetic resources in Morocco, especially the species for which no specific knowledge on local adaptation or no data about population differentiation are currently available. This is the first study that represents a precise map of Regions of Provenance for Moroccan forest reproductive material and that provides detailed description on topographical, environmental and forest characteristics that characterize each Region of Provenance, by using geographical information system (GIS) techniques. A biogeography-based approach was applied and revealed that the territory was hierarchically organized into 2 Biogeographic Divisions, 9 Biogeographic Units and 19 Regions of Provenance. The RoP proposed are intended as a practical provenance decision-making tool to guide the movement of forest reproductive material in Morocco. This ensures the traceability of planting stock throughout the harvesting-seedling production-plantation process to a specified Forest Basic Material.

Keywords: region of provenance; local provenancing; germplasm movement; forest reproductive materials; seed transfer guideline; provenancing strategy

INTRODUCTION

Forests are the most important reservoirs of biodiversity in terrestrial ecosystems. They offer a wide variety of products and services. Maintaining genetic variation of this unique and irreplaceable repository is vital, not only now, but also for the future generations.

Forest genetic resources (FGR), which represent the heritable materials contained within and between forest plant species (FAO 2002), are at the root of sustainable forest management, providing the basis to safeguard their health (EUFORGEN 2021). Moreover, they are essential for the adaptive capacity and the evolutionary processes of forests (FAO 2014b). Their genetic diversity, both inter and intraspecific, promotes survival and good growth while at the same time enhances resilience and resistance to biotic and abiotic stresses, such as environmental variations, including those caused by climate change (Dawson et al. 2009, Pautasso 2009, Schueler et al. 2012) or pests and diseases (Schweitzer et al. 2005, Cardinale et al. 2012).

Due to its privileged position between oceanic, continental and Saharan influences, Morocco is of the largest biodiversity hotspot in the Mediterranean Basin after Turkey (Medail and Quezel 1997, MEMEE 2009). It has a very rich natural heritage, 39 terrestrial ecosystems, including 30 forest ecosystems covering an area of approximately 9 million hectares, among which 5.8 million hectares corresponds to wooded forests (HCEFLCD 2016). The identified terrestrial ecosystems are home to more than 4,200 vascular plant species and subspecies, including more than 800 endemic ones (Fennane et al. 1999, Fennane et al. 2007, Fennane et al. 2014). The climate is Mediterranean across the greater part of the territory, but it is strongly influenced by the ocean (Sauvage 1963, Achaal et al. 1980).

The Moroccan forests provide environmental, economic and social functions valued at 17 billion dirhams per year. In addition to its role in protecting the environment and combating desertification, the forestry sector also participates in the socio-economic development of rural populations. It generates an annual value of about 5 billion dirhams to users, who represent nearly half of the rural population. The activities undertaken annually in the sector create eight to ten million working days (the equivalent of 50,000 permanent jobs). Moreover, the forestry sector contributes to 30% of the country's needs in lumber and industrial wood (600,000 $m^3 \cdot year^{-1}$), 18% of the national energy balance (4 million tons of oil equivalent), 4% of the world supply of cork (150,000 quintals$\cdot$year^{-1}) and 17% of the needs of livestock for forage (equivalent to 15 million quintals of barley) (DEF 2020).

However, in view of the alarming levels of degradation of natural ecosystems, it is particularly urgent to conserve forest genetic resources in Morocco (Cauvin et al. 1997).

The conservation of these resources aims to preserve groups of genotypes or populations and their various combinations of genes (Gregorius 1991) by maintaining conditions where the genetic composition of a species can continue to evolve in response to changes in its environment (Eriksson 2001). It was also the reason why FAO has launched a global plan of action for the conservation, sustainable use and development of forest genetic resources in 2014 (FAO 2014a).

The introduction of nonlocal and potentially maladapted genotype is a major concern in conservation of forest genetic resources. A number of studies have shown that in most cases, using locally adapted populations not only preserves alleles that are adapted to local conditions but also prevents numerous dangers regarding the introduction of non-local material (Kawecki and Ebert 2004, Bischoff et al. 2006, Urban et al. 2008, Bischoff et al. 2010). These include the disruption of genotype frequencies across geographic areas, the introduction of genes poorly adapted to local conditions, the fixation of maladapted genotypes due to genetic drift, impaired ability to adapt to future environmental change and potential threats to the integrity of the natural genetic structure of populations (Jones 2013). The transfer of germplasm has also raised concerns, such as the potential for spreading pests and diseases (Koskela et al. 2014). Several authors argued that the use of local materials reduce outbreeding depression and genetic swamping in natural populations (Hufford et al. 2003, Crémieux et al. 2010, Vander Mijnsbrugge et al. 2010).

In addition, it has been shown that local plants performed significantly better than foreign plants at their site of origin (Leimu and Fischer 2008, Hereford 2009), because they have higher fitness, higher levels of survival, reproduction, productivity, disease resistance and abiotic resilience than non-local materials.

However, the use of "local" germplasm is hampered by the lack of knowledge concerning the question "how local is local?" (McKay et al. 2005). Thus, there is a need for guidance on the choice of appropriate germplasm for forest restoration in Morocco, and also for determining how far it can be moved from its native environment.

The most basic guidelines for germplasm-movement involve the use of Regions of Provenance (RoP). This is an essential tool currently used in forestry practice to manage forest genetic resources (Carolina 1998). An additional benefit of RoP is that they contribute to maintaining genetic diversity and structure of forest trees at landscape scales that are likely most important for adaptation (St Clair 2014). The use of well-adapted provenances can give many advantages, from survival rate to growth rate (O'Neill and Aitken 2004).

"Local-is-best" is the pivotal assumption that has given rise to the delineation of Regions of Provenance (De Kort et al. 2014). This means that, even with limited or no knowledge of genetic structure of a species, a reasonable assumption is that native populations are at least relatively adapted to their local environments (Savolainen et al. 2007).

The definition of Regions of Provenance has been discussed by several authors (e.g. Burley et al. 1976, Zobel and Talbert 1984). According to the definition published by the Organization for Economic Cooperation and Development (OECD 1974, OECD 2019), the RoP for a forest species or sub-species can be defined as following: "the area or group of areas subject to sufficiently uniform ecological conditions in which stands or seed sources showing similar phenotypic or genetic characters are found, taking into account altitudinal boundaries where appropriate".

The definition of Regions of Provenance is not only scientific, it is, first of all, a legal instrument (Camerano et al. 2012). Following several countries' regulations, the Regions of Provenance are a compulsory tool for the management of forest genetic resources; thus, the country must create its own map of RoP, according to the ecological variability of its environment, its administrative structure and its most valuable forest species (Marchi et al. 2016).

Establishing Regions of Provenance is an important tool in the implementation of the scheme for the certification of forest reproductive material moving through international trade (OECD 2019). All the activities connected to the nursery process and reforestation (e.g. forest reproductive material, forest basic materials), must be linked to the RoP (Marchi et al. 2016).

However, there is little information concerning Regions of Provenance and limited knowledge about safe limits to the movement of forest reproductive material in Morocco. No previous study has mapped and described RoP in detail. Currently, no precise tools are available to restoration actors to minimize maladaptation in forest plantations. Therefore, given the huge environmental variability of Morocco

(Benabid 1982b), there is a demand for guidelines on the movement of forest reproductive material that (1) regulate the movement between donor origin and restoration site, and (2) are practical and operationally manageable.

The objectives of this paper were: (i) to present a conceptual framework that is designed to help researchers, practitioners and administrators to better conserve and manage Forest Genetic Resources in Morocco and (ii) to show the delineation, mapping and description of the Regions of Provenance through a biogeography-based approach that can be used as a guide for specifying sources and control movement of forest reproductive material (FRM).

This study presents the first delineation that shows precise mapping of Regions of Provenance for forest reproductive material and provides detailed key information about topographical, environmental and forest characteristics that characterize each Region of Provenance, by using geographical information system (GIS) techniques, with accurate geospatial data and long time-series climate dataset.

MATERIALS AND METHODS

Study Area

The study area corresponds to the kingdom of Morocco. Located in the extreme north-western part of the African continent between 21° and 36° north latitude and between the 1° and 17° west longitude (Figure 1), Morocco covers a surface area of 710 850 km^2 (HCP 2018).

Conceptual Basis

To establish the Regions of Provenance, two main approaches are generally used: associative and partitive (CTGRF 1976). The associative method mainly takes into account the genetic parameters of populations; it groups the stands of a species with similar genetic structure to form a region of provenance (Kleinschmit et al. 2004). This method can be used when a large amount of information on genetic variation is available on a considerable number of populations, in order to ensure sufficient representativeness. Due to this difficulty, most of the national systems use the partitive method.

The partitive method divides the country into disjoint ecologically homogeneous regions for all species. Therefore, each portion of the territory is necessarily included in a region of provenance**.** The major advantage of this method is that it defines the same regions for all the species under consideration (García del Barrio et al. 2001)**.** Usually a divisive method has been applied to the delineation of regions of provenance, using geographical and ecological information (Auñón et al. 2011). In this study the second approach was applied due to the scarcity of genetic information on Moroccan forest species and their populations.

Delineation and Mapping Procedure

We used the partitive method to establish the regions of provenance, as adopted in similar studies (CEMAGREF 2003, BFW 2017, UKFC 2017).

Firstly, the division was carried out from the forest regions of Morocco, which are described as relatively large units of land sharing large similarities in physical, topographical and

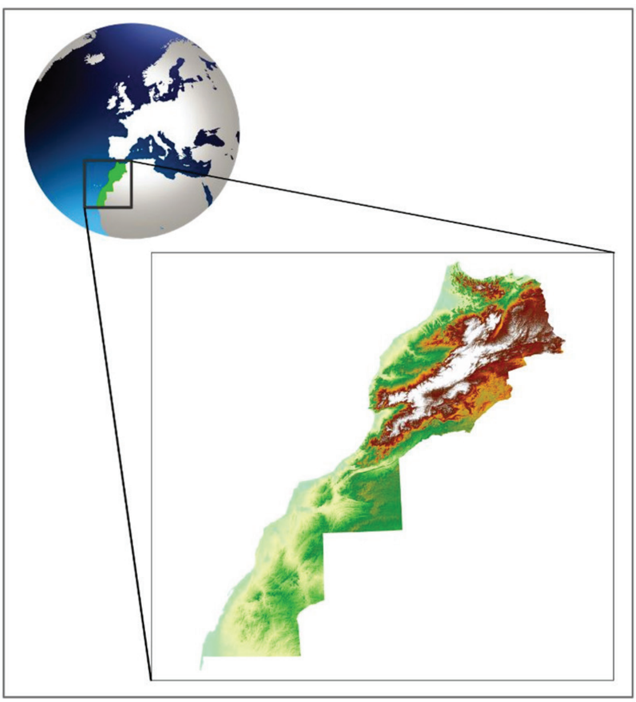

Figure 1. Map of the study area, showing the location of Morocco in the world map.

forest characteristics. This major homogeneous regions were used as fundamental biogeographic units (BgU) serving as a basis for the establishment of the regions of provenance.

However, the BgU are largely to be considered as areas with identical or similar ecological conditions. Therefore, the resulting map of fundamental biogeographic units were, secondly, used to establish Regions of Provenance, subject to sufficiently uniform ecological conditions. In other terms, the polygons of the biogeographic units were split into ecological homogeneous sub-polygons. Then, in order to establish a practical and easily usable tool, the boundaries of RoP have been chosen to follow natural or physical features.

Lastly, we classified RoP using a coding system that includes a two-digit number, with ascending order number from Northwest to Southeast. The first digit written in Roman numerals system designates the biogeographic units within the country, when the second written in Arabic numerals system identifies the RoP within the biogeographic unit.

Features Description

Following the OECD guidelines (OECD 2019), we have delimited the Regions of Provenance by means of geographical boundaries and established maps showing the boundaries of this RoP with their biogeographic units. We have also characterized each RoP by means of most important topographical, environmental and forest characteristics.

Climate is generally considered a useful indirect indicator of genetic variability (De Dato et al. 2018). It represents the most important driving force behind the spatial distribution of forest species, and reliable time series are one of the more valuable dataset for forest monitoring (Ferrara et al. 2017). For this reason, based on the RoP's maps created, the polygons obtained were employed with a long-term (30-year) averages of climate data (temperature and precipitation), to characterize the environmental variability within the RoP, by using a GIS software.

Spatial and Climatic Datasets

To map and characterize the environmental variability of Regions of Provenance, we used and processed the data listed below.

Elevation data: the ASTER digital elevation model (DEM) was used to retrieve the altitude. The data (spatial resolution of 30 m) are publicly available at https://lpdaac.usgs.gov.

Bioclimatic data: to perform the description of climate variability, we considered climate data of a reference period that precedes the climatic disturbances currently observed, using averages from 30 years (1960-1990 climate normal). The data was downloaded from Worldclim dataset (Hijmans et al. 2005), available at http://www.worldclim.org. This dataset provides interpolated current climate layers (for the climate period 1960-1990), for each bioclimatic variable based on historical data with a resolution of 30 arcsec (cell of ≈ 1 km^2). The following six bioclimatic variables were considered to characterize climate in each RoP (Table 1).

Topographic data: in addition to the open access online topographic map collections (https://www.lib.utexas.edu), the maps used were acquired from other official databases of the administrative units.

Physical features: general morphological settings such as prevalently mountainous chains, plains, plateaus and valleys were obtained from the Scientific Institute of Rabat database. Additional information from other sources covering the whole national territory (Michard 1976, El Gharbaoui 1987, Michard et al. 2008, MATUHE 2009) were also compiled.

Administrative data: were acquired from the Moroccan High Commission for Planning. The data are available at https://www.hcp.ma.

Biogeographical features: the forest descriptions for the whole country (Boudy and Guinier 1958, Nanson 1995, AEFCS, 1997) represent the basic information for the geographical and ecological characterization of BgU and RoP. The national forest inventory produced for the country (NFI 2005) served as a basic database to collect information on major forest plant species, and was supplemented with more detailed contributions (DEFCS 1978, Benabid 2000).

Data Processing and Analysis

To achieve the objectives of this study, the open source Geographic Information System Quantum-GIS software (QGIS ver. 3.22) was used for the implementation, visualization, processing and analysis of geospatial data and the long time-series climate dataset.

Table 1. Complete list of bioclimatic variables used to describe climate in RoP.

Raster layer	Unit	Acronym
Mean annual temperature	°C	MAT
Mean maximum temperature of the warmest month	°C	MMTWM
Mean minimum temperature of the coldest month	°C	MMTCM
Mean annual precipitation	mm	MAP
Mean precipitation of wettest month	mm	MPWM
Mean precipitation of driest month	mm	MPDM

RESULTS

Conceptual Framework

The basis for the delineation of the biogeographic units were the Moroccan forest regions, which have been identified based on their homogeneous characteristics (physical, topographical and forest). The delimitation of this regions depended largely on the natural distribution of the major species, especially with regard to forest climatological differences. These forest regions were then adjusted and disaggregated into Regions of Provenance with similar ecological conditions, based on expert judgment and knowledge of the local prevailing characters that can protect natural patterns of intraspecific biodiversity. Subsequently, in order to simplify practical implementation, the exact borders of the resulting regions of provenance have been chosen to follow natural features, such as great rivers (Moulouya, Souss, Drâa) and valleys, or physical features, such as roads, highways and railroads.

This procedure resulted in a final number of 19 Regions of Provenance concentrated in 9 biogeographic units as shown in Table 2.

Regions of Provenance Delineation

Using Geographical Information System techniques, the Regions of Provenance recognized in the present study have been mapped, as well as the biogeographic regions in which they are located. The maps of the resulting BgU and RoP are shown, respectively, in Figure 2 and Figure 3.

Regions of Provenance Description

The geographic location, administrative distribution and concise description of geography, landforms and climate of

Table 2. Hierarchical arrangement of Biogeographic Units and Regions of Provenance in Morocco.

Biogeographic unit	Region of provenance	Acronym		Code	
		BgU	RoP	BgU	RoP
Rif		RBgU		I	
	Atlantic Rif		ARRoP		I.1
	Western Rif		WRRoP		I.2
	Eastern Rif		ERRoP		I.3
Eastern Lands		ELBgU		II	
	Moulouya Plain		MPRoP		II.1
	High Plateaus		HPRoP		II.2
Atlantic Plain		APBgU		III	
	Maamora		MARoP		III.1
	Central Plateau		CPRoP		III.2
Middle Atlas		MABgU		IV	
	Western Middle Atlas		WMARoP		IV.1
	Eastern Middle Atlas		EMARoP		IV.2
	Steppic Middle Atlas		SMARoP		IV.3
Meseta		MBgU		V	
	Atlantic Meseta		AMRoP		V.1
	Continental Meseta		CMRoP		V.2
High Atlas		HABgU		VI	
	Western High Atlas		WHARoP		VI.1
	Central High Atlas		CHARoP		VI.2
	Eastern High Atlas		EHARoP		VI.3
Souss		SBgU		VII	
	North Souss		NSRoP		VII.1
	South Souss		SSRoP		VII.2
Presahara		PSBgU		VIII	
	Presahara		PSRoP		VIII.1
Sahara		MSBgU		IX	
	Sahara		MSRoP		IX.1

Abbreviations: BgU – biogeographic unit, RoP - region of provenance.

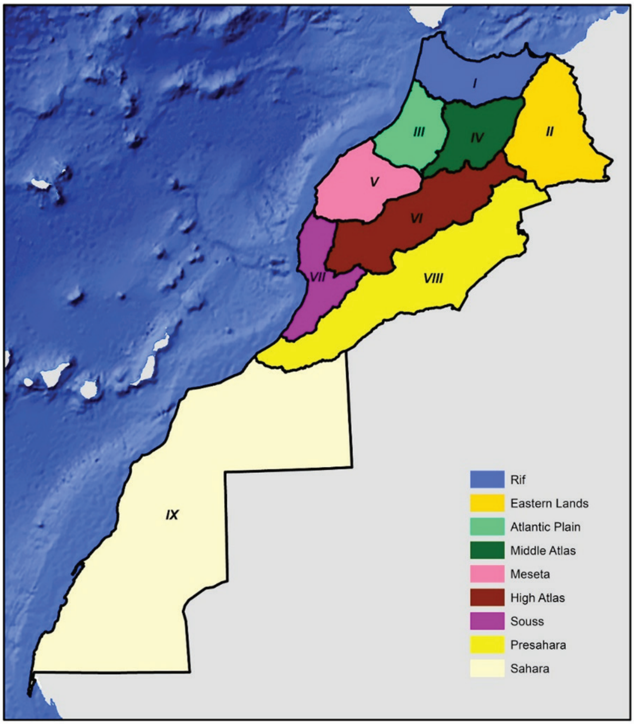

Figure 2. Map of Biogeographic Units of Morocco produced in this study.

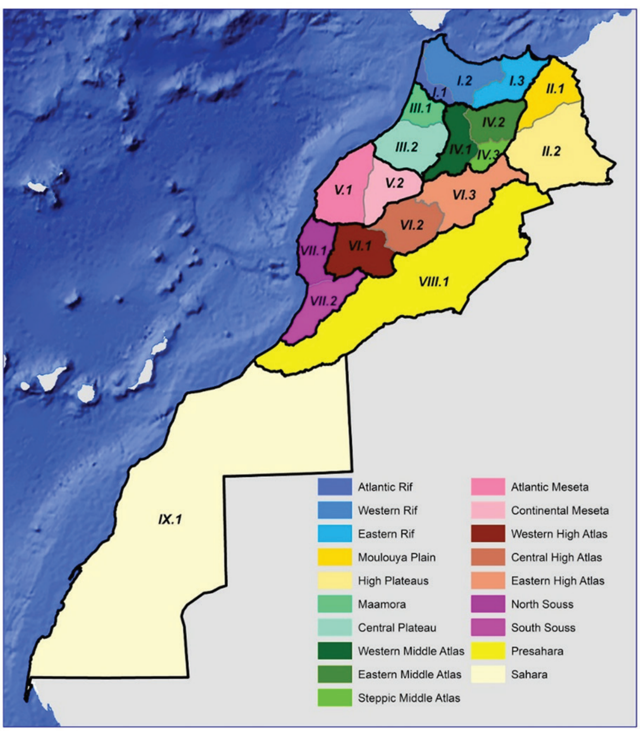

Figure 3. Map of the Regions of Provenance of Morocco produced in this study.

the 9 Moroccan biogeographic units, are presented below. The Regions of Provenance within each biogeographic unit are described by means of a synthetic table with the most important topographical, environmental and forest characteristics.

The Rif biogeographic unit occupies the northernmost part of Morocco and extends east to the Moulouya River. The unit forms a coastal mountainous area. It covers an area of 41 250 km^2 (i.e. 5.8% of the national territory) and straddling several administrative regions: Tanger-Tétouan-Al Hoceima (43%), Oriental (25%), Fès-Meknès (24%) and Rabat-Salé-Kénitra (8%).

It is the most watered biogeographical unit in Morocco and benefits from two oceanic facades, one on the Mediterranean Sea and the other on the Atlantic Ocean. There is a marked contrast in climate according to Emberger's quotient (Emberger 1930). While the west belongs to the humid (typically found in the Rif chain) and sub-humid bioclimatic stages, the east falls within the semi-arid and arid bioclimatic stages.

The privileged geographical situation gives the Rif a climatic originality which, combined with the regional orographic and geological diversity, favoring great ecological wealth (Benabid 1982a).

The Rif biogeographic unit contains the three Regions of Provenance described in the Table 3 below.

The Eastern Lands biogeographic unit starts from the Moulouya River and extend to the easternmost part of Morocco, over an area of 58 700 km^2, representing 8.26% of the national territory. Two administrative regions are concerned: Oriental (91%) and Fès-Meknès (9%).

The two regions of this unit (see Table 4) are distinguishable from each other based on their biophysical attributes: the generally sparsely forested plains in the north and the High Plateaus Steppic landscapes in the south. From an orographic perspective, except for the northern part with a wrinkled topography, particularly in the Beni Snassen Mountain and Horst Chain, most of the land is generally tabular.

The whole of the Eastern Lands unit belongs to the arid bioclimatic stage of Morocco according to Emberger's quotient (Emberger 1930). The presence of a few isolated semi-arid patches is mainly limited to the mountain ranges of Beni Snassen, Gadat Debdou and Zekkara.

The Atlantic Plain biogeographic unit is bordered by the Rif chain to the north, the Atlas chain to the east, the Atlantic Ocean to the west, the meridional Meseta to the south-east and the phosphate plateaus to the south-west. The area covered is 29 800 km^2 (i.e. 4.19% of the national territory), including several administrative regions: Rabat-Salé-Kénitra (56%), Béni Mellal-Khénifra (20%), Casablanca-Settat (17%), Fès-Meknès (8%).

The northern and southern parts of this unit have distinct form of land topography. To the north, the Rharb-Mamora plain represents a vast enclosed depression without pronounced topographic features, with a lower altitude. In the south, with the exception of the low coastal fringe, the central plateau forms tabular mountains (Beaudet 1969), which progressively gain altitude towards the western edges of the Atlas Mountains.

Climatically, the Atlantic Plain is relatively homogeneous due to its geographical location between two natural barriers, the Rif and Atlas mountain ranges. Aside from the mountainous part of the central plateau and the northern coastline fringe, which belong to the sub-humid bioclimatic stage, the large portion of lands belongs to the semi-arid stage, with a small arid patch at Maaziz.

This biogeographic unit is subdivided into two Regions of Provenance (Table 5).

The Middle Atlas biogeographic unit separates Atlantic Morocco from arid Eastern Morocco. It is bordered north by the South-Rifan corridor, south by the High Atlas, east by the Moulouya river valley and west by the Atlantic Plain. This unit is completely continental and has an area of 34 600 km^2, representing 4.87% of the country's surface area. Several administrative regions are included: Fès-Meknès (70%), Béni Mellal-Khénifra (13%), Oriental (10%), Draa-Tafilalet (7%).

Table 3. Topographical, environmental and forest characteristics of the Rif Regions of Provenance.

	Atlantic Rif	Western Rif	Eastern Rif
Area (km^2)	6 150	19 700	15 400
Part of Morocco (%)	0.86	2.77	2.17
Average elevation (m)	100	564	547
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 18.5 33.3 6.2 672 125 0	 16.5 31.9 4.2 737 125 1	 16.8 32.0 4.4 392 62 2
Major forest plant species	*Quercus suber* L., *Quercus coccifera* L., *Ceratonia siliqua* L., *Pinus pinaster var. atlantica* H. del Villar, *Pinus pinea* L.	*Abies maroccana* Trab., *Cedrus atlantica* Manetti, *Tetraclinis articulata* (Vahl) Mast., *Pinus nigra var. mauritanica* Maire & Peyerinhoff, *Pinus pinaster var. maghrebiana* H. del Villar, *Pinus pinaster var. Iberica* H. del Villar, *Pinus halepensis* Mill., *Quercus suber, Quercus pyrenaica* Willd., *Quercus rotundifolia* Lam., *Quercus faginea* Lam.	*T. articulata, P. halepensis, Pistacia atlantica* Desf., *Juniperus phoenicea* L., *Q. rotundifolia*

Table 4. Topographical, environmental and forest characteristics of the Eastern Lands Regions of Provenance.

	Moulouya Plain	High Plateaus
Area (km^2)	17 400	41 300
Part of Morocco (%)	2.45	5.81
Average elevation (m)	835	1 231
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 15.4 31.2 2.6 303 42 3	 15.8 34.7 0.6 257 34 4
Major forest plant species	*T. articulata, Acacia gummifera* Willd., *J. phoenicea, P. atlantica, Q. rotundifolia, Q. coccifera, P. halepensis, Stipa tenacissima* L., *Artemisia herba-alba* Asso.	*S. tenacissima, Artemisia inculta* Delile., *Atriplex halimus* L., *Chamaecytisus albidus* (DC.) Rothm., *Rosmarinus officinalis* L.

Table 5. Topographical, environmental and forest characteristics of the Atlantic Plain Regions of Provenance.

	Maamora	Central Plateau
Area (km^2)	17 400	41 300
Part of Morocco (%)	1.32	2.87
Average elevation (m)	122	570
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 18.8 33.7 6.8 546 102 0	 16.9 33.6 3.7 521 86 1
Major forest plant species	*Q. suber, J. phoenicea, T. articulata*	*Q. suber, Q. rotundifolia, T. articulata, C. siliqua, P. atlantica*

The western and eastern part of the Middle Atlas, which respectively corresponds to the pleated and tabular Middle Atlas called Middle Atlas Causse by Henri (1937), are separated by the major tectonic accident known as the "North-Middle Atlas" (Colo 1961).

There is a marked contrast in climate between sides of the mountain range. The northern and western sides, which are open to the Atlantic, are more watered, while the southern and eastern sides receive much less water and are subject to intense insolation and evaporation. The mountain stops the clouds rising from the ocean on its Atlantic side and places the eastern side in the "rain shadow", which increases the continental character of the Moulouya plain and reduces the rainfall significantly.

In climate terms, the sub-humid and humid bioclimatic stages are the most predominant. The arid bioclimatic stage is located in the steppe portion.

The Middle Atlas biogeographic unit is composed of three Regions of Provenance. Their topographical, environmental and forest characteristics are shown in Table 6.

The Meseta biogeographic unit covers an area of 39 200 km^2 (i.e. 5.51% of the national territory), including the plains, plateaus and massifs that are located between the Atlantic plain, the Atlas and the Souss biogeographic units. It extends over the administrative regions of Marrakech-Safi (44%), Casablanca-Settat (43%) and Béni Mellal-Khénifra (13%).

In general, the Meseta plains have a subdued topography, a level surface and a fertile soil with high agricultural potential. These plains can be distinguished into two categories: the sub-Atlantic plains (Chaouia, Abda, Doukkala, Bahira) and the continental plains (Tadla and Haouz).

The plateaus are regularly inclined from north to south, between the altitudes of 1 000 and 600 m, and include those of the Phosphates and the Ganntour. The massifs have a generally moderate altitude with an East-West direction, and concern the Rehamna (less than 700 metres altitude) and the Jbilete (culminating around 1 000 m altitude).

Table 7 shows the Meseta Regions of Provenance and its corresponding description.

The High Atlas biogeographic unit occupies 9.30% of the landmass of Morocco (i.e. 66 100 km^2). Several administrative regions are covered: Draa-Tafilalet (43%), Béni Mellal-Khénifra (22%), Marrakech-Safi (21%), Souss-Massa (9%), Oriental (2%) and Fès-Meknès (2%).

It mainly extends over the High Atlas mountain chain, which forms a 800 km long and 40 to 80 km wide barrier. This unit is bordered northwest by the Continental and Atlantic

Table 6. Topographical, environmental and forest characteristics of the Middle Atlas Regions of Provenance.

	Western Middle Atlas	Eastern Middle Atlas	Steppic Middle Atlas
Area (km^2)	14 800	13 700	6 100
Part of Morocco (%)	2.08	1.93	0.86
Average elevation (m)	1 186	1 132	1 399
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 14.4 33.5 -0.1 641 93 6	 14.4 32.8 0.2 397 55 6	 14.0 33.0 -0.5 293 40 7
Major forest plant species	*C. atlantica, Q. rotundifolia, Q. faginea, T. articulata, P. pinaster var. maghrebiana, P. halepensis, Juniperus thurifera* L.	*C. atlantica, P. pinaster var. maghrebiana, P. halepensis*	*Q. rotundifolia, J. phoenicea, S. tenacissima*

Messeta, northeast by the Western and Steppe Middle Atlas, east by the High Plateaux, south and southwest by the Pre-Sahara, and west by the South Souss RoP.

From west to east, there are increases in drought. The Western High Atlas is the highest and wettest segment of the entire range, including Mount Toubkal (ranging to over 4 167 m). However, generally lower altitudes and a drier climate, particularly in its eastern limit at the contact with the high plateaus of Eastern Morocco, characterize the Eastern High Atlas.

The characteristics of the High Atlas Regions of Provenance are shown in Table 8.

Table 7. Topographical, environmental and forest characteristics of the Meseta Regions of Provenance.

	Atlantic Meseta	**Continental Meseta**
Area (km^2)	22 900	16 300
Part of Morocco (%)	3.22	2.29
Average elevation (m)	248	486
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 18.1 31.5 6.3 331 57 0	 18.4 36.4 4.3 372 62 1
Major forest plant species	*P. atlantica, J. phoenicea, A. gummifera, C. siliqua*	*A. gummifera*

Table 8. Topographical, environmental and forest characteristics of the High Atlas Regions of Provenance.

	Western High Atlas	**Central High Atlas**	**Eastern High Atlas**
Area (km^2)	20 300	19 100	26 700
Part of Morocco (%)	2.85	2.69	3.76
Average elevation (m)	1 403	1 624	1 747
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 14.2 31.9 -1.0 439 62 3	 14.0 34.6 -2.2 432 62 4	 13.4 34.2 -2.4 369 51 7
Major forest plant species	*Argania spinosa* (L.) Skeels, *Q. rotundifolia, T. articulata, Cupressus atlantica* Gaussen, *J. phoenicea, P. halepensis, J. thurifera, C. siliqua, Juniperus oxycedrus* L.	*Q. rotundifolia, T. articulata, P. halepensis, P. pinaster var. maghrebiana, J. oxycedrus, J.phoenicea, J. thurifera, C. siliqua*	*Cedrus atlantica, Q. rotundifolia, Q. faginia, J. thurifera, J. phoenicea, T. articulata, P. halepensis, P. pinaster var. maghrebiana, C. siliqua, S. tenacissima*

The Souss biogeographic unit is the most original unit of all North Africa in terms of ecology and forestry (Boudy and Guinier 1958). It is bordered to the north by the Jbilete massif and the Mouissate plateau, to the east by the High Atlas and the Anti-Atlas chains, to the south by the Oued Noun Valley and to the west by the Atlantic Ocean.

With an area of 31 500 km^2, which represents 4.43% of the country's surface area, this unit falls within the semi-arid and arid bioclimatic stages and extends across three administrative regions: Sous-Massa (55%), Marrakech-Safi (33%), and Guelmim-Oued Noun (11%).

The terrain is characterized by step-like topography. The Haha and Ida-Outanane high plateaus dominate the septentrional part. They gradually descend from the Assif Aït Moussa-Tizi-Machou break in the east, towards the Atlantic Ocean in the west. Further north, the plateaus cedes place to the Chiadma plain. In the south, the Siroua massif connect the High Atlas and the Anti-Atlas chains, to border the Souss plain and protect it from the desert influences of eastern and southern Morocco. The most southerly portion of the unit is occupied by the Chtouka and Tiznit plains. The dunes of marine origin are characteristic of most of the coastal fringe.

The characteristics of each of the two Souss Regions of Provenance are given in Table 9.

The Presahara biogeographic unit occur as band in a Southwest-Northeast direction, from the southern limits of the High Atlas to the northwestern limit of the Moroccan desert. Extending over 15.19% of the country, this unit forms a broad transition between the lands of Mediterranean and Saharan Morocco. The area covered falls within the territory of four administrative regions: Draa-Tafilalet (55%), Sous-Massa (29%), Guelmim-Oued Noun (13%), and Oriental (2%).

The unit falls within the arid and Saharan bioclimatic stages, with a significant difference between the western and eastern parts, which includes, respectively, the Draa and Ziz Rivers watersheds. The eastern one is considerably more desertic.

There are four major landforms. The mountains located in the Anti-Atlasic area, Mount Sagho and Mount Bani. A continuum of Hamada, raised rocky plateaus typical of desert areas, including from North to South: the Guir, Kem-Kem, Daoura, Draa and Touassine Hamadas. Numerous steppic valleys are located at the foot of the mountains, consisting of: the Dadès, Draa, Todgha, Ziz and Guir valleys. One of the most specific landscape feature is the occurrence of an isolated oasis in southeastern portion of this unit, lying in the hollow of the Ghéris and Ziz valleys.

The one Region of Provenance that constitute this unit is described in Table 10.

Table 9. Topographical, environmental and forest characteristics of the Souss Regions of Provenance.

	North Souss	**South Souss**
Area (km^2)	14 400	17 100
Part of Morocco (%)	2.03	2.40
Average elevation (m)	560	666
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 16.2 26.8 5.1 322 53 1	 17.4 29.8 4.8 230 40 1
Major forest plant species	*J. phoenicea, A. spinosa, T. articulata, A. gummifera, C. siliqua, J. oxycedrus, Q. rotundifolia*	*A. spinosa, T. articulata*

Table 10. Topographical, environmental and forest characteristics of the Presahara Region of Provenance.

	Presahara
Area (km^2)	108 000
Part of Morocco (%)	15.20
Average elevation (m)	886
Climate MAT (°C) MMTWM (°C) MMTCM (°C) MAP (mm) MPWM (mm) MPDM (mm)	 19.6 38.9 2.7 129 23 1
Major forest plant species	*A. spinosa, Dracaena draco subsp. ajgal* Benabid & Cuzin*, A. gummifera, Acacia raddiana* Savi*, Acacia ehrenbergiana* Hayne.*, Balanites aegyptiaca* (L.) Delile*, Tamarix articulata* Vahl*, Capparis decidua* (Forssk.) Edgew.*, Faidherbia albida* (Delile) A.Chev

The Sahara biogeographic unit covers an area of 301 700 km^2 and represents consequently the largest biogeographical unit in Morocco. It includes several administrative regions: Laayoune-Boujdour-Sakia Al Hamra (48%), Ed Dakhla-Oued Eddahab (43%) and Guelmim-Oued Noun (9%).

It is characterized by a Saharan climate, which is arid only on some portions of the littoral band where the oceanic influences attenuate it. The aridity become more pronounced further east and south. The rainfall is very little, with less than 42 mm of precipitation a year.

The territory is marked by a notable physical homogeneity. Excluding some major massifs in the northeast (Mount Ouarkziz, Mount Zini and Mount Janfra) and the littoral dune ridge, most of the rest of the territory is principally dominated by the large areas of the Hamadas, with the presence of several depressions (Graara-Maader and Sebkhas).

Table 11 shows the Sahara Region of Provenance and its corresponding characteristics.

DISCUSSION

The delineation of Regions of Provenance is a starting point for the implementation of a national forest resource conservation and management program. It also provides a unified global framework for coordinating the actions of the various forestry actors in the planting process: seed collection, nursery management and plantation operations.

The Regions of Provenance which have been proposed here are delineate areas with sufficiently uniform ecological conditions within which forest germplasm can be moved with limited risk of maladaptation and loss of productivity. The use of the homogeneous forest regions as biogeographic units, which are then partitioned into regions with uniform ecological conditions, has allowed obtaining of the areas subject to sufficiently uniform ecological conditions, taking into consideration the altitudinal gradient, which can be used within Regions of Provenance. It is generally assumed that ecological distance between source and introduction sites is often a better indicator of local adaptation of forest germplasm than geographic distance (McKay et al. 2005, Noël et al. 2011).

The application of a biogeography-based approach in this study revealed that the territory was hierarchically organized into 19 Regions of Provenance concentrated in 9 biogeographic units. The resulting biogeographical units can be aggregated into two biogeographical divisions: Mediterranean and Saharan (Figure 4). A similar division was also proposed by Benabid (2000).

It has also been shown that the Biogeographical Divisions are unequal in terms of the number of BgU and RoP. The Mediterranean Division is represented by 7 BgU, compared to only 2 BgU for the Saharan Division. The highest number of Regions of Provenance was found in the Mediterranean division (18 RoP), when there are only two RoP in the Saharan Division. It is interesting to note that in terms of area, 57% of the national territory (409 700 km^2) is contained in just 2 RoP (Presahara and Sahara).

Another important finding was that three categories of biogeographical units can be recognized depending on the number of RoP: (i) those extending over the Rifan and Atlas Mountains included three RoP, (ii) those with two RoP located on the northwest and northeast sides and (iii) those covering the pre-Saharan and Saharan part of Morocco constituted by a single RoP.

Climatically, the present study shows that the Mean Annual Temperatures ranged from 13.5°C in the Eastern High Atlas RoP to 22°C in the Sahara RoP. In addition, Mean Maximum Temperatures of the Warmest Month reached 39°C within the continental part of Presahara RoP, whereas the Mean Minimum Temperatures of the Coldest Month decreased until the negative value of -2.4°C in the Eastern High Atlas RoP. Thus, Eastern High Atlas was the coldest RoP, while Presahara and Sahara were the warmest. This can be explained by the effect of the high altitude on the Eastern High Atlas RoP and the influence of the Saharan climate on the Presahara and Sahara RoP.

For precipitations, the Mean Annual Precipitations varied between 737 mm and 42 mm, in high mountains of the Western Rif RoP and the Sahara RoP respectively. With a decreasing gradient from north to south, Mean Precipitations of wettest month exceed 125 mm at the Western and Atlantic Rif RoPs, while the mean precipitations of the driest month was less than 1 mm at Sahara, Atlantic Rif, Atlantic Meseta and Maâmora RoPs.

The obtained RoP are intended as a practical provenancing decision-making tool to guide the movement of seed, cuttings and planting stock used for forestry

Table 11. Topographical, environmental and forest characteristics of the Sahara Region of Provenance.

	Sahara
Area (km^2)	301 700
Part of Morocco (%)	42.44
Average elevation (m)	261
Climate	
MAT (°C)	22.0
MMTWM (°C)	34.5
MMTCM (°C)	10.4
MAP (mm)	42
MPWM (mm)	10
MPDM (mm)	0
Major forest plant species	*A. raddiana, Rhus tripartita* (Ucria) Grande, *A. ehrenbergiana, F. albida, B. aegyptiaca, Tamarix articulata, C. decidua, Maerua crassifolia* Forssk

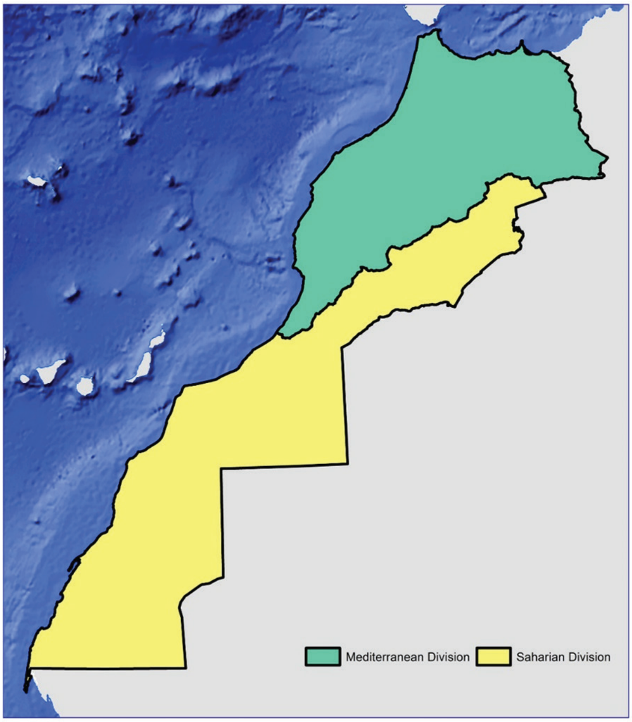

Figure 4. Map of the Biogeographic Divisions of Morocco produced in this study.

purposes in Morocco. They can serve as a unified national framework to better locate seed stands, select seed sources with low risk of maladaptation and plan seed procurement needs for national forestation programmes. This allows ensuring of the traceability of planting stock throughout the harvesting-seedling production-plantation process to a specified source of forest basic material. The RoP obtained from this study can be used also as a starting step for planning breeding or conservation programs.

Thus, the RoP represent a valuable tool for implementing a certification system that ensures the production and use of forest reproductive material in a manner that ensures their trueness to name, such as the scheme established by the Organisation for Economic Co-operation and Development (OECD 2019). Moreover, the adoption of this system will encourage and facilitate international exchange in forest seeds and plants for genetic evaluation and trade.

It is important to note that the RoP defined are not species-specific, but are equally applied to all species, in order to simplify practical implementation. They are destined to be used with species for which no specific knowledge on local adaptation or no data about population differentiation are currently available. The boundaries in these Regions of Provenance maps should not be perceived as lines but rather as large transition zones encompassing a certain degree of risk of maladaptation.

The strengths of our study include the use of expert-based approach mixed with accurate geospatial data and long time-series climate dataset. However, the findings of this study have to be seen in light of some limitations. The Regions of Provenance have been established on the basis of their ecological similarities. Certain criteria were not considered, such as: soil characteristics (compaction, mineral wealth, waterlogging, acidity, salinity, rooting depth, etc.), biotic risks (insect pest attack, fungal pathogen infection, etc.), abiotic risks (storms, forest fire, etc.), human impacts (silviculture, land cover, etc.), microclimate (side effect, frost corridor, etc.) and extreme weather events (heatwave, drought episode, etc.).

More information on intra-specific local adaptation would help to improve the Regions of Provenance established in this study. The use of elevation bands within RoP would also be of interest. We recommend, thus, the establishment of reciprocal transplant studies to better evaluate the establishment, survival, growth and reproduction of ecotypes from each of the RoP defined in a series of common garden test sites within this RoP (Kawecki and Ebert 2004).

CONCLUSION

In order to better understand, protect and use the genetic diversity in the Moroccan's forest trees, this study proposes a conceptual framework based on Regions of Provenance. This system aims to spatially contextualize the actions according to conservation and management of forest genetic resources.

The present study is the first to present a precise map of Regions of Provenance for Moroccan forest reproductive material and provide a detailed description on topographical, environmental and forest characteristics that characterize each Region of Provenance, by using geographical information system (GIS) techniques to manipulate and analyze accurate geospatial data and long time-series climate dataset.

Our suggested Regions of Provenance delineation are equally applied to all species and include 19 Regions of Provenance. Their limits should not be considered as fixed lines, but rather as large transition areas with a certain degree of risk of maladaptation.

The RoP results from this study represent a valuable tool that may help ensure that seeds, cuttings and planting stock used are well adapted to conditions at the restoration sites. However, to better evaluate the establishment, survival, growth and reproduction of ecotypes, we recommend the establishment of reciprocal transplant studies from each RoP at trial sites within each of these RoP. The reciprocal transplant would help to provide more information on intra-specific local adaptation and, thus, provide precise guidelines on transfers of genetic material between separated or adjacent Regions of Provenance.

Finally, we concur with the claim that the development of Regions of Provenance is more art than science, because practical knowledge and experience remains the significant component of the process (Ying and Yanchuk 2006). Using biogeography-based approach simply enables us to have a practical provenancing decision-making tool to guide the spatial movement of forest reproductive material, avoiding loss of productivity and forest health issues caused by maladaptation.

Author Contributions

KL, MF and LS study conception and design, KL and LS data collection, processing and analysis, MF supervised the research and helped to draft the manuscript, KL and LS writing of the manuscript draft, KL and MF checking the references and writing of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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