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Forestry Insights of Some Asian and European Countries: National Forest Harvesting Strategies and New Approaches

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Abstract

As forestry approaches have been formed according to the demands and aspirations of the society, the forest sector implies different concerns such as social, economic, and environmental. Harvesting and extraction of wood at low cost, protection of stands against degradation and changes in land use, proper implementation of afforestation and forest extension, conservation of endemic species, preservation of soil, providing jobs, and supporting national and domestic development have a different priority for foresters, depending on the time and area conditions. Of course, all of these have always been discussed by the shareholders in the forest sector with the main attention to forest sustainability. However, the question is: Are forestry approaches compatible with the changes in the world today? With increasing environmental concerns, as discussed at the Glasgow 2021 Conference, the importance of forests and their protection has doubled, and it seems that forestry practices in the world need a new approach. In addition to climate change, increasing human population and regional and global economic changes affect the use of forests and the form of forest management and utilization. This paper aims to take an analytical look at this issue and examine the current situation in five countries (Iran, Germany, Croatia, Turkiye and Italy). It was also targeted with the help of the DPSIR Framework to elaborate on the social consequences of the situation, and an analysis was presented about what to do or not. This paper emphasizes that forest managers and policymakers need to modify and adapt the plans and methods in a way that is appropriate to the progress of time and its changes, while protecting forests and ensuring their sustainability, limiting non-professionals from involving directly in the decision-making process.

Keywords: Conservation, Climate change, DPSIR, Forest operation, Sustainable forest management, Forest policy.

1. Introduction

The aim of sustainable forest management (SFM) is to ensure that forests supply goods and services to meet both present-day and future needs and contribute to the sustainable development of communities. For these purposes SFM is based on three main criteria and their balanced and synergistic application (Erler, 2017). In wood production, sustainability means conserving resources through wood harvesting, which is equivalent to wood growth. In forest management, sustainability also refers to a steady income (Wildberg and Mohring, 2021). Today, there is no need to argue that forestry plans preserve and protect the resource. However, it must also be acknowledged that any interference in the forest ecosystem, if not reasonably done, can cause disturbances of ecosystem balance and severe damage. It is recommended in almost all the forestry texts to conserve and protect natural resources during forest management operations in a way that allows for maintaining and preserving water and soil resources in accordance with the principles of forest fertility and sustainable forest management (Lotfalian, 2013).

The international community is currently grappling with several social and environmental threats, such as climate emergency, Covid-19, the threat of widespread hunger, and the growing loss of biodiversity. These threats show that sustainable land and forest management is essential (Aggarwal et al., 2021). Biodiversity leads to the resilience of forest ecosystems and forest-based economies and increases the long-term sustainability of forest production (Pukkala, 2022). The goal of Sustainable Forest Management (SFM) as a dynamic and evolving concept is to preserve and promote the economic, social, and environmental values

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of all types of forests for the benefit of present and future generations. SFM provides vital assistance to both people and the planet and responds to climate change (FAO, 2021). A proper monitoring strategy, based on widely recognized criteria and indicators, is crucial in implementing and promoting SFM by providing relevant information for the development and evaluation of forest policies, national forest plans, and programs. It also represents the basis for collecting cross-sectoral data related to forestry and communicating it to the sector and the public. The application of proper monitoring also allows the evaluation and reporting of progress in SFM at the regional and national levels (Forest Europe, 2021). Criteria and indicators (C&I) for sustainable forest management (SFM) need further development and testing at the local level (Mrosek et al., 2006). During the evolution of SFM, governments and other stakeholders have pursued three important frameworks for defining and pursuing SFM: public land forest policies, Criteria and Indicators, and certification (Golec and Lukert, 2008).

However, considering the lack of financial resources and the difference in the level of scientific management of forests in different countries, the question arises whether the best decision is made for the forests in each region. Today, the state of the planet Earth is endangered. Urgent requests for transformational change are increasing. Technical solutions play an important role in addressing global challenges, but they are not enough. In addition, who decides what kind of transformation, what, and for whom it is needed? What principles guide these decisions, and how are decision-makers accountable? (Larson et al., 2021).

Despite worries about the future of the earth, there have been some promising news from the recent Glasgow Climate Change Conference, including the commitment of more than 100 world leaders with around 85% of the world's forests to stop deforestation by 2030 and a 19 billion USD investments to protect and rehabilitate forests. Climate change threatens the stability of forests and the provision of ecosystem services from managed forests. In response, managers are developing climate-friendly strategies that focus primarily on changes in abiotic conditions (Champagne et al., 2021).

In SFM, there is always talk of three principles: environment, economy, and society. In the case one of these principles is ignored, forest sustainability cannot be ensured. It seems that the process of changing management priorities from the beginning of scientific forest management until now has been such that initially, the economic aspect of the issue has been prominent (Steve and Luc, 2010). Ecological aspects and considerations developed with the passage of time and the development of forestry. Also, to better manage and be safe from social and political pressures, the social aspects of forestry must be developed from now on. Thus, discussing conventional forest management versus SFM plays a key role in the political and scientific agenda (Soler et al., 2021).

A vital issue in forest management is to keep it in the hands of forest experts. However, there is a danger that if forest experts make mistakes in their decisions, other policymakers and decision-makers unfamiliar with the forest sector may control the decision-making process. Weiss et al. (2021) provide a tentative definition of "innovation governance" and attempt a state-of-the-art review of innovation governance research in the forest sector (Weiss et al., 2021). They propose distinguishing between organizational/managerial, policy, or innovation studies. The main concern of this paper is to point out what the role of forest harvesting is, how to use equipment, how to apply current knowledge in forest management and how it may be effective in decisions. Shouldn't we think about changing and updating forest management and harvesting at the same time as ecological, economic, and social changes? For this purpose, we will examine the situation further. In particular, this review has been focused on 5 nations as it aims to be an example of the complexity of the problem and the need for a shared way of thinking at a technical and scientific level.

1.1. Harvesting Policy

The harvesting policy is part of the forest management policy that cannot be separated from current world events. Forests provide essential raw materials for human beings, and the demand for these materials has been increasing (Levers et al. 2014). With increasing global demand for wood-based forest products and an understanding of the role of forests while dealing with climate change, forests face new challenges in the 21st century. Harvesting in the forest has significant benefits in providing income and jobs. At the same time, it is necessary to pay attention to other forest services.

Considering the consequences of different management strategies and estimating the economic, environmental, and social performance of different processes, products, or services is an important challenge in forest operations (Schweier et al., 2019). Since the beginning of the 21st century, forest policy and governance have been trying to cope with the emerging challenges for forestry in numerous activities on a national and international level (Krott, 2008).

Defining a government`s forest policy is fundamental since the definition sets the framework in which all forestry activities in the country must be carried out. The most important of the forestry activities affected by a country`s forest policy may be categorized as (1) conservation, protection, administration, management, and utilization of forests, (2) environmental protection, and (3) forest industries and marketing of forest products. However, it must be emphasized that the ultimate purpose of a forest policy is to benefit society, not trees, land or products (Husch, 1987).

More in detail, harvesting policies can also be generalized as fixed and adaptative (Zhou et al., 2008). Normally, the fixed policies are more common than adaptive policies. A fixed harvesting policy consists mainly in an approach for homogeneous management unit at regular cutting cycles, with minimal exception (De Liocourt, 1901; Arbogast, 1957; Buongiorno and Gilless, 2003). Adaptive harvesting policies foresees that the decisions are tied to the state of the forest and of timber markets. Adaptive resource management is a strategic approach that acknowledges uncertainty and uses it in making decisions (Holling, 1978; Walters, 1986). In theory, adaptive policies are superior to fixed policies, however, they are somewhat more costly to develop and require more information to implement, without considering the difficulties in planning interventions in an integrated manner.

However, in recent years, at the application level, harvesting policies referred to the selection of approaches in planning, cutting, bucking and wood transportation following a sustainable forest approach (Marchi et al., 2018; Sohrabi et al., 2020; Venanzi et al., 2023).

1.2. Forest Harvesting Damage on Soil

Harvest damage is mainly assessed in three ways: damage to the residual stand, natural regeneration, and soil (Picchio et al., 2020b). Since the recovery of the physical, chemical, and biological conditions of the soil and the forest area from the operation of harvesting, in the long term, is difficult, costly, and time-consuming, humans should seek a technique or solution that can reduce these effects (Rab, 2003).

Among these, forest soil, the basis of all the fundamental changes in the forest, is of special importance. The soil and vegetation of the forest are influenced by each other; in other words, they interact (Blinkley and Giardina, 1998). On the other hand, skid trails and strip roads are located directly on forest soil. The paths of wood transported from the stump to the landings are called the skid road. Skid roads may be used by cable skidders and grapple skidders. However, the same infrastructure is usually named as strip road when referring to CTL machinery like forwarders and harvesters (Lotfalian, 2012; Picchio et al., 2020a). In countries where most of their forests are mountainous, ground skidding and cable yarding are the most common ways to extract wood. In these areas, skidding trails may cover about 16 to 25 percent of the total area, depending on the type of machine, topography, and the design of the skidding operations (Murphy 2004). Mechanized ground-based extraction can lead to soil compaction, deep ruts, and soil erosion in skid trails (Wood et al., 2003). As the number of machinery traffic increases, the amount of soil compaction increases, leading to rutting of the skid trails (Lotfalian and Parsakhoo, 2009). Compaction as one of the main types of soil damage, causes the restriction of root growth and reduces water infiltration in soil and production ability. Maybe it can be said, one of the most important effects of harvesting in forests is the compaction and change in soil conditions. For example, the type of machine, soil type, logging method, number of passes, and so on will have different effects on the soil (Lotfalian, 2013). Due to the compaction of the soil, the growth and root development rate decreases, leading to less absorption of nutrients and water and, consequently, the decline of trees growth (Jordan-Lopez et al., 2009). Since the soil in skid trails is displaced by the passes and the soil surface cover is lost, soil erosion in skid trails is far more than intact areas (Trautner and Arvidsson, 2003). Besides, soil compaction reduces the flow of water into the soil and increases the amount of runoff and erosion (Williamson and Neilson, 2000).

Of course, after extraction operations in natural sub-boreal forests managed by single-tree selection cutting, some species, such as Abies sachalinensis (F. Schmidh) Mast. on the disturbed soil and under closed canopy are well regenerated. In fact, the soil disturbance in the path of skidding is a suitable treatment for the regeneration of these trees (Nakagawa and Kurahashi, 2005). Also, the regeneration of Picea abies (L.) H. Karst. easily grows after the selective cutting method in the monoculture of this species, when the light reaches the forest floor and even the skidding roads. On the other hand, there is no precise information on the condition of the establishment of these seedlings in the long term. It depends on the flora and fauna inside the soil and the chance to get oxygen for breathing is essential for these organisms. Compaction is important because it interrupts the tubes and controls the relationship between Carbon dioxide and oxygen in the ground air.

1.3. Harvesting Damage on Residual Stand and Regeneration

Another form of damage in the forest is injury to the remaining trees in the stand and damage to young seedlings, which occur in selective cutting and shelterwood systems (Picchio et al., 2020b). The mechanization level in some cases can influence the damage magnitude species diversity but more other variables participate (Latterini et al., 2023). Some researchers have shown that mechanized harvesting damage on each of the vegetative groups of seedlings, juveniles, and saplings is more than semi-mechanized harvesting damages (Hosseini et al., 2002; Lotfalian et al., 2009; Naghdi et al., 2009), however, in some other studies was showed the contrary (Stańczykiewicz et al., 2015) or founded like only matching machine/equipment type, size and deployment to stand and site conditions damage to regeneration can be limited (Picchio et al., 2020b). Hosseini et al. (2002) observed that the ground skidding in the shelterwood system had damaged more than 20% of the remaining stand (Hosseini et al., 2002). The results of this study indicate that the forest regeneration damage from the whole tree method is more

than tree length and short-wood methods. A specific review paper (Picchio et al., 2020b) found that it is possible to restrict the level of damage to the remaining stand at a low level by using mechanized CTL forest operations. In harvester–forwarder-based thinning, damage ranged from 2% to 15% with maximum level of 20% (Picchio et al., 2020b). In average, a higher share of injured trees can be observed when skidding is used, and it can vary from ca. 10 to 35% with maximum level of 50% (Picchio et al., 2020b). Therefore, to reduce damages to the stand and regeneration, a comprehensive economic and environmental assessment should be undertaken regarding the logging methods.

1.4. Review Focus

Meanwhile, foresters have carried out various activities to minimize harvesting damage, including but not limited to determining the suitable workdays in terms of soil moisture, limiting the slope of skid trails, paying attention to the pressure imposed on the unit area by the machinery, construction of water bars after skidding, use of shielding for the rub trees against the skidding logs.

This paper aims to show the current status of harvesting, the efforts made to achieve a higher degree of sustainability, their strength and weaknesses, providing a qualitative analysis of the harvesting performance using the DPSIR (Drivers, Pressures, State, Impacts and Responses) Framework.

2. Analytical Review

In this section, we aimed to examine the issue of forest harvesting and its effects with an analytical review using the DPSIR Framework. The DPSIR is a framework developed by the European Environmental Agency (EEA) and it is an effective solution to analyzing natural resource problems (Tscherning et al., 2012). It is based on the Drivers, Pressures, State, Impacts, and Responses (Fig 1). Kim et al. (2021) identified global patterns of worsening wildfire risks with the double-exposure to globalization and climate change using the DPSIR Framework.

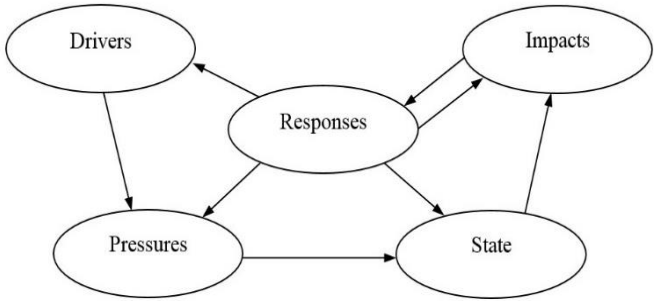

Figure 1. The DPSIR conceptual model.

We do not intend to examine the strengths and weaknesses issue here using the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis method. In fact, our purpose here is to describe the efforts made and the strengths and weaknesses of each of them in some countries in protecting soil and stand in harvesting, to analyze the subject better using the DPSIR Framework.

This review can be somehow considered "non-conventional"; generally, a review paper is based on the current scientific literature in each topic collected within the scientific database. Instead, the present work is based on the authors` knowledge, who are worldwide recognized experts concerning the general situation of the forestry sector in their country. In particular, recent trends and policies adopted in the optic of SFM in the five target countries are described and analyzed using the DPSIR approach. The authors believe this approach was the most suitable to fulfill the goals of this specific review.

2.1. Iran

2.1.1. Limiting the slope of skid trails

One of the actions taken to protect the soil in Iranian mountain forests is to limit the design of skid trails to a maximum slope of 25%. The strengths of this effort are to reduce the risk of skidding on a steep slope by skidder and reducing damage to the soil within skidding routes. However, the weaknesses of this action are more significant. For example, in a slope of 30%, it can easily pass the same gradient and cause the least damage to the soil. At the same time, according to this instruction, it is necessary to have a diagonal path with a maximum gradient of 25% such as a road with excavation, which will significantly cause the soil to be replaced and degraded. It will also increase the unnecessary length of the skid trails and their maze in the forest, which will also cause double damage to the trees and the soil.

2.1.2. Limiting the skidding to dry days

Although there is no specific plan in this subject, using machines during rainy days is prohibited, and the skidders are allowed to pass on skid trails two days after the rain, usually with forester recognition. The strength of this is to prevent soil damage by moving on wet soils. The weak points of this action are not having specific instructions and somewhat depending on personal approaches and being experienced.

2.1.3. Reducing the density of skid trails

Considering the unpleasantness of the view and the negative impact of skidder trails at first glance, even some foresters believe that the less trace is, the better, and they try to have a lower density per unit area. The strength of this approach is to reduce the degradation of the landscape and popular acceptance. Among the weaknesses of this action are gaps in access to the logs, and unauthorized exit of the skidder from the skid trails, followed by widespread destruction of the soil and stand.

2.1.4. Construction of waterbars

One of the other protective activities against soil erosion is the construction of a waterbar across the skidding routes at the end of work. With the flow of water

in the tire tracks on skidding paths on steep slopes, soil erosion has occurred and with the construction of waterbars, water flows out of the paths. One of the strengths of this is the prevention of erosion in skid trails and its weaknesses, leaving the runoff on the forest floor, which can be maintained by the many transverse vertical channels (vertical waterbar) and infiltrates into the soil.

2.1.5. Use of shielding for the rub trees

Along the skidding routes, and especially inside the turns, the shields from the wood or used tires are mounted on the rub trees so that the skidding logs` collision does not injure them. The strength of this idea is to prevent damage in many cases, and its weakness is that it cannot completely prevent damage.

2.1.6. Using animals in steep slopes

In areas with a slope of over 50%, the construction of diagonal skid trails is costly and damaging. On the other hand, winching operations in these areas also have many difficulties. In these slopes, the harvesting method is changed, and the big logs are cut down and converted to traditional dimensions, such as railroad ties, lumbers and carried by animals. Areas with slopes higher than 70% have been announced as protected areas and will not be harvested. The strength of this act is to create the possibility of operation on slopes of 50-70% and full protection on slopes above 70%. The weakness of this act is the cost of cutting the logs into timber with a high wastage percentage (at least 10%), along with decreased work productivity when dealing with extraction via animals. Also, the forest products on slopes above 70% will be unused.

2.1.7. Logging ban

The last effort with the pressure of non-specialists introduced in Iran is a logging ban. Today, due to the importance of climate change, forest degradation, stand quality deterioration, and administrative problems, efforts have been made to protect the forests by NGOs, one of the results of which is the logging ban in Hyrcanian forests in Iran. The strengths of the logging ban were believed to regenerate natural forests, but in practice, it caused more damage due to socio-economic issues (as a weaknesses). A study by Liu and Xia (2021) showed that while the logging quota scheme was effective in halting the country's deforestation and forest degradation from the late 1980s to the early 1990s, it has played a minimal role in promoting forest restoration and regrowth by inhibiting investment in forest management. They suggest the government phase out the scheme, especially in regions with abundant commercial forests.

In sustainable forest management, the harvesting of forests in the form of forestry plans covers the costs of forest maintenance, protects forest areas and prevents conversion to other uses. However, logging ban would result in loss of income, closure of forestry plans, unprotected forests, and subsequent raids of people to smuggle wood and take possession of the areas. Relying on government budgets for forestry management is also misleading because it is temporary and not reliable, and, as stated in the SFM, forests should be managed on a reliance upon their income.

2.2. Germany

2.2.1. Reducing the density of skid roads

One of the efforts taken in the state of Saxony and more other federal states to reduce damage to the soil is to increase the distance between the skid roads from 20 to 40 meters. For this purpose, the trees are cut by harvesters up to the distance that the harvester can reach and at greater distances with the help of chainsaws. Usually, the trees are felled towards the skid road; thus, the harvester can grip the trees from the top and pull them to the machine. In some cases, pre-skidding (winching) is carried out with the help of cable skidders toward the skid roads. One of the strengths of this is to reduce areas under the machine traffic from 20% to 10%. In addition to reducing the dispersion of soil compaction at the field, this act provides a more chance of better establishment of the stand. The weaknesses of this method are higher costs and the concentration of soil compaction in the skid road used.

2.2.2. Definition of working conditions standards

With the help of a planning tool used the Brandenburg state, soil damage must be kept as low as possible from the outset. Two classification systems are matched: technogram and ecogram. For each forest stand, a technogram is developed based on the soil, the moisture, and the value for the forest owner, and it describes the sensitivity of the soil to technical loads. In addition, an ecogram for each timber harvesting process is developed to explain the general conditions under which this method is compatible. Both together make it possible to find the most suitable method for the respective location, the precautionary policy of its owner and the current soil moisture (Fig 2).

For more explanation of fig. 2, the left side is a functiogram of a partly mechanized cut-to-length method with a supporting chain saw that fells the trees on the area between two strip roads where the harvester cannot reach the stems (rows from top down: standing tree - full tree - tree length - cut to length; columns from left to right: in the stand - on the strip road - on the forest road). The right side is technogram of the forest stand (x-axis humidity of the stand from dry to very wet; y-axis indicating the opening-up from down upwards: driving on forest soil without limitation - distance of strip roads 20 m - 40 m - 60 m - no traffic in the stand at all). The colors indicate the individual assessment of the owner (red not accepted - yellow allowed - green favorite - orange special procurement). The red ring marks a given local situation. This technogram is matched with the ecogram of possible working methods, indicating their suitability with blue signs. The star means perfect - plus

good - minus with borderline values. Together, the graphs say that the selected working method fits well (plus) under normal conditions, but after a few days of dry weather (left column with sun), it will be perfect (star).

The strengths of this act are to make it easier and logical to diagnose working conditions regularly and plan accordingly. The likelihood of soil damage can be reduced before the machine starts working. It means that forest management does not only react to situations that occur during the working process but foresees possible accidents and avoids them using a compatible working method (Erler et al. 2023).

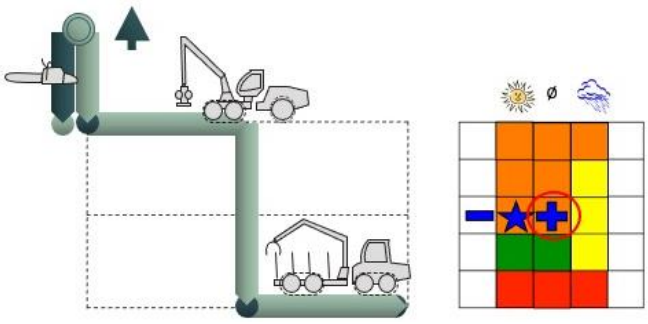

Figure 2. Colored table: Graphs for decision making, indicating the assessment of the forest owner; left: functiogram describing the working method; right: Technogram of a humid soil with the selected filed (red ring); blue marks: Ecogram of this harvesting method, indicating the compatibility under different moisture conditions (Erler, 2018).

2.2.3. Improving stand volumes

One of the ways to improve the forests in Germany is increasing the timber stock as stand volume by about 15.3 million cubic meters per year. The timber growth in Germany is 121.6 million m3 per year, and nearly 13% is saved annually. The strength of this act is going toward the natural forests with a high-volume stand. The weakness is to reduce the annual growth per hectare because of older trees.

2.2.4. Changing silvicultural method

Moving from monoculture to uneven-aged multi-species forestry is another conservation effort in Germany. The monoculture of even-aged spruce is changing to uneven-aged with adapted species like beech, oak, larch, and pine. The strengths of this act are that it is more sustainable against the wind and pests and more suitable for forest diversity, soil richness, and fauna. Among the weaknesses of this management, we can mention the lower volume growth and higher cost for harvesting operations.

2.3. Croatia

2.3.1. Forest policy

With the establishment of the Croatian Chamber of Forestry and Wood Technology Engineers in 2006, a mandatory licensing procedure for forestry contractors began in Croatian forestry, which the chamber implements as a public authority. The licensing procedure primarily refers to the certification of professionals (employed forest engineers and trained professional forest workers) and technical equipment (machines and devices) of forest contractors. Since most forest operations are performed through three phases (preparation, execution, and supervision), the bylaw stipulates that in the stages of preparation and supervision of forest operations contractors must have a certified forest engineer – who has passed the professional exam and is a member of the Chamber. It should be noted that in 2015, the Chamber adopted the first professional guideline related to the preparation of the Elaborate for the harvesting operations and silvicultural treatments, which is a set of rules of best management practice (BMP), and whose application provided the initial preconditions for safe, efficient, and environmentally sound forestry operations (Poršinsky and Zec, 2015). The Chamber also conducts lifelong education of its members, acquainting them with the latest professional achievements.

2.3.2. Production of the study of primary forest accessibility

Investment in the construction of forest roads is one of the measures of rural development of the Republic of Croatia, which is fully funded by the European Union (Pentek et al., 2016a; Pentek et al., 2016b). As examples of BMP from the study of primary forest accessibility, the criteria for determining the density of primary forest transport infrastructure (Poršinsky et al., 2017) and Analysis of the average geometric (Euclidean) timber extraction distance of the existing and improved network of forest roads (including newly designed zero forest road lines) were subsequently incorporated into the Bylaw on Forest Management.

2.3.3. Longitudinal slope limitation of 20 (25%) on built skid roads in pre-mountain forests

In the pre-mountain beech-fir forests rich in karst phenomena, the construction of skid roads ensures the mobility of cable-skidders during timber extraction (Duka et al., 2017). In order to reduce erosion processes, in the technical conditions for forest roads, the longitudinal slope of skid roads is limited to 20% (at shorter distances to 25%). This will lead to an increase in skid road density per unit area, ultimately increasing the costs.

2.3.4. Parallel trail network of 20 m apart in lowland forest areas

In lowland pedunculate oak forests, forwarders have been used for timber forwarding since 1971. Over time, different distances between parallel trails (initially at 75 m and soon at 37.5 m) were used to reduce forest soil disturbances (Pandur et al., 2014). From 2018, it has been gradually moved to a denser trail network with a

distance of 20 m between trails (two ranges of the forwarders' boom reach), with the restriction of forwarders' movement exclusively on the network of trails, primarily to protect oaks' natural seedling.

2.3.5. Use of traction aids

In conditions of high soil moisture content and limited soil bearing capacity, the guideline is to equip skidders with chains on tires to assure traction and forwarders with tracks on bogie wheels (Poršinsky et al., 2020) in order to reduce contact pressures and wheel slippage as the leading causes of forest soil damage (Poršinsky et al., 2011; Poršinsky et al., 2012). In addition to restricting the movement of forest vehicles on the network of secondary network, the additional equipment ensures the trafficability of skid trails during multiple passes of timber extraction.

2.3.6. Limitations of harvesting of narrow-leaved ash stands in summer

Rejuvenation of even-aged forest stands by shelterwood cuttings is related to vegetation dormancy and is carried out from October 1 to March 31 (so-called winter felling). An exception to this practice is narrow-leaved ash stands in the lowland areas, which are developed on different types of wetlands gley soils with a high proportion of clay particles and, which for most of the year, are fully saturated with water from various sources of moisture (i.e., high groundwater levels, precipitation, and drained water from adjacent slopes, floods.). In order to protect these stands during the movement of forest vehicles, the implementing bylaw of the Forest Act allows shelterwood cuttings during the summer.

2.3.7. Protection of boundary trees by wooden poles

Damage (peeling of bark) on boundary trees close to the secondary forest road network is a common occurrence during timber extraction by cable skidders. An example of BMP of tree protection along the infrastructure network in the area of pre-mountain mixed forests of sessile oak and common beech is the method of protective poles driven into the ground next to the boundary trees (Ursić et al., 2022).

2.3.8. Height of tree stumps

Due to the prevention of erosion processes on sloped terrains, but also considering NATURA 2000, which claims for a certain amount of dead wood in the stand, stump harvesting is not used in Croatia. However, the implementing regulations of the Forest bylaw prescribe the maximum height of stumps: "The height of stumps in stands after felling and production in lowland areas must not exceed one quarter of the breast height diameter or one-third of the breast height diameter on sloped terrain", to achieve two goals: higher utilization during felling and processing (Duka et al., 2020), and reducing the height of the surface obstacles.

2.4. Turkiye

2.4.1. Forestry approaches

In Turkiye, forest areas cover approximately 29.2% of the total area, with 22.74 million hectares. The productive high forest area constitutes 57.53% of the total forest area, while the rest is covered with the degraded high forest. About 94.72% of the forests are operated as high forests and 5.28% as coppice forests (GDF, 2021). According to the Statistical Institute, the economic contribution of the forest sector is about 2.0%, considering the monetary value of primary and secondary forest products and services, and the subsidies arising from inputs given to other sectors (Bilici and Akay, 2021). The wood-based forest products constitute the main source of this economic contribution (Serin et al., 2010). Considering that the demand for forest products in the world and as well as in Turkiye will gradually increase, it becomes clear that even the slightest value loss that may occur in the line of producing wood-based forest products should be prevented. In this context, production, and maintenance work in forest enterprises in Turkiye are carried out according to management plans, which are developed and implemented based on the principles of sustainable forestry approaches. The 11th Development Plan (2019-2023) also suggested increasing the forest sector`s economic contribution while ensuring sustainable management of forest resources (DP, 2020). Thus, wood-based forest products are to be produced sustainably by considering the use of appropriate methods and approaches in forest harvesting. When all these are considered, the risk of occupational accidents is higher in forest harvesting activities than in most other work sectors (Albizu-Urionabarrenetxea et al., 2013). Accordingly, it is required to give specific training and qualifications to the people who carry out forest harvesting work in the field.

2.4.2. Harvesting methods

Due to the necessity of giving priority to forestry villagers and the low rate of mechanization use in Turkiye, the cut-to-length method is mostly used in forest harvesting carried out with the traditional method. Recently, as the practice of stumpage sales dramatically increased, buyers most often want to produce longer logs and prefer to implement the tree-length method, which is used to a limited extent (Genç and Arıcak, 2016). This method, which requires using more machine power, when necessary, will reduce the time of removal from the harvesting unit and the cost over time. The usage area of longer logs is wider, and the casualties are less likely to occur (Buğday and Menemencioğlu, 2014). In addition, this method reduces the risk of occupational accidents, shortens the time between harvesting and sale, and increases transport efficiency. On the other hand, there is a new debate on improving forest road standards since forest roads with limited standards restrict the movement of high-tonnage logging trucks required for tree-length

production (Akay et al., 2021). Thus, appropriate harvesting methods are determined considering the available road standards in the region.

2.4.3. Mechanization in forest harvesting

In Turkiye, forest harvesting jobs are first offered to villagers, called as "forest villagers", who live in the forest villages near the harvesting unit or to the forestry cooperatives mostly established by the villagers. These local contractors (i.e., villagers and cooperatives) usually cannot afford advanced mechanized harvesting equipment due to their high initial cost and operating costs (Bilici and Akay, 2021). They mostly use farm tractors for skidding and winching the logs from stump to roadside landing areas (Şafak et al., 2019). In recent years, the use of advanced mechanized harvesting equipment in forest harvesting has been growing in industrial forests where stand characteristics and ground slopes are suitable for ground-based harvesting equipment. Particularly, large logging companies operate harvesting equipment, such as skidders, harvesters, and feller-bunchers to meet the high volumes of wood raw material demands of domestic companies producing wood-based panels. In mountainous regions, cable yarders have been effectively used, particularly in the northeast region of Turkiye. Recently, GDF (General Directorate of Forestry) purchased a number of medium-distance (800 m) cable yarders (Tajfun MOZ 500GR) that are mounted on the farm tractors. In order to make these cable yarders available for local people, GDF rents the equipment to them at an acceptable price range.

2.4.4. Professionalization in forest harvesting

Forestry works is the main source of income for forest villagers and about seven million people live in about 23000 forest villages in Turkiye (FS, 2020). The forest harvesting activities are mostly conducted by forest villagers or their cooperatives that have over 200 thousand members. On the other hand, not all forestry workers receive adequate technical training and professional education (Eker and Sessions, 2020). It is very important economically, ecologically, and ergonomically that the machine operators and forest workers working in the production of forest products perform their activities using the right techniques and following the standards. On the other hand, fatal occupational accidents occur when machine operators and harvesting workers, who often work in dangerous and challenging terrain conditions, do not act by occupational health and safety principles. In recent years, training programs with certification for certain jobs have been organized, and forest harvesting is one of them. Through training activities, it is aimed to increase the quality of production and labor productivity in forest harvesting (Bilici and Akay, 2021). The trainers are provided with the opportunity to specialize in the relevant profession as certificate holders. Forest harvesting workers are given the necessary theoretical and practical training in professional issues and occupational health and safety issues.

2.5. Italy

2.5.1. Forest policy and rules

In Italy, Forest Legislation differs from region to region (more than 20 in the national territory). Indeed, each territorial entity has or better should have its own Forest Law, which regulates forestry activities. This fragmentation is one of the main problems that needs to be addressed to obtain a clear direction on the national forest policy. However, in 2018, the "Consolidated Text on Forests and Forestry Supply Chains" was enacted, which contains a series of guidelines to harmonize the forestry sector in the optic of SFM. The start was not the easiest, and the entry process was complex. However, after a series of complicated mediations, with all the stakeholders, the implementation phase is currently proceeding at the territorial level. Currently, the technical execution of forest harvesting-logging is a topic that has entered marginally in this law. However, in the implementation phase, it is hoped that a series of transpositions will be aimed at best management practices, focusing on the principles of sustainable forest operations.

2.5.2. Forest roads

Apart from classifying the different kinds of forest roads (mainly in agreement with the existing technical classification) the Consolidated Text set up a maximum threshold of 250 m/ha for skid trails, and a width range of 4-8 m of cable yarding corridors. Moreover, the act proposes the creation of a georeferenced database of the forest road network for each Region. The positive aspect of such a new rule consists of trying to give a national guideline to the issue of ground-based operations; the weakness is that it is difficult to define a threshold that can be valid in all the yards along Italy, also considering the great variability of stands and topography along the national territory.

2.5.3. Operators' training

To be allowed to carry out any kind of forestry intervention forest enterprises must be listed in a dedicated register developed for each Region. The owner or at least one permanent worker of the enterprise must have followed a specific training course by the regulation UNI 11660:2016 (Professional activity of forest operator – requirements of knowledge, skills, and know-how). Such kinds of courses have to be organized by the Forest Sector of each Region. The positive aspect is the growing attention to the operators' training with the aim of increasing their skills. The negative ones could be (but it is something rather unpredictable) the way these courses will be carried out, the knowledge of the teachers, and mostly their ability to involve the attendants into the course. Finally, an aspect that should not be underestimated is the lack structures equipped with

suitable technical equipment to support this type of course.

2.5.4. Shifting to a close-to-nature silviculture

Apart from what was reported in the Consolidated Text on Forests and Forestry Supply Chains, in the last years in Italy, there has been growing attention putting into practice close-to-nature silviculture, mostly in the areas on Natura 2000 Network but also outside such zones. Silvicultural practices like the release of deadwood and habitat trees are common and requested by the various regional regulations. For instance, in the Umbria Region, it is mandatory to release at least one habitat tree per hectare, reporting its GPS coordinates within the harvesting plan, as well. Furthermore, another silvicultural practice that is strongly encouraged is the application of continuous- cover forestry, mainly with shelterwood treatments, thus limiting clear-cuts, which indeed are nowadays absent, or however very limited, in the Italian context. The advantages of these approaches are related to increased biodiversity and limited soil erosion. The disadvantage is related to lower timber obtained from the intervention and lower work productivity, increasing harvesting costs. Considering these approaches, adapting the harvesting systems by interacting with the new technologies available (precision forest harvesting) is becoming increasingly important.

3. Analytical Discussion

In the forest research sector, there is a growing focus on the institutional, policy, and social dimensions, particularly on supporting innovation in the forestry sector (Weiss et al., 2021). Here follows an analytical discussion with the help of the DPSIR Framework (Fig 1).

A) Drivers are changes in the social, economic, and institutional system that affect the environment. Four driving forces have been proposed, affecting the structure and relationship between social, economic, political, and environmental systems (Rodriguez-Labajos et al., 2009).

The use of resources is always the economic function of all societies, whether in developing or developed ones. However, as soon as the basic needs of the community are provided, the form of economic activity of the people changes and usually leads to more rational in relation to natural resources. The utilization of forests beyond the economic justifications and needs of communities depends on our view and attitude toward forestry. With the economic improvement of societies, forestry activities attempt to restore forest to the nature and the original ecosystem towards higher sustainability, even though its economic income could be lower. Patterns of consumption are also changing, particularly in some European countries. Replacing clean energies instead of firewood, replacing massive woods with synthetic materials, and reducing the use of tropical wood are all essential factors that play a key role in changing the utilization of forests, even if they have not turned out to be very sustainable choices in environmental terms.

B) Pressures are the anthropogenic factors inducing environmental change, like the increase of pollution, physical and biological agents, the use of resources, and the use of land by human activities.

The greatest pressure on the forests is when local communities are low-income, governments are not economically well-off, and are involved in administrative problems. In this situation, the needs of local communities and the marketplace are mainly provided through the smuggling of timber, and the worst form of it is the seizure of forest areas and their change of use. In the milder form of this pressure, the undesirable performance of a man with the forest is observed such that the implementation of forestry plans is not carried out correctly or even ecotourism may cause severe damage to the forest ecosystem. Sometimes, forest areas are considered as a place to bury municipal waste or cheap land for any activity of statesmen. On the other hand, excessive conservational approaches driven by the pressure of citizens who are not experts in the forest sector can lead to several problems in the optic of SFM. There is a need to train citizens about the importance of active and the SFM, which does not mean stopping forestry activities but performing them sustainably. Regular people (i.e., those not dealing with forests in their usual work or study life) should understand that loggers are not the enemies of forests but their primary protectors.

C) The state can refer to a wide range of features, from the qualitative and the quantitative characteristics of ecosystems to the quantity and quality of resources and human living conditions.

Currently, forests in developed countries have a qualitative and acceptable status and are still improving. This is a state seen in the Saxony forests in such a way that the volume per hectare of forest is increasing, forests are changing from the form of monoculture to uneven-aged mixed seedlings and covering the skid roads from 20 percent of the forest to 10 percent has been reduced. In Italy as well, the development of close-to-nature silviculture has been evolving.

However, the worrying issue in developing countries is the presence of a rural population in the vicinity of forests and their socio-economic affairs.

D) Impacts can include changes in environmental functions such as resource access, water and air quality, soil fertility, health, or social cohesion (Maxim et al., 2009).

The current harvesting trend in developed countries seems to impact the ecosystem and humans positively. Positive impacts on ecosystems by studying forest communities and adapting more forestry plans to ecosystems and ensuring their sustainability. Effects on humans also have direct economic and indirect effects on forest ecosystem benefits.

Unfortunately, the forests of developing countries do not have good prospects. In Iran, the implementation of nearly 60 years of forestry plans has not been able to protect these ecosystems well, although the harvesting of these forests to a large extent results in the supply of wood required by the market, the creation of job opportunities and the cost of any forestry activities and it has also been the physical protection of the forest against change of use. However, if there is no forestry plan, the situation will get worse. These areas are more than ten times more affected by wood smugglers and seizure of land than in areas with a forestry plan (Lotfalian, 2013).

E) Responses can come from different levels of society, such as people, governments, or non-governmental organizations.

Usually, the first managerial response to the impacts-mentioned above is presented by foresters, as always in forestry plans (Graves, 1937). As noted earlier, various efforts have been made in Iran, Germany, Croatia, Turkiye, and Italy, presented and carried out by relevant experts and managers. However, sometimes, these efforts are inadequate and cannot guarantee the qualitative and quantitative improvement of forests, as has happened in Iran. Today, this quantitative and qualitative decline in Iranian forests has had a dual effect on the public. On the one hand, it has caused disappointment and frustration; on the other hand, it created solidarity and created associations to help natural resources. The formation of various NGOs and their pressure has even led forest managers to stop harvesting, which is not acceptable because it unilaterally supports the sight of nature conservation and ignores the need of the local low-income population for sustainably produced raw material for different purposes like construction, furniture, home cooking, and heating. Forestry specialists, as a warrantor for balanced functions, fear that mostly unprofessional nature conservationists can cast out multifunctional forestry at the expense of the local population.

4. Conclusion

Along with climate change, what is observed is the process of socioeconomic changes in human societies and their interactions in forest and forestry. Forest policymakers and operators must act so that the forests do not suffer from a lack of quality and quantity but adapt themselves to the needs of the time to improve their point of view and performance. As seen in the above assessments, different activities have been taken by foresters to prevent damage. However, the apparent display of forest damage, the visibility of harvesting machinery and equipment, and the disturbance of the forest floor by the people provide an opportunity for non-specialist sympathizers with social media noise to bring the issue to the community level.

In this paper, we emphasize drawing the attention of forest managers and harvesting policymakers to this issue so that while observing the three principles of SFM, the forest operations minimize the damage to soil and stand implemented. Also, the appearance of forest operations should not be annoying to the public. Otherwise, the involvement of non-expert groups such as NGOs in the issue, the wrong decisions of the managers to stay in power, and sometimes, the politicization of the issue will complicate the situation and worsen the condition of the forests as well as the supply of the local low-income communities. The communities' need for wood-based products from the forests is inevitable; however, some NGOs strictly make propaganda to prohibit the wood utilization. If the NGOs win, the consequence will be a worsening of the economic condition of the rural population and a more intensive utilization of oil and gas. Therefore, we suggest implementing economically feasible, environmentally sound, and more acceptable forestry approaches in a modern forestry plan to integrate both functions, utilization on the one hand and nature conservation on the other hand. This plan should be developed by foresters in close collaboration with professionals and NGOs in the field of natural conservation.

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References

Aggarwal, S., Larson, A., McDermott, C., Katila, P., Giessen, L., 2020. Tenure reform for better forestry: An unfinished policy agenda. *Forest Policy and*

Economics 123:102376 https://doi.org/10.1016/j.forpol.2020.102376.

Akay, A.E., Serin, H., Sessions, J., Bilici, E., Pak, M., 2021. Evaluating the Effects of Improving Forest Road Standards on Economic Value of Forest Products. *Croatian Journal of Forest Engineering* 42(2):245-258. https://doi:10.5552/crojfe.2021.851.

Albizu-Urionabarrenetxea, P., Tolosana-Esteban, E., Roman-Jordan, E., 2013. Safety and health in forest harvesting operations. Diagnosis and preventive actions. A review. *Forest Systems* 22(3):392-400. https://doi.org/10.5424/fs/2013223-02714.

Arbogast, C.J., 1957. Marking guides for northern hardwoods under the selection system. 21. Station Paper LS-56. St. Paul, MN: US Department of Agriculture, Forest Service, Lake States Forest Experiment Station

Bilici, E., Akay, A.E., 2021. Forestry and Forest Operations in Turkey: Challenges and Developments. *Revista Pădurilor* 136(1):37-52.

Binkley, D., Giardina, C., 1998. Why do tree species affect soils? The warp and woof of tree-soil interactions. *Biogeochemistry* 42:89-106. https://doi.org/10.1023/A:1005948126251.

Buğday, E., Menemencioğlu, K., 2014. Assessment of Existing Forest Road Standards Conformity for Stumpage Sale in Turkey. II. National Mediterranean Forest and Environment Symposium. 22-24 October. Isparta, Turkey.

Buongiorno, J., Gilless, J.K., 2003. Decision Methods for Forest Resource Management. Academic Press, San Diego 439p.

Champagne, E., Raymond, P., Royo, A.A., Speed, J.D.M., Tremblay, J.P., Côté, S.D., 2021. A Review of Ungulate Impacts on the Success of Climate-Adapted Forest Management Strategies. *Current Forestry Reports* 7:305–320. https://doi.org/10.1007/s40725-021-00148-5.

De Liocourt, F., 1901. Sapinières. Manuscript held in the Library of the Ecole Nationale du Génie Rural, des Eaux et des Forêts Nancy, France 42-82

DP., 2020. Forestry and Forest Products. The Eleventh Development Plan (2019-2023). Ministry of Development, Ankara 2020:87p.

Đuka, A., Grigolato, S., Papa, I., Pentek, T., Poršinsky, T., 2017. Assessment of timber extraction distance and skid road network in steep karst terrain. *iForest – Biogeosciences and Forestry* 10:886–894.

Đuka, A., Sertić, M., Pentek, T., Papa, I., Janeš, D., Poršinsky, T., 2020. Round Wood Waste and Losses – Is Rationalisation in Scaling Possible? *Croatian Journal of forest engineering* 41(2):287–298.

Eker, M., Sessions, J., 2020. Refocusing on Operational Harvest Planning Model for State-Owned Forestry in Turkey. *European Journal of Forest Engineering* 6(2):96-106. https://doi.org/10.33904/ejfe.829946.

Erler, J., 2017. Transfer system to adapt timber harvesting operations to local conditions. *Croatian Journal of forest engineering* 38(2):197-208.

Erler, J., 2018. Educational leaflets in Institute of Forest Utilization and Forest Technology. 2018 (Unpublished).

Erler, J., 2017. Transfer system to adapt timber harvesting operations to local conditions. *Croatian Journal of Forest Engineering* 38(2):197-208.

FAO., 2021. Sustainable forest management. 2021 Available from: https://www.fao.org/forestry/sfm/en/ Accessed 9 Jan 2022.

Forest Europe., 2021. SFM Criteria & Indicators 2021 Available from: https://foresteurope.org/sfm-criteria-indicators/. Accessed 9 Jan 2022.

FS., 2020. Forestry Statistics. Official Statistics, General Directorate of Forestry. Ankara.

GDF., 2021. Performance Program of 2021. Strategy Development Department, General Directorate of Forestry, Ankara, Turkey, 55p.

Genç, Ç., Arıcak, B., 2016. Determination of Routes as Type-A Forest Roads for Long Haulage Vehicles: Küre Forest Sub-District Directorate. *Kastamonu University Journal of Forestry Faculty* 16(2):474-484. https://doi.org/10.17475/kastorman.289757.

Golec, P.J., Luckert, M.K., 2008. Would harmonizing public land forest policies, Criteria and Indicators, and certification improve progress towards Sustainable Forest Management? A case study in Alberta, Canada. *Forestry Chronicle* 3:410-419. https://doi.org/10.5558/tfc84410-3.

Graves, H.S., 1937. Cooperative Effort in Forestry. *Journal of Forestry* 35(7):639-644. https://doi.org/10.1093/jof/35.7.639.

Hosseini, S.M., Majnounian, B., Namiranian, M., 2002. Investigation of logging damage on two mechanized skidding system on the trunk of remaining trees in north of Iran. *Journal of Iranian Forest Resources* 54(1):23-29. (In Persian).

Husch, B., 1987. Guidelines for forest policy formulation, FAO forestry paper. 81 Rome. 91p.

Jordan-Lopez, A., Martinez-Zavala, L., Bellinfante, N., 2009. Impact of different parts of unpaved forest roads on runoff and sediment yield in a Mediterranean area. *Science of the Total Environment* 407:937-944. https://doi.org/10.1016/j.scitotenv.2008.09.047.

Kim, Y.S., Rodrigues, M., Robinne, F.N., 2021. Economic drivers of global fire activity: A critical review using the DPSIR framework. *Forest Policy and Economics* 131:102563. https://doi.org/10.1016/j.forpol.2021.102563.

Krott, M., 2008. Forest government and forest governance within a Europe in change. The Multifunctional Role of Forests Policies, Methods and Case Studies. 13:EFI Proceedings No. 55.

Larson, A.M., Mausch, K., Bourne, M., Luttrell, C., Schoneveld, G., Cronkleton, P., et al., 2021. Hot topics in governance for forests and trees: Towards a (just) transformative research agenda. *Forest Policy*

and Economics 131:102567. https://doi.org/10.1016/j.forpol.2021.102567.

Latterini, F., Mederski, P.S., Jaeger, D., Venanzi, R., Tavankar, F., Picchio, R., 2023. The Influence of Various Silvicultural Treatments and Forest Operations on Tree Species Biodiversity. *Current Forestry Reports* 9(2):59-71.

Levers, C., Verkerk, P.J., Müller, D., Verburg, P.H., Butsic, V., Leitão, P.J., et al., 2014. Drivers of forest harvesting intensity patterns in Europe. *Forest Ecology and Management* 315:160-172. https://doi.org/ 10.1016/j.foreco.2013.12.030.

Liu, S., Xia, J., 2021. Forest harvesting restriction and forest restoration in China. *Forest Policy and Economics* 129:102516. https://doi.org/10.1016/j.forpol.2021.102516.

Lotfalian, M., Majnounian, B., Rezvanfar, M., Parsakhoo, A., 2009. Investigation of damages due to forest logging under selection cutting system on stand and regeneration. *Journal of Science and Technology of Agriculture and Natural Resources* 46(12a):363-376.

Lotfalian, M., Parsakhoo, A., 2009. Investigation of forest soil disturbance caused by rubber-tired skidder traffic. *International Journal of Natural and Engineering Sciences* 3(1):79-82. http://www.ijnes.org/index.php/ijnes/article/view/446.

Lotfalian, M., 2013. Forest logging, Aiizh Press, 467p. ISBN 978-964-970-319-0. Tehran.

Lotfalian, M., 2012. Wood transportation, Aiizh Press, 342p. ISBN 978-964-970-303-9. Tehran.

Marchi, E., Chung, W., Visser, R., Abbas, D., Nordfjell, T., Mederski, P.S., McEwan, A., et al. 2018. Sustainable Forest Operations (SFO): A new paradigm in a changing world and climate. *Science of the Total Environment* 634:1385-1397.

Maxim, L., Spangenberg, J., O'Connor, M., 2009. The DPSIR framework for Biodiversity Assessment. *Ecological Economics* 69(1):12-23. https://doi.org/10.1016/j.ecolecon.2009.03.017.

Mrosek, T., Balsillie, D., Schleifenbaum, P., 2006. Field testing of a criteria and indicators system for sustainable forest management at the local level. Case study results concerning the sustainability of the private forest Haliburton Forest and Wild Life Reserve in Ontario, Canada. *Forest Policy and Economics* 8(6):593-609. https://doi.org/10.1016/j.forpol.2004.11.002.

Murphy, G., 2004. Long-Term impacts of forest harvesting related soil disturbance on log product yields and economic potential in a New Zealand forest. *Silva Fennica* 38(3):279-289. https://doi.org/10.14214/sf.416.

Naghdi, R., Lotfalian, M., Bagheri, I., Jalali, A.M., 2009. Damages of Skidder and Animal Logging to Forest Soils and Natural Regeneration. *Croatian Journal of Forest Engineering* 30(2):141-149.

Nakagawa, M., Kurahashi, A., 2005. Factors affecting soil-based natural regeneration of Abies sachalinensis following timber harvesting in a sub-boreal forest. *New Forests* 9(2):199-205. https://doi.org/10.1007/s11056-005-0273-5.

Pandur, Z., Poršinsky, T., Šušnjar, M., Zorić, M., Vusić, D., 2014. Soil Disturbance during Timber Forwarding in Cut-Blocks of Common Oak. *Nova Mehanizacija Šumarstva* 35:23–34.

Pentek, T., Đuka, A., Papa, I., Damić, D., Poršinsky, T., 2016. The Effectiveness Study of Primary Forest Road Traffic Infrastructure – an Alternative to Study of Primary Forest Opening or Just a Short-term Solution? *Šumarski List* 140(9–10):435–453.

Pentek, T., Poršinsky, T., Đuka, A., Tomašić, Ž., 2016. Planning of primary forest road network on strategic and tactical level – from idea to implementation in operational forestry. Proceedings of 49th Symposium on Forest Mechanization – FORMEC, Warsaw, September 4–7, 322.

Picchio, R., Latterini, F., Mederski, P.S., Tocci, D., Venanzi, R., Stefanoni, W., Pari, L., 2020. Applications of GIS-Based Software to Improve the Sustainability of a Forwarding Operation in Central Italy. *Sustainability* 12(14)5716. https://doi.org/10.3390/su12145716.

Picchio, R., Mederski, P.S., Tavankar, F., 2020. How and How Much, Do Harvesting Activities Affect Forest Soil, Regeneration and Stands?. *Current Forestry Reports* 6,115–128. https://doi.org/10.1007/s40725-020-00113-8.

Poršinsky, T., Đuka, A., Papa, I., Bumber, Z., Janeš, D., Tomašić, Ž., Pentek, T., 2017. Criteria for Determining Primary Forest Traffic Infrastructure Network Density – Examples of The Most Common Cases. *Šumarski List* 141(11–12):593–608.

Poršinsky, T., Matas, J., Horvat, D., Đuka, A., 2020. Pneumatici kotača šumskih vozila (Tyres of Forestry Vehicles). *Šumarski List* 144 (9–10):509–522.

Poršinsky, T., Pentek, T., Bosner, A., Stankić, I., 2012. Ecoefficient Timber Forwarding on Lowland Soft Soils. In: Global Perspectives on Sustainable Forest Management (ed: C. A. Okia), In Tech, 275–288.

Poršinsky, T., Stankić, I., Bosner, A., 2011. Ecoefficient Timber Forwarding Based on Nominal Ground Pressure Analysis. *Croatian Journal of Forest Engineering* 31(1):345–356.

Poršinsky, T., Zec, S., 2015. Croatian Chamber of Forestry and Wood Technology Engineers Issued Their First Professional Guidelines. *Nova Mehanizacija Šumarstva* 36:91–102.

Pukkala, T., 2022. Assessing the externalities of timber production. *Forest Policy and Economics* 135:102646. https://doi.org/10.1016/j.forpol.2021.102646.

Rab, M.A., 2003. Recovery of Soil Physical Properties from Compaction and Soil Profile Disturbance Caused by Logging of Native Forest in Victorian Central Highlands, Australia. *Forest Ecology and*

Management 191:329–340. https://doi.org/10.1016/j.foreco.2003.12.010.

Rodriguez-Labajos, B., Binimelis, R., Monterroso, I., 2009. Multi-level driving forces of biological invasions. *Ecological Economics* 69:63-75. https://doi.org/10.1016/j.ecolecon.2009.08.022.

Şafak, İ., Eker, M., Erdem, M., Turan, İ., 2019. Time and motion analysis on cable skidding with agricultural tractors of coniferous logs. *Turkish Journal of Forestry Research* 6(1):58-47. https://doi.org/10.17568/ogmoad.451128.

Schweier, J., Magagnotti, N., Labelle, E.R., Athanassiadis, D., 2019. Sustainability Impact Assessment of Forest Operations: a Review. *Current Forestry Reports* 5:101–113. https://doi.org/10.1007/s40725-019-00091-6.

Serin, H., Akay, A.E., Pak, M., 2010. Estimating the Effects of Optimum Bucking on the Economic Value of Brutian Pine (Pinus Brutia) Logs Extracted in Mediterranean Region of Turkey. *African Journal of Agricultural Research* 5(9):916-921.

Sohrabi, H., Jourgholami, M., Jafari, M., Shabanian, N., Venanzi, R., Tavankar, F., Picchio, R., 2020. Soil recovery assessment after timber harvesting based on the sustainable forest operation (SFO) perspective in Iranian temperate forests. *Sustainability* 12(7): 2874.

Soler, R., Lorenzo, C., González, J., Carboni, L., Delgado, J., Díaz, M., et al., 2021. The politics behind scientific knowledge: Sustainable forest management in Latin America. *Forest Policy and Economics* 131:102543. https://doi.org/10.1016/j.forpol.2021.102543.

Stańczykiewicz A, Szewczyk G, Kulak D., 2015. Damage to advance growth resulting from timber harvesting during final cuttings. *Balt. For* 21(1):144–51.

Steve, D., Luc, L., 2010. Forest harvesting entrepreneurs, perception of their business status and its influence on performance evaluation. *Forest Policy and Economics* 12(4)287-298. https://doi.org/10.1016/j.forpol.2009.11.004

Trautner, A., Arvidsson, J., 2003. Subsoil compaction caused by machinery traffic on a Swedish Eutric Cambisol at different soil water contents. *Soil and Tillage Research* 73:107-118. https://doi.org/10.1016/S0167-1987(03)00104-1.

Tscherning, K., Helming, K., Krippner, B., Sieber, S., Paloma, S.G., 2012. Does research applying the DPSIR framework support decision making?. *Land Use Policy* 29(1):102-110. https://doi.org/10.1016/j.landusepol.2011.05.009

Ursić, B., Vusić, D., Papa, I., Poršinsky, T., Zečić, Ž., Đuka, A., 2022. Damage to Residual Trees in Thinning of Broadleaf Stand by Mechanised Harvesting System. *Forests* 13(1):51. https://doi.org/10.3390/f13010051

Venanzi, R., Latterini, F., Civitarese, V., Picchio, R., 2023. Recent Applications of Smart Technologies for Monitoring the Sustainability of Forest Operations. *Forests* 14(7):1503.

Walters, C.J., 1986. Adaptive Management of Renewable Resources. MacMillan, New York, NY.

Weiss, G., Hansen, E., Ludvig, A., Nybakk, E., Toppinen, A., 2021. Innovation governance in the forest sector: Reviewing concepts, trends and gaps. *Forest Policy and Economics* 130:102506. https://doi.org/10.1016/j.forpol.2021.102506.

Wildberg, J., Möhring, B., 2021. Continuous timber harvest — Costly restriction or profitable solution? *Forest Policy and Economics* 123:102349. https://doi.org/10.1016/j.forpol.2020.102349.

Williamson, J.R., Neilson, W.A., 2000. The influence of forest site on rate and extent of soil compaction and profile disturbance of skid trails during ground based harvesting. *Canadian Journal of Forest Research* 30(8):1196-1205. https://doi.org/10.1139/x00-041.

Wood, M.J., Carling, P.A., Moffat, A.J., 2003. Reduced ground disturbance during mechanized forest harvesting on sensitive forest soils in the UK. *Forestry* 76(3):345-361. https://doi.org/10.1093/forestry/76.3.345.

Zhou, M., Liang, J., Buongiorno, J., 2008. Adaptive versus fixed policies for economic or ecological objectives in forest management. *Forest Ecology and Management* 254(2):178-187. doi: 10.1016/j.foreco.2007.07.035.