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ARE SLOVENIA'S FORESTS DEVIATING FROM SUSTAINABLE DEVELOPMENT?
ALI SE SLOVENSKI GOZDOVI ODMIKAJO OD TRAJNOSTNEGA RAZVOJA?

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ABSTRACT

This paper provides an overview of the sustainable development of Slovenian forests between 2000 and 2018. The state and development of Slovenian forests in terms of sustainability were examined using a set of variables and indicators of sustainable forest management such as forest area, basal area, growing stock, stand density index, age structure/diameter distribution, demographic balance, optimal growing stock, increment, felling, species diversity, species mixture, forest regeneration, naturalness and deadwood. We also assessed the suitability of the systematic 4 x 4 km sampling grid. All estimates were calculated at the national, ecoregional and forest region levels. In 2018, forest cover was estimated at 60% and was slightly higher than that in 2012. Conversely, growing stock volume decreased and was estimated at 329.6 m^3/ha. Young forests accounted for 29%, older forests for 68% and uneven-aged forests for 3% of the total forest area. Beech and spruce were the dominant tree species. The proportions of other species were less than 10%, and concerns were raised about their recruitment. Comparative analyses of the desired values of the indicators and the values reported by the Forest Europe process member states and some selected countries raised doubts about Slovenia's progress towards sustainable forest development. Furthermore, the 2018 dataset does not fully support the indicators of sustainable forest management.

Key words: sustainable forest management, indicators, temporal analysis, Slovenia

IZVLEČEK

Prispevek nas seznanja z osnovnimi informacijami o trajnostnem razvoju slovenskih gozdov med letoma 2000 in 2018. Stanje in razvoj slovenskih gozdov z vidika trajnosti smo preverili z nizom spremenljivk in kazalnikov trajnostnega gospodarjenja z gozdovi: površina gozdov, temeljnica, lesna zaloga, indeks sestojne gostote, starostna struktura/porazdelitev prsnih premerov, ravnotežje razvojnih faz, optimalna lesna zaloga, prirastek, posek, različnost drevesnih vrst, mešanost sestojev, pomlajevanje, naravnost in odmrla drevnina. Ocenili smo tudi ustreznosti sistematične mreže 4 x 4 km, ki se je uporabljala za velikoprostorsko inventarizacijo. Vse vzorčne ocene so bile izračunane za raven države, ekoregije in za gozdnogospodarska območja. Leta 2018 je gozdnatost dosegala 60 % in je bila višja kot l. 2012. Nasprotno se je lesna zaloga zmanjšala in je bila ocenjena na 329,6 m^3/ha. Površinski delež mlajših gozdov je znašal 29 %, starejših (sečno zrelih) 68 %, raznodobnih pa 3 %. Med drevesnimi vrstami je največji delež pripadal bukvi in smreki. Deleži drugih vrst niso presegli 10 %, posebej zaskrbljujoča je bila njihova vrast. Na osnovi primerjav z zaželenimi vrednostmi in vrednostmi kazalnikov v gozdovih držav članic procesa Forest Europe in nekaterimi izbranimi državami, je mogoče skleniti, da se razvoj slovenskih gozdov odmika od trajnostnega razvoja. Glede na razpoložljive podatke l. 2018 je tudi mogoče zaključiti, da velikoprostorska inventura MGGE l. 2018 s podatki ne zapolni vseh kazalnikov trajnostnega gospodarjenja z gozdovi.

Ključne besede: trajnostno gospodarjenje z gozdovi, kazalniki, časovna analiza, Slovenija

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1 INTRODUCTION
1 UVOD

The concept of sustainability has been known in European forestry since Carlowitz (von Carlowitz, 1713) published his book on forestry. Although he likely believed that fixed forest resources were inexhaustible, he advocated for a balanced approach between wood demand and wood supply. He claimed that the growing demand for wood could only be met by expanding wood production through silvicultural techniques (Warde, 2018), promoting coppicing and planned tree harvesting followed by systematic replanting (Schmithüsen, 2013; Vollmuth, 2022). Since Carlowitz's time, the idea of sustainable forest use has undergone many transformations and evolved into a complex development pattern that presently pervades forestry, many environmental sectors and industries (Schmithüsen, 2013; The European green ..., 2019; Forest Europe, 2022).

Forests are currently perhaps the most heavily burdened by human demands of all natural renewable resources. They are vital for the forest sector, in which planners and managers with diverse knowledge and skills aim to conserve their ecological integrity as well as plant and animal inhabitants (Maurer, 1993), protect soils, and ensure sustainable wood supply. Forests also play a crucial role in storing carbon, purifying water and enabling numerous human activities. Many of these forest contributions have been known for decades (Dieterich, 1953; McArdle, 1953). What is new is the growing increase in demands presently affecting almost all forest services, generated primarily by environmental sectors, energy-consuming industries and policies (e.g. EU biodiversity and forest strategies, EU Green Deal (Verkerk et al., 2022; The European Green …, 2019, EU biodiversity strategy …, 2020; Wolfslehner et al., 2020; New EU forest …, 2021)). These demands are not adequately prioritized or harmonized, leading to challenges in managing forests sustainably.

To monitor changes and assess forest development and management status over time, a list of sustainable forest management (SFM) indicators has been developed (Forest Europe, 2022). These indicators are used for forest reporting at the pan-European level and are often adopted and further developed by national forest sectors to support their policies and practices (Linser and Wolfslehner, 2022). However, measuring and assessing the status of sustainable forest development and management remains challenging due to the incomplete list of SFM indicators, including the attributes of forest ecosystem services (e.g. soil protection, erosion control, forest biodiversity (Kovač et al., 2017; Alberdi et al., 2019)) and their undefined reference values (Linser and Wolfslehner, 2022). An additional dilemma arises from the ambiguous definition of SFM (Forest Europe, 2022), which does not explicitly state that a seminatural managed forest only functions in perpetuity if its tree population is at or near demographic equilibrium ((Schütz, 2006; Schütz et al., 2016), e.g. age classes/developmental phases, J-shaped curves). As this condition is not explicitly included, the definition allows for various interpretations, such as i) increasing wood (carbon) storage despite the surplus of overaged forests already saturated with wood biomass (Verkerk et al., 2022; Nabuurs et al., 2013) or ii) allowing large areas of already overaged forests to grow even older to improve species habitats, even though such actions undermine their stability and expose them to high risks (Brang et al., 2013; Albrich et al., 2018). As recently reported by Lier et al. (2022), a different political understanding of the definition of SFM is also underway. SFM indicators are usually derived from data collected through field sampling, aerial photographs and other means. The data on forest development are usually provided by national forest inventories (NFI) conducted in most EU 27 countries (Tomppo et al., 2009).

The principle of sustainability was introduced to Slovenian forests (then part of the Austrian monarchy) with the Forest Act of 1852 (Johann, 2013; Perko et al., 2014; Perko, 2018) and has been applied nationwide since 1853. Presently, Slovenian forestry is committed to SFM and participates in the Forest Europe process (Forest Europe, 2022). However, despite investing significant resources to improve near natural forest management (Diaci, 2006; Johann, 2007; Schütz et al., 2012) and develop an intensive forest planning system (Gašperšič, 1995; 2006), limited efforts have been devoted to monitoring the outcomes of these practices at the national level. Consequently, some data and information on SFM are only available at the level of forest regions and forest management units (Pregledovalnik …, s. a.). Such statistical design makes the data unsuitable for evaluating sustainable forest development and management at the national level or for shaping national forest policy.

A better approach to assess forest conditions at the national level is provided by the national forest inventory named the "Forest and forest ecosystem survey" (hereafter FFECS), introduced in 1985 (Kušar et al., 2009). Unlike most NFIs, the FFECS provides a limited amount of data sufficient to derive only some of those SFM indicators that can be collected by the NFI. To improve the system of SFM indicators and the National Forest Program, the indicators have been revisited and an SFM-based set of indicators has been designed for simultaneous monitoring. However, no reference values have been set for any of these indicators (Bončina, 2017; Kovač et al., 2019a).

Apart from reporting for the needs of Forest Europe and occasional assessments of forest conditions (Kovač, 2014b; Veselič et al., 2014; Bončina, 2017; Poročilo o izvajanju …, 2021) , Slovenian forests have not yet been thoroughly analysed from a sustainable development perspective. This paper aims to introduce readers to the basic information about the development of forests at the national level between 2000 and 2018. Additionally, it provides some information about the suitability of the systematic grid used for data collection. The study also examines how many SFM indicators can be assessed using the 2018 FFECS data. Lastly, it compares the findings with information available for European forests and the forests of some selected countries and discusses them in the context of SFM.

2 METHODS

2 METODE DELA

2.1 Definition of sustainable forest development

2.1 Definicija trajnostnega gospodarjenja z gozdovi

This study defined SFM in the same way as Forest Europe (i.e. "… the stewardship and use of forests and forestlands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national and global levels, and that does not cause damage to other ecosystems" (Forest Europe, 2022)). The understanding of the definition was more rigid as it considered the development of semi-natural forests to be sustainable only if their tree populations were demographically balanced. Such an understanding also suggested that the demographic balance should take precedence when searching for balance among the ecological, productional and social components of SFM. This condition stems from the idea that only forests at or near equilibrium can provide the basic forest ecosystem services over long time horizons.

2.2 Specific indicators and SFM indicators

2.2 Specifični kazalniki in kazalniki trajnostnega gospodarjenja z gozdovi (TGG)

All used data came from the FFECS database (GIS-NMGK, 1985–2018), collected between the years 2000 and 2018 on a 4 x 4 km systematic grid. Because this inventory provided a very small amount of data due to its irregular repetition and the exclusion of many variables from regular assessments, some of the SFM indicators could not be included in this analysis.

The number of concentric permanent sample plots in the observed period varied (582 in 2000; 724 in 2007; 760 in 2012; 759 in 2018) due to necessary inventory improvements (Kovač et al., 2014). Their numbers stabilized in 2012 and since then have been dependant only on land use changes. The geo datasets of ecoregions and forest regions (Kutnar et al., 2002; Pregledovalnik …, s. a.) were used for post-stratifications.

The evaluation of sustainable forest development was carried out with the data of a rather small number of simple and composite variables and available SFM indicators (Forest Europe, 2015), presented in Table 1. All analyses were performed using Microsoft 365, R-core team, Statistica v. 13, and ArcGIS v. 10.8.1 (R core …, s. a.; Statistica …, s. a.; ArcMap …, s. a.).

2.3 Computations

2.3 Izračuni

2.3.1 Forest area, basal area, growing stock, stand density index

2.3.1 Površina gozdov, temeljnica, lesna zaloga, indeks sestojne gostote

Apart from the forest area, the plot values for basal area (BA), growing stock (GS) and stand density index

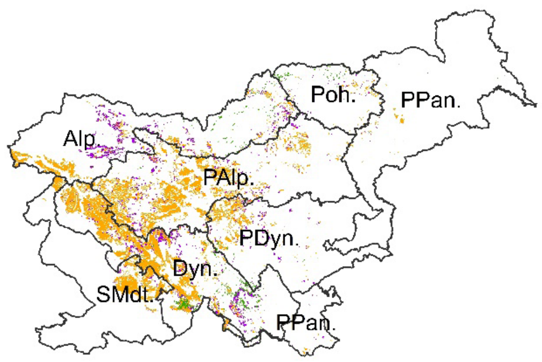


Fig. 1 a

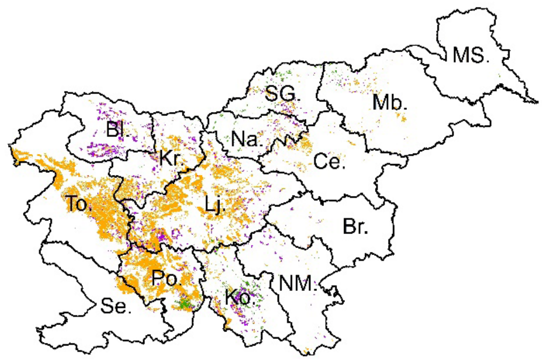


Fig. 1 b

Fig. 1: a) Ecoregions: Alp = Alpine; Poh = Pohorje; PPan = Prepannonian; Palp = Prealpine; Pdyn = Predinaric; Dyn = Dinaric; SMdt = Submediterranean, b) 14 Forest regions: To = Tolmin; Bl = Bled; Kr = Kranj; Lj = Ljubljana; Po = Postojna; Ko = Kočevje; NM = Novo mesto; Br = Brežice; Ce = Celje; Na = Nazarje; SG = Slovenj Gradec; Mb = Maribor; MS = Murska Sobota; Se = Sežana. Both figures show damaged forest areas by cause: bark beetles (violete; 2015–2018), ice storm (orange; 2014) and windthrows (green; 2017–2018) (Pregledovalnik …, s. a.).

Slika 1: a) Ekoregije: Alp = Alpska; Poh = Pohorska; Ppan = Predpanonska; Palp = Predalpska; Pdyn = Preddinarska; Dyn = Dinarska; SMdt = Submediteranska, b) 14 Gozdnogospodarska območja: To = Tolmin; Bl = Bled; Kr = Kranj; Lj = Ljubljana; Po = Postojna; Ko = Kočevje; NM = Novo mesto; Br = Brežice; Ce = Celje; Na = Nazarje; SG = Slovenj Gradec; Mb = Maribor; MS = Murska Sobota; Se = Sežana. Obe sliki prikazujeta območja poškodovanosti gozdov zaradi: podlubnikov (vijolično; 2015–2018), žledoloma (oranžno; 2014) in vetrolomov (zeleno; 2017–2018) (Pregledovalnik …, b. l.).

Table 1: Original and calculated FFECS data and SFM indicators (Kovač, 2014a)

Preglednica 1: Osnovni in izračunani podatki Monitoringa gozdov in gozdnih ekosistemov (MGGE) in kazalniki TGG (Kovač, 2014a)

SFM indicator definition (Forest Europe)	Original data	Description	Description (continuation)	Used composite / auxiliary variables	Source
	Concentric permanent sample plot	R1: 3.09 m (small trees DBH < 10 cm, H ≥ 1.3 m) R2: 7.98 m (DBH ≥ 10 cm)	R3: 13.82 m (DBH ≥ 30 cm) R4: 25.23 m (deadwood, site exposition, microrelief, …)		FFECS
1.1 Forest area (by forest type* and OWL*)	Forest area	Forest area ≥ 0.25 ha			FFECS
1.2 Growing stock (GS) (by forest type* and OWL*)	DBH of a tree	Alive: DBH ≥ 10 cm Standing dead: DBH ≥ 10 cm	Ingrown: DBH ≥ 10 cm Cut: DBH ≥ 10 cm	Basal area (BA), number of trees, stand density index (SDI), balanced and optimal growing stock	FFECS
1.3 Age structure and/or diameter distribution	Vertical structure	Evenly-aged Unevenly-aged	Coppice, Multi-storey		FFECS
	DBH of a tree	Alive: DBH ≥ 10 cm		Diameter distribution	FFECS
	Even-aged stand Development phase	Young stand = Yst; DBH < 10 cm Pole1 = DBH 10–19.9 cm Pole2 = DBH 20–29.9 cm	Sawlog1 = Swl1: DBH 30–39.9 cm Sawlog2 = Swl2: DBH 40–49.9 cm Sawlog3 = Swl3: DBH ≥ 50 cm	Current and normal shares of development phases	FFECS
	Uneven-aged stand	UnevA = all DBH ≥ 10 cm		Taken as a whole, not classified with respect to DBH	FFECS
3.1 Increment and felling	DBH of a tree	Alive: DBH ≥ 10 cm Ingrown: DBH ≥ 10 cm	Cut: DBH ≥ 10 cm	Increment, felling (the tendency in increment in severely damaged stands)	FFECS
4.1 Diversity of tree species	Tree species	Share in volume		Species composition (the composition of ingrown trees)	FFECS
	Ingrowth	No. of ingrown trees (by DBH classes)		Future species composition	FFECS
4.2 Regeneration of forests	Presence	Yes, No		Regeneration area by type	FFECS
	Development phase	Young forest			
	Stand origin	Natural regeneration Artificial regeneration	Combined (natural + artificial) Unknown		
4.3 Naturalness	Naturalness	Natural forest Seminatural forest	Forest with exchanged tree species composition	Share of naturalness	FFECS
4.5 Deadwood		Standing: DBH ≥ 10 cm Downed: DBH ≥ 10 cm Snag: DBH ≥ 10 cm, H ≥ 50 cm	Stump: DBH ≥ 10 cm, H ≥ 20 cm Course woody debris: DBH ≥ 10 cm, L ≥ 50 cm	Deadwood assessment (unclassified by type)	FFECS

* Forest type and other wooded lands (OWL) not assessed.

(SDI) were calculated using FFECS protocols (Kušar et al., 2010). Because the FFECS did not provide any information on forest types, forest areas available for wood supply and other wooded lands, all estimates referred to forests only. All density variables were calculated to values per hectare. The values of growing stock were calculated via the Kauffman approach (2001).

Stand density index (SDI; Pretzsch, 2009) is suggested for the assessment of stocking at large scales (Woodall et al., 2005). Despite the large variability of tree diameters, the formula for evenly aged forests was used ($SDI = N_{trees}*(25/D)^{-1.605}$; D is mean diameter) because of the predominance of shelterwood stands (97% according to FFECS). To compare the SDI values, we derived the reference ("normal") SDI line segments for spruce and beech (Fig. 7a, b, 8a). As suggested by Hladnik and Žižek Kulovec (2014), these reference values were calculated using the "average" site index values (SI) given in the Swiss (Badoux, 1966) and Slovak (Kotar, 2003) yield tables (Swiss tables: SI_{50} for beech and mountain spruce = 18; Slovak tables: SI_{100} for beech and mountain spruce = 28, productivity level = 2). Both tables are well known and widely used in Slovenian forest research. The SDI values represent the following forest densities: 0–400 = very low density; 400–600 = low density; 600–800 = normal density; 800–1200 = high density; and SDI > 1200 = very high density (Brassel, 2001).

2.3.2 Age structure and/or diameter distribution, balance of developmental phases, normal and optimal growing stock

2.3.2 Starostna struktura/porazdelitev prsnih premerov, ravnotežje razvojnih faz, normalna in optimalna lesna zaloga

Instead of using the age-class approach (FFECS provided the data on stand age for most plots; the variable was not determined accurately, e.g. by drilling, but by visual assessments and by counting stump rings), we derived the demographic picture of evenly aged forests, managed by various forms of shelterwood systems, by analysing the distributions of developmental phases and constructing the normal forest model (von Gadow, 2005). Average transition periods were derived from the diameters of the same 9,032 trees, measured from 2000 to 2018. Because each plot belonged to only one developmental phase, the average time for overgrowing each phase was calculated from all trees in that developmental phase. After the calculation, the transition periods were modified, considering the results of specific forest growth and yield studies (Čokl, 1965; 1966; 1968; Kadunc, 2009; 2011) and the data of the Swiss and Slovak (Halay) yield tables. This modification was unavoidable because the calculated developmental phase transition times were overshadowed by the unevenness of stands due to long regeneration periods and delayed transitions, caused by a series of large-scale natural events.

Another reason for this modification was the long production periods, often leading to tree over-maturity. In accordance with scientific suggestions for increasing the resilience of forests (Brang et al., 2013; Levanič et al., 2020), we set the average production period for all forests in the country at 125 years (for forests under 600 m a.s.l. at 110 years, and for forest above 600 m a.s.l. at 135 years). The normal growing stock was computed using the normal areas of developmental phases and their actual mean growing stocks. For the needs of future forest management (viz. carbon sequestration), we also derived the optimal growing stock using the aforementioned normal areas of developmental phases and the growing stocks suggested by the Swiss and Slovak yield tables. The same site index values were used as in the SDI calculations. Furthermore, to show that future forest management had many options, we also performed a simulation with the balanced growing stock by using the mean growing stock values of developmental phases of the Swiss and the Burgenland (AT) forests (Österreichische … s. a.; Swiss … s. a.). This Austrian region is ecologically very similar to the forest region of Murska Sobota and the Prepannonian ecoregion. Its forest composition is also comparable with Slovenian forests because of its larger share of broadleaves than in Carinthian and Styrian forests.

2.3.3 Increment and felling

2.3.3 Prirastek in sečnja

The plot values of increment and felling were computed using FFECS protocols (Kušar et al., 2010). We computed i) the gross increment including ingrowth and half of the increment of felled trees and ii) the gross increment without ingrowth and the increment of felled trees (GI). The second option was used for comparisons. Because of many natural disasters between 2012 and 2018 (ice storm, bark beetles, windthrows), the mean increment and felling were also separately evaluated for damaged areas (Fig. 1) (Pregledovalnik …, s. a.)).

2.3.4 Diversity of species, species mixture, forest regeneration, naturalness, deadwood

2.3.4 Različnost drevesnih vrst, mešanost sestojev, pomlajevanje, naravnost, odmrla drevnina

The data on species proportions (forest mixture), naturalness and deadwood were collected using the FFECS protocol. Tree species proportions were presented with volume proportions, and differences between the observed years were examined with statistical tests. To show what species composition would prevail in the future, a more detailed analysis based on tree counts was carried out. To simplify the calculations with different weights of circular plots, only the inner plot, determined by the R2 radius, was used. Tree species proportions were calculated using the 2018 dataset. Classes included trees with the diameters of 10–12 cm (this range was chosen for statistical purposes), 12.1–20 cm, 20.1–30 cm, 30.1–40 cm, 40.1–50 cm and over 50 cm. Apart from beech, fir and spruce, whose proportions were analysed at the ecoregional level, changes in the proportions of the other species were analysed solely at the national level.

The rejuvenated area was estimated with the percent of area belonging to the young developmental phase. The FFECS estimate was also compared with the normal forest model value.

2.3.5 Evaluation of sustainability with the selected indicators of SFM

2.3.5 Presoja trajnosti gozdov z izbranimi kazalniki TGG

The state of sustainability of selected SFM indicators is normally determined by evaluating the discrepancies between their current and target values. Because the target values have not yet been set (Bončina, 2017; Kovač et al., 2019a; Kovač et al., 2019b), the desired values (Bennetts and Bingham, 2007), represented by the long-term averages, normal forest model values, yield table values, and suggestions and evidence from the scientific literature, were used instead. The states of the current conditions were defined either as favourable or unfavourable. As mentioned, the list of SFM indicators used was incomplete. Nevertheless, with the exception of forest ecosystem health and vitality and soil indicators, the most pertinent ones characterizing forest development were included.

- Forest area has become a notable indicator after being recognized as one of the carbon pools. The research of Žumer (1976) reveals that Slovenia's forest cover has been increasing since 1875, when it was estimated at 36% (737,000 ha). For the sake of this study, a desired value for forest cover was defined subjectively, with a range. The range was compared with the forest areas of the EU27 Member states (Eurostat, 2022).
- From an ecological point of view, the height of growing stock volume is a less critical factor of forest ecosystem development. However, its role becomes significant as soon as we begin dealing with mitigating climate change effects and with the national forest economy. To be able to evaluate its further development, we defined its desired value with the range of the possible values of the optimal growing stock.
- Despite often being underestimated, age structure (demographic portrayal) is a notable factor in the development of seminatural forests. As this indicator has not been collected by the FFECS, it was replaced by the structure of developmental phases. Desired proportions for all developmental phases were defined with the normal forest model.
- The ratio of felling and increment defines the intensity of forest management. Its desired value was set at a level that upholds a more intensive management and a faster improvement of the demographic portrayal. The ratio was checked with yield tables.
- Along with the demographic portrayal of stands, tree species composition is an essential factor of near natural forest management. It helps determine the degree of forest naturalness and the conservation status of forest habitat types (Kovač et al., 2020). Because the definition of tree species composition is meaningful at the forest habitat type level, we defined desired values (viz. ranges) by means of vegetation models (Veselič, 2000) at the national level and evaluated their development trend.
- The desired area of forest regeneration was defined by the normal forest model. This value was compared with the actual FFECS values between 2000 and 2018 and with some historical data.
- Deadwood is suggested as one of the many biodiversity indicators (Harmon et al., 1986). As the amounts for concrete species are generally unknown, the desired value was set by comparing the current national data and some of the EU27 data.

2.3.6 Suitability of the systematic sampling grid
2.3.6 Primernost sistematične vzorčne mreže

The aim of this analysis was to investigate whether the estimates were influenced by periodicity in the population of Slovenian forests. We arranged the permanent sample plots into 20 km wide strips (odd, even) and aligned them in four cardinal directions (north-south = $a_{1,2}$, east-west = $b_{1,2}$, northeast-southwest = $c_{1,2}$, southeast-northwest = $d_{1,2}$; Fig. 2). We then tested the differences in variances and mean growing stocks of these eight combinations for the years 2012 and 2018. Additionally, we investigated (2018 data) the autocorrelation of the growing stock with four- and eight-km lags (Isaaks and Srivastava, 1989). Among the 37 west-east parallels with sample plots, 11 line segments with at least seven consecutive sample plots were selected. Because of the small number of segments and plots, we decided not to derive a correlation function.

2.3.7 Statistical computations
2.3.7 Statistični izračuni

Familiar design-based statistics, such as sample total, mean, ratio and variance were used (Table 2). The

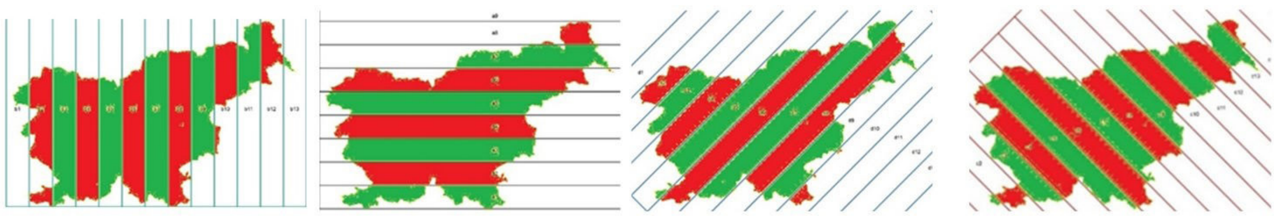


Fig. 2: Division of the country's area into 20 km wide strips (N-S odd, even; E-W odd, even; NE-SW odd, even; SE-NW = odd, even)

Slika 2: Razdelitev površine države na 20 km proge (S-J lihe, sode; V-Z lihe, sode; SV-JZ lihe, sode; JV-SZ = lihe, sode)

Table 2: Statistical techniques used

Preglednica 2: Uporabljene statistične metode

Estimators/statistics	Used for
Estimation of totals, means, variances, confidence intervals	Total forest area, mean growing stock and increment
Estimation of ratios $R = \Sigma (Y_i / X_i)$	Felling/increment ratio
Comparison of proportions: Z under H_0: $p_1 – p_2 = 0$	Proportions of tree species in successive observations
Comparison of two means: T/Z under H_0: $y_1 – y_2$; pooled and separate (not-pooled) variance approaches	Growing stock values, increment, felling
Comparison of two means; t-test for independent and dependant samples	Growing stock, increment, increment of damaged forests, deadwood comparison
Comparison of means; one-way analysis of variance; H_0: $M_1 = M_2 = \ldots = M_n$	SDI of different ecoregions, forest regions, development phases, grid analysis differences among the growing stock values in the 20 km wide strips, differences in deadwood among ecoregions
Comparison of equality of variances: Levene test	Comparison of variances in the 20 km wide strips
Spatial continuity; autocorrelation $Acor = \Sigma(Z_i Z_{i+h})^2 / \sigma_i \sigma_{i+h}$	For the 4 km and the 8 km lags

significance of differences over time was examined using the strategies shown in Table 2. Because of exhaustive computations, significance tests were performed only for subjectively selected variables and those considered relevant at the national or regional level. Time series were largely represented by frequency distributions.

2.3.8 Completeness of indicators for the purpose of SFM analyses and reporting

2.3.8 Popolnost kazalnikov za potrebe presojanja TGG in poročanja

The completeness of data needed for constructing the indicators of SFM was checked by a simple gap analysis. After the list of all sub-indicators was formed, we only determined which sub-indicators could be calculated either completely or partly.

3 RESULTS

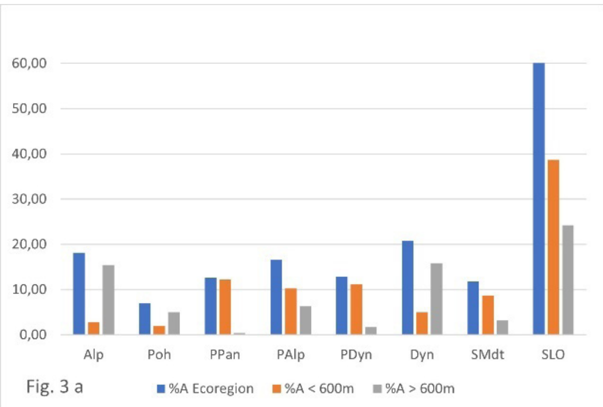
3 REZULTATI

3.1 Forest area, basal area, stand density index, growing stock

3.1 Površina gozdov, temeljnica, indeks sestojne gostote, lesna zaloga

After long-lasting spontaneous afforestation of abandoned agricultural lands (Kobler et al., 2005), occasional reclamation of forest land, and land use conversions, the national forest area began to stabilize after 2000 (1,139,200 ± 55,348 ha; forest cover = 56%) and was estimated at 1,214,000 ± 54,663 ha in 2018 (forest cover = 60%). The change in proportions was insignificant ($Z = 1.86 < 1.96$; $P = 0.0314 > \alpha/2 = 0.025$). Fifty-two per cent of forests were below 600 m a.s.l. and 48% were above this line. Forests were most abundant in the Dinaric, Alpine and Prealpine ecoregions. The richest in forests were the forest regions of Tolmin (ca. 155,000 ha), Ljubljana (ca. 139,000 ha), Novo mesto (ca. 102,000 ha) and Kočevje (ca. 102,000 ha) (Fig. 3).

The mean basal area increased from 29.4 m²/ha ± 1.1 m²/ha to 32.2 m²/ha ± 1.1 m²/ha between 2000 and



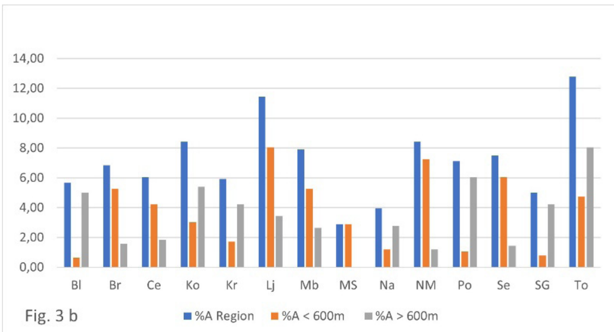
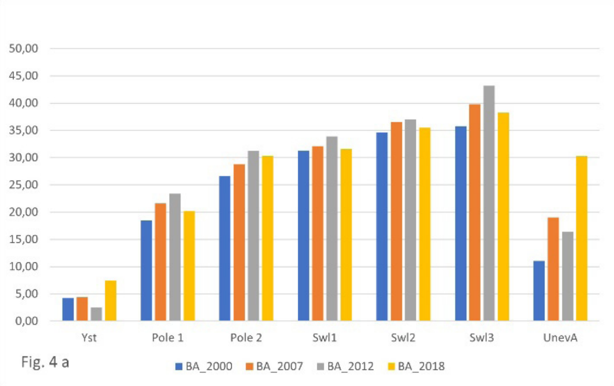


Fig. 3: Distribution of national forests (in % area = % A) by ecoregions (a) and forest regions (b). % A < > 600 m = % of area below/above 600 m a.s.l. See also Table 1 for abbreviations.

Slika 3: Porazdelitev slovenskih gozdov (v % površine = % A) po ekoregijah (a) in gozdnogospodarskih območjih (b). % A < > 600 m = % površine pod/nad 600 m nadmorske višine. Za okrajšave glej tudi Preglednico 1.



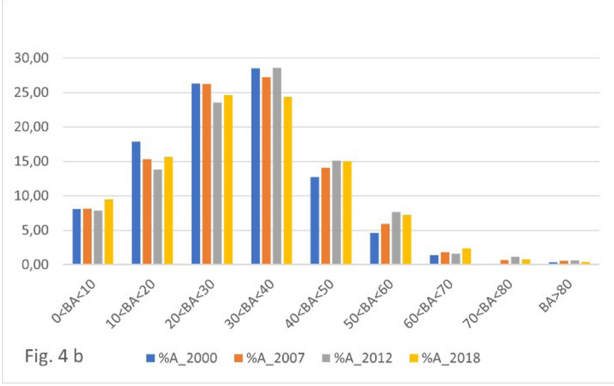


Fig. 4: a) Distribution of mean basal area (BA; m^2/ha) by development phases and in unevenly-aged forests between 2000 and 2018. The differences in BA within sawlog1 (P = 0.09) and sawlog2 (P = 0.45) were insignificant. Yst, Pole 1, 2, …, etc. see Table 1 for abbreviations; b) Distribution of forest areas A% by BA (m^2/ha) classes between 2000 and 2018.

Slika 4: a) Porazdelitev povprečne temeljnice (BA; m^2/ha) po razvojnih fazah in v raznodobnih gozdovih med letoma 2000 in 2018. Razlike v BA znotraj Swl 1 (debeljak 1) (P = 0,09) in Swl 2 (debeljak 2) (P = 0,45) so bile neznačilne. Yst (mladovje), Pole 1, 2 (drogovnjak 1 in 2), … itd. glej Preglednico 1 za okrajšave; b) Porazdelitev gozdnih površin A% po razredih BA (m^2/ha) med letoma 2000 in 2018.

2012 and then decreased to 30.7 m^2/ha ± 1.1 m^2/ha in 2018. The basal area of the forests above 600 m a.s.l. was ca. 17% higher than that of the lowland forests. Although the changes in basal areas over time were statistically significant (all phases from pole2–swl3; P = 0.000), the changes in basal areas within the particular development phases were not (Fig. 4a). The highest basal areas occurred in the Pohorje ecoregion (40 m^2/ha) and the lowest in the Submediterranean ecoregion (24 m^2/ha). During the observed period, almost 50% of forestlands had basal areas lower than 30 m^2/ha.

Various analyses of stand density index (SDI) provided detailed insights into stand structures. Between 2000 and 2012, the mean SDI grew steadily from 576 ± 21 to 619 ± 21 and then decreased to 592 ± 21 (2012–2018); the differences between these means were statistically significant (P = 0.039). Conversely, the difference in mean SDIs between 2000 and 2018 was not significant (P = 0.291). In 2018, the highest mean SDI values occurred in the forest regions of Slovenj Gradec (744 ± 112) and Kranj (701 ± 99) and the lowest in the regions of Sežana (512 ± 77) and Ljubljana (516 ± 55) (Fig. 5a). Its values within the developmental phases remained homogeneous (Fig. 5b).

Similarly, the highest average SDIs were found in the Pohorje (615 ± 48) and the Alpine (653 ± 62) ecoregions and the lowest in the Submediterranean (494 ± 60) and Predinaric (552 ± 54) ecoregions. The distribution of forest areas, classified by the SDI classes in ecoregions, showed that the area proportions with SDIs higher than 800 remained mostly below 20% (exceptions were in the Pohorje ecoregion and in the Alps; Fig. 6a). Additionally, a detailed examination of sawlog stands revealed that about 31% (ca. 261,000 ha) of them had SDIs lower than 500 and 24% of them had SDIs higher than 800 (Fig. 6b).

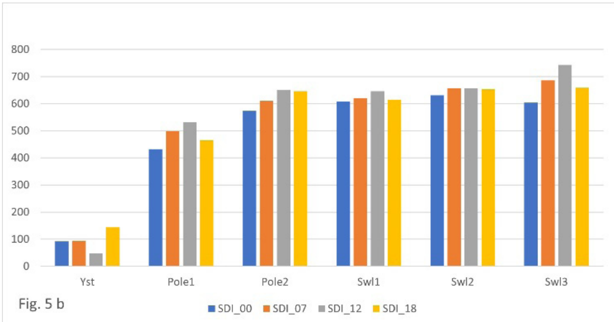
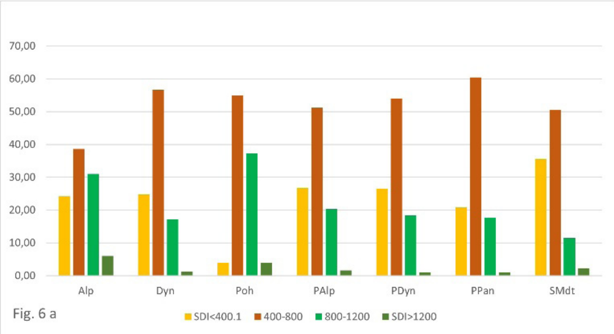


Fig. 5: a) Distribution of mean SDI by forest region; b) Distribution of mean SDI by development phase (young stands excluded from analysis; within the individual phases, viz. Pole1, Pole2, … Swl3, differences in SDIs between years were insignificant; P values ranged between 0.08 and 0.78).

Slika 5: a) Porazdelitev povprečnega SDI po gozdnih regijah; b): Porazdelitev povprečnih SDI po razvojnih fazah (mladi sestoji izvzeti iz analize; znotraj posameznih faz, tj. Pole1 (drogovnjak 1), Pole2 (drogovnjak 2), … Swl3 (debeljak 3), so bile razlike v SDI med leti neznačilne; vrednosti P so se gibale med 0,08 in 0,78).



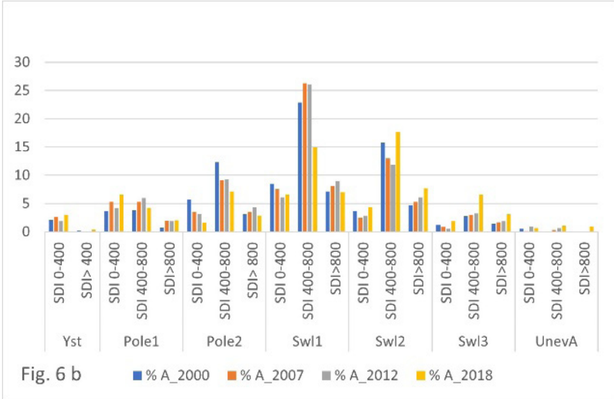
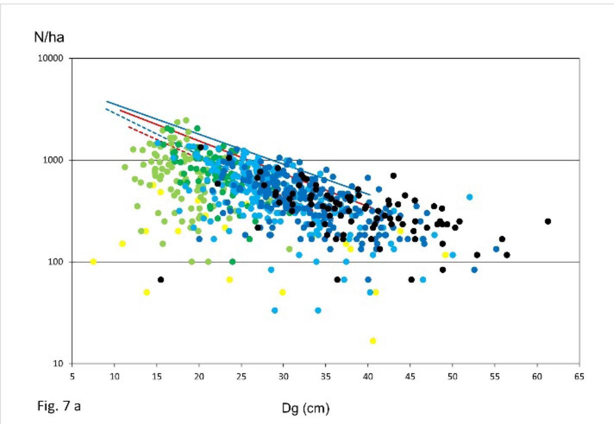


Fig. 6: a) Distribution of SDI classes (relative area %) by ecoregions; b) Distribution of area % (A %) by SDI and developmental phase over time.

Slika 6: a) Porazdelitev razredov SDI (relativna površina %) po ekoregijah; b) Porazdelitev % površine (A %) po SDI in razvojnih fazah po letih.

As Fig. 7a shows, the spread of SDIs in pole (1, 2) and a sawlog1 stands was large. In a considerable proportion of stands, the SDIs were lower than their "normal" values (line segment). The stand structures in the Pohorje and Dinaric ecoregions were quite different (Fig. 7b, 8b). While the stands in the Pohorje ecoregion were fully stocked, the stands in the Dinaric ecoregion were not (especially in sawlogs).

The mean growing stock increased from 2000, when it amounted to 299.3 ± 13.8 m^3/ha, to 2012, when it reached the value of 333.9 ± 13.7 m^3/ha. It then decreased to 329.6 ± 13.71 m^3/ha in 2018 (Fig. 8b). The difference between 2000 and 2012 was significant (F = 4.80; P = 0.002), but the difference between 2012 and 2018 was not (unpaired; t = 0.437; P = 0.66). In 2018, the highest mean growing stocks were observed in the forest regions of Slovenj Gradec (450 ± 60 m^3/ha) and Nazarje (422 ± 83 m^3/ha), while the lowest were in the regions of Sežana (199 ± 35 m^3/ha) and Ljubljana (275 ± 33 m^3/ha). Similarly, the Pohorje ecoregion had the highest mean growing stock (469 ± 54 m^3/ha) and the Submediterranean ecoregion the lowest (199 ± 28 m^3/ha; Fig. 9a). These two ecoregions also made the differences in growing stocks statistically significant (P = 0.000). With the exception of the Prepannonian and Submediterranean lowlands, mean growing stocks



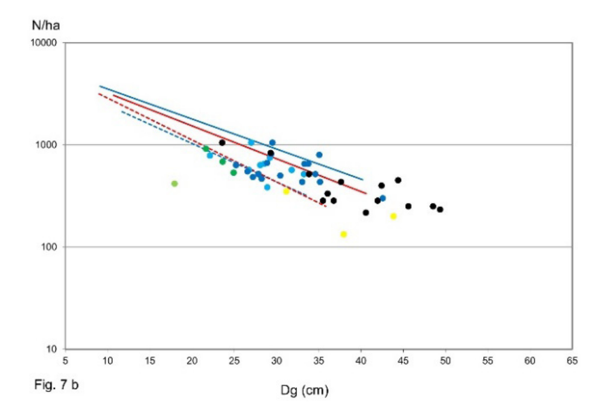
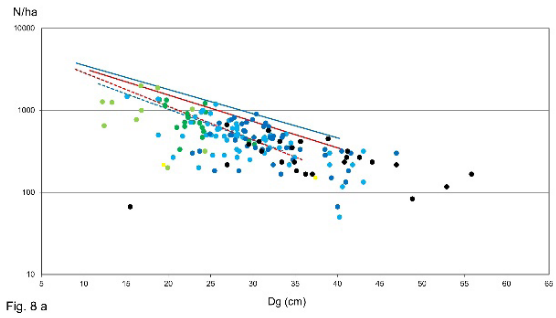


Fig. 7: a) Relationship between the Dg and N/ha in national forests. Slovenia (n = 744, 2018; missing inaccessible plots without field data). Dots: yellow = young stands; light green = pole1; dark green = pole2; light blue = sawlog1, dark blue = sawlog2, black = sawlog3; Normal line segments: blue = spruce (mountain sites), Slovak tables (SI_{100} = 28, productivity level = 2); red = beech (mountain sites), Halay tables (SI_{100} = 28, productivity level = 2); dashed blue = spruce, Swiss tables (SI_{50} = 18); dashed red = beech, Swiss tables (SI_{50} = 18). Swiss tables provide lower values than Slovak (Halay) tables. X-axis: Dg (cm) = middle basal area tree; b) Relationship between the Dg and N/ha in the Pohorje ecoregion (n = 51, 2018).

Slika 7: a) Razmerje med Dg in N/ha v slovenskih gozdovih. Slovenija (n = 744, 2018; manjkajo nedostopne ploskve brez terenskih podatkov). Točke: rumena = mladovje; svetlo zelena = drogovnjak 1; temno zelena = drogovnjak 2; svetlo modra = debeljak1, temno modra = debeljak2, črna = debeljak3; črte: modra = smreka (gorska rastišča), slovaške tablice (SI_{100} = 28, raven produktivnosti = 2); rdeča = bukev (gorska rastišča), Halayeve tablice (SI_{100} = 28, stopnja produktivnosti = 2); črtkana modra = smreka, švicarske tablice (SI_{50} = 18); črtkana rdeča = bukev, švicarske tablice (SI_{50} = 18). Švicarske tablice dajejo nižje vrednosti kot slovaške (Halayeve) tablice. Os X: Dg (cm) = srednje temeljnično drevo; b) Razmerje med Dg in N/ha v ekoregiji Pohorje (n = 51, 2018).



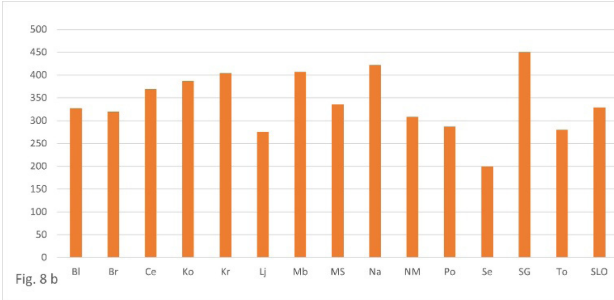


Fig. 8: a) Relationship between the Dg and N/ha in the Dinaric ecoregion (n = 157, 2018); b) Mean GS (m³/ha) in forest regions.

Slika 8: a) Razmerje med Dg in N/ha v dinarski ekoregiji (n = 157, 2018); b) Povprečna lesna zaloga (GS, m³/ha) v gozdnogospodarskih območjih.

were higher above the 600 m a.s.l. line (by ca. 20%). Between 2012 and 2018, the growing stock decreased in all developmental phases, except for young stands and unevenly-aged stands (Fig. 9b).

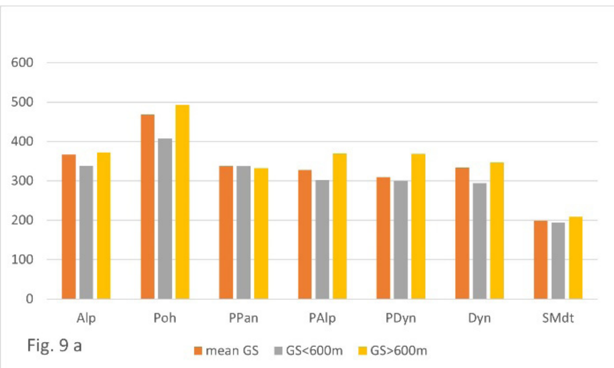
3.2 Age structure and/or diameter distribution, balance of developmental phases, optimal growing stock

3.2 Starostna struktura/porazdelitev prsnih premerov, ravnotežje razvojnih faz, optimalna lesna zaloga

Until the end of 2018, shelterwood and irregular shelterwood were the predominant stand forms of national forests (97%). Their demographic portrayal between 2000 and 2012 was stable (Fig. 10a; first three columns within each phase). However, after 2012 it began to change because of a series of natural events, such as the 2014 ice storm (Kobler et al., 2015), subsequent bark-beetle infestations, and occasional snow and wind storms. Although these large-scale events affected forests in various ways, overall changes at the national level were not large; the proportion of younger stands (i.e. Ystd + Pole1,2) decreased from 32% in 2000 to 30% in 2018, while the proportion of older stands (Swl 1,2,3) increased from 68% to 70% (Z_{Ystd} = 0.398 < 1.96; Z_{Swl} = 1.294 < 1.96 => P in both cases > $\alpha/2$ = 0.025) (Fig. 10a). The distribution of the developmental phases in the altitudinal belts was similar. The diameters of trees (Fig. 10b) were positively skewed in all developmental phases, indicating their large uneveness.

Regarding the differences in the area shares of developmental phases among the ecoregions or forest regions, the 2018 dataset showed that they were large and statistically significant (see details: Fig. 11a, b). The Dinaric, Pohorje and Prealpine ecoregions harboured more than 70% of older stands. Conversely, a much more favourable ratio between young and older stands was exhibited by the forests in the Submediterranean ecoregion (ca. 50% of sawlogs). Similarly, older forests accounted for more than 75% of the forest regions of Kranj, Kočevje, Nazarje and Maribor, while they amounted to about 53% in the regions of Tolmin and Sežana.

The demography of shelterwood stands was analysed with the normal forest model (Fig. 10a). The mod-



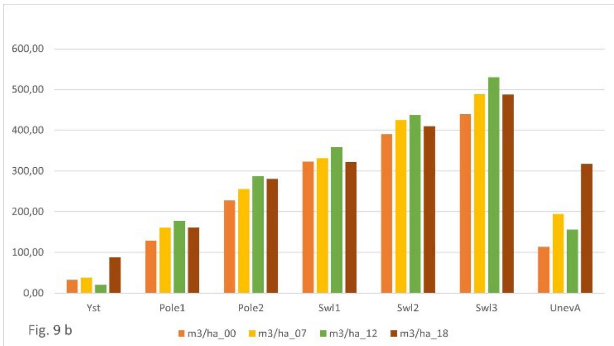
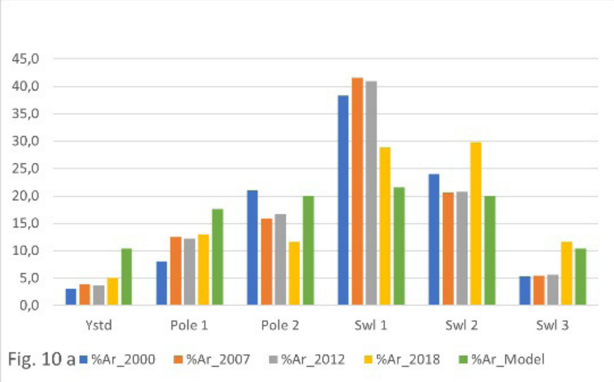


Fig. 9: a) Mean growing stock by ecoregions and altitude belts in ecoregions; b) Mean growing stock in developmental phases (both 2018). Large differences in growing stock in unevenly-aged stands are due to the transition of some plots from evenly aged into unevenly aged.

Slika 9: a) Povprečna lesna zaloga po ekoregijah in višinskih pasovih v ekoregijah; b) Povprečna lesna zaloga v razvojnih fazah (oboje 2018). Velike razlike v lesni zalogi v raznodobnih sestojih so posledica prehoda nekaterih ploskev iz enodobnih v raznodobne sestoje.



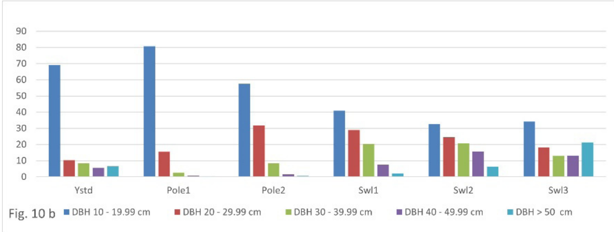


Fig. 10: a) Distribution of the developmental phase areas (in %) between 2000 and 2018 (first four columns). The fifth column (% A_Model) represents the areas derived by the normal forest model (Area = 1,180,800 ha, production period/rotation = 125 years); b) Distribution of DBH classes (in % of trees of each developmental phase) by developmental phases in 2018. An exponentially decaying curve is significant for most developmental phases.

Slika 10: a) Porazdelitev površin razvojnih faz (v %) med letoma 2000 in 2018 (prvi štirje stolpci). Peti stolpec (% A_Model) predstavlja površine, izračunane z modelom normalnega gozda (površina = 1.180.800 ha, proizvodna doba = 125 let); b) Porazdelitev razredov DBH (v % dreves posamezne razvojne faze) po razvojnih fazah v letu 2018. Za večino razvojnih faz je značilna eksponentno padajoča krivulja.

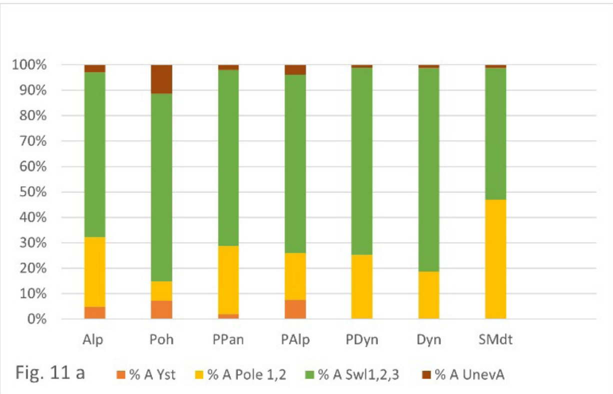
el revealed shortages of young and surpluses of older stands. The following findings are worth mentioning:

- In 2018, Slovenian forests lacked 169,152 ha of young stands (110,835 ha of young stands, approx. the area of the whole forest region of Postojna, and 58,417 ha of pole stands, approx. the area of all forests in the region of Bled). At the same time, there was a surplus of older stands in the same amount.
- The balanced growing stock was set at 296 m^3/ha (only shelterwood) and at 297 m^3/ha combined with unevenly-aged stands. A value of 276 m^3/ha was computed for the forests below the 600 m a.s.l. line and 303 m^3/ha for forests above this line.
- The balanced growing stock was lower than the optimal growing stocks (derived with the Swiss and Slovak yield tables) that were set at 319 m^3/ha and 421 m^3/ha, respectively. Similarly, a simulation with the balanced growing stock, computed with the values of the Burgenland and Swiss developmental phases (Österreichische ... s. a; WSL, 2022), amounted to 347 m^3/ha and 322 m^3/ha, respectively.

3.3 Increment and felling

3.3 Prirastek in sečnja

The 2012–2018 gross increment without ingrowth and half increment of cut trees (GI) was estimated at 6.85 ± 0.30 m^3/ha and was lower than the value between 2000 and 2007, which was 7.92 ± 0.32 m^3/ha (the 2018 gross increment with ingrowth and half increment of cut trees equalled 7.86 ± 0.32 m^3/ha, while the 2012 value was 8.60 ± 0.33 m^3/ha). With the exception of the Alpine ecoregion, gross increment first



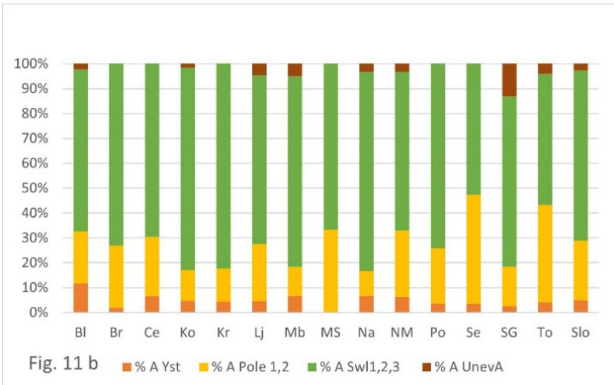
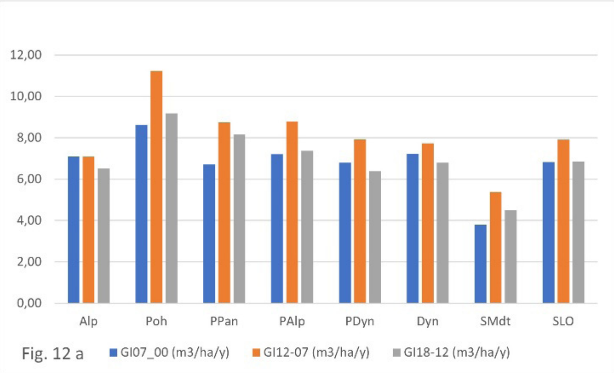


Fig. 11: a) Distribution of developmental phase area shares by ecoregions. Significance of differences in the shares of sawlogs: Dinaric vs Submediterranean–significant: Z = 4.96 > 1.96 at P = α/2 = 0.975; Dinaric vs Pohorje–insignificant: Z = 0.74 < 1.96 at P = α/2 = 0.975); b) Distribution of developmental phase area shares by forest regions.

Slika 11: a) Porazdelitev deležev površin razvojnih faz po ekoregijah. Značilnost razlik v deležih debeljakov: dinarska proti submediteranski – značilno: Z = 4,96 > 1,96 pri P = α/2 = 0,975; dinarska proti pohorski–neznačilno: Z = 0,74 < 1,96 pri P = α/2 = 0,975); b) Porazdelitev deležev površin razvojnih faz po gozdnogospodarskih območjih.



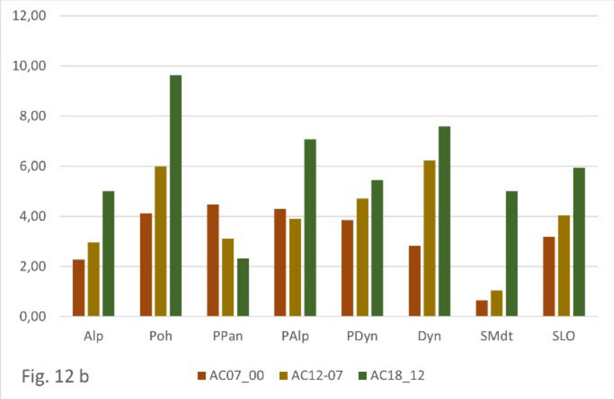


Fig. 12: a) Mean gross increment (GI) by ecoregions between 2000 and 2018. In 2018, differences in gross increment between ecoregions and forest regions (Fig. 13a) were significant (in both cases P = 0.0000). The difference in average annual increment (SLO) between 2000 and 2018 was insignificant (t = -0.089; df > 1000 => t => Z << 1.96, P = 0.0975); b) Mean annual cut (AC) by ecoregions between 2000 and 2018. In 2018, differences in felling between ecoregions and forest regions were insignificant. The difference in average annual felling (SLO) between 2007 and 2018 was significant ($t = -4.01 < -1.96; df_{unpooled} = 382 \Rightarrow t = 1.96$ for $\alpha/2 = 0.025$).

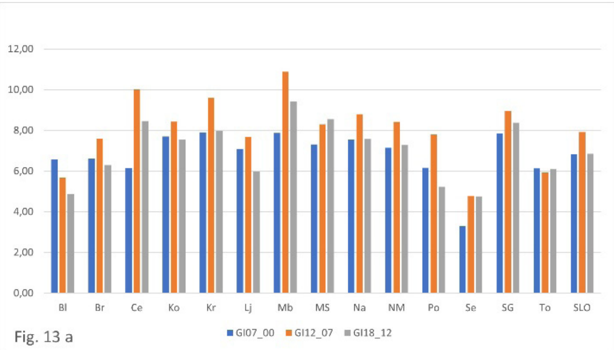
Slika 12: a) Povprečni bruto prirastek (GI) po ekoregijah med letoma 2000 in 2018. V letu 2018 so bile razlike v bruto prirastku med ekoregijami in gozdnogospodarskimi območji (slika 13a) značilne (v obeh primerih P = 0,0000). Razlika v povprečnem letnem prirastku (SLO) med letoma 2000 in 2018 je bila neznačilna (t = -0,089; df > 1000 => t => Z << 1,96, P = 0,0975); b) Povprečni letni posek (AC) po ekoregijah med letoma 2000 in 2018. V letu 2018 so bile razlike v poseku med ekoregijami in gozdnogospodarskimi območji neznačilne. Razlika v povprečnem letnem poseku (SLO) med letoma 2007 in 2018 je bila značilna ($t = -4,01 < -1,96; df_{unpooled} = 382 \Rightarrow t = 1,96$ za $\alpha/2 = 0,025$).

increased and then decreased in all other ecoregions (Fig. 12a). A similar trend was observed in forest regions (Fig. 13a). Quite a different trend was observed in the Bled forest region, where gross increment was continuously decreasing and in Murska Sobota, where it was constantly increasing. In the forest region of Tolmin, gross increment remained stable over the period.

Between 2012 and 2018, the mean annual felling without half increment of cut trees was estimated to be 5.94 ± 1.18 m^3/ha (with half increment 6.27 ± 1.2 m^3/ha) and was higher than that between 2007 and 2012, which equalled 4.03 ± 0.80 m^3/ha. Since 2000, the mean annual felling increased in all regions except the Pre-Pannonian, where it decreased (Fig. 12b, 13b).

During the 2000–2007, 2007–2012 and 2012–2018 periods, gross increment and annual felling developed with different trends. While gross increment first increased in most ecoregions and forest regions despite increasing annual felling, this direction reversed after 2012. This fact is noteworthy because not all ecoregions and forest regions were impacted by hazardous events and increased felling.

From 2000 to 2012, the mean annual felling in the developmental phases was lower than the gross increment (GI) (Fig. 14a). From 2000 to 2007, the ratio of felling and increment (R_{ACGI}) was 47% and increased to 52% between the years 2007 to 2012. However, after 2012, a series of consecutive hazardous events struck forests, leading to a significant change in trend, and the R_{ACGI} increased to 88% (Fig. 14b, see SLO).



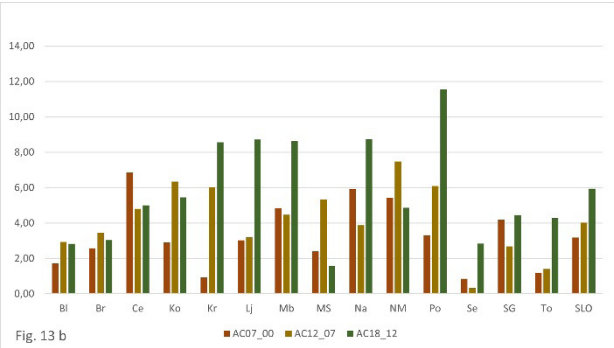
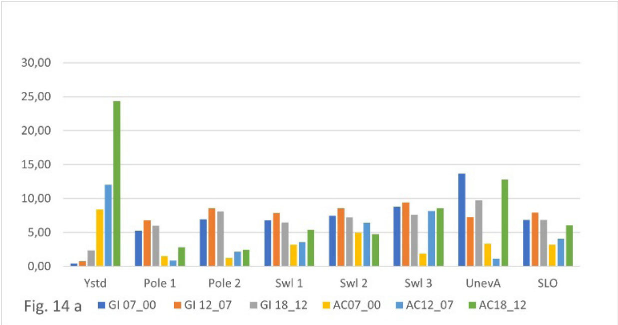


Fig. 13: a) Mean gross increment (GI) by forest regions between 2000 and 2018; b) Mean annual felling (AC) by forest regions between 2000 and 2018.

Slika 13: a) Povprečni bruto prirastek (GI) po gozdnogospodarskih območjih med 2000 in 2018; b) Povprečni letni posek (AC) po gozdnogospodarskih območjih med 2000 in 2018.



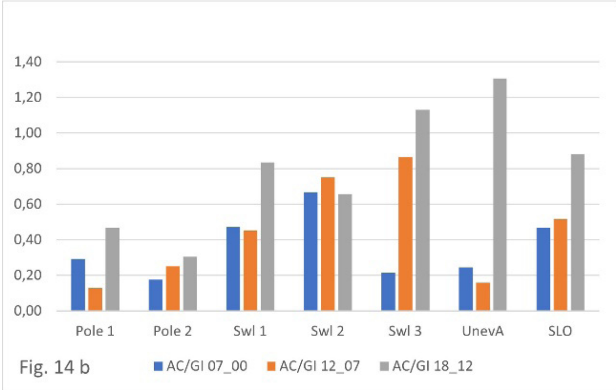
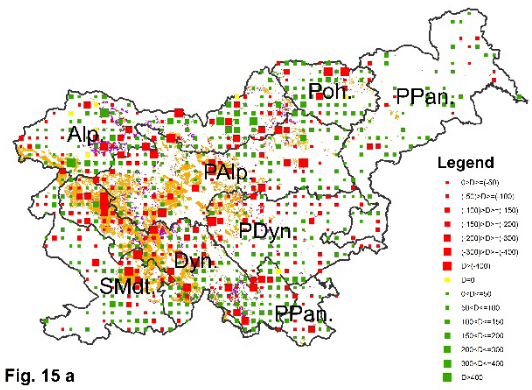


Fig. 14: a) Gross increment (GI) and annual felling (AC) by developmental phases between 2000 and 2018 (both in m^3/ha/y); b) R_{ACGI}: Ratio of annual felling and gross increment in developmental phases between 2000 and 2018, in uneven-aged stands and Slovenia (the ratio for young stands not shown; its values were 19.42 between 2007 and 2000, 15.45 between 2007 and 2000 and 10.35 between 2018 and 2012).

Slika 14: a) Bruto prirastek (GI) in letni posek (AC) po razvojnih fazah med letoma 2000 in 2018 (oboje v m^3/ha/leto); b) R_{ACGI}: Razmerje med letnim posekom in bruto prirastkom v razvojnih fazah med letoma 2000 in 2018, v raznodobnih sestojih in Sloveniji (razmerje za mlade sestoje ni prikazano; njegove vrednosti so bile med letoma 2007 in 2000 19,42, med leti 2007 in 2000 15,45 oz. 10,35 med letoma 2018 in 2012).

Apart from the forests in the Prepannonian ecoregion (R_{ACGI} = 0.29), the events affected all forests. In the Dinaric, Submediterranean and Pohorje ecoregions, the ratios reached 1.12, 1.12 and 1.05, respectively. In the other regions they ranged from 0.83 to 0.97. Of all forest regions, the largest increase in felling took place in the forest regions of Postojna (by a factor of 2.20), Ljubljana (1.50), Nazarje (1.29) and Kranj (1.07). Of 702 paired plots (viz. measured consecutively) between 2007 and 2018, 143 plots were affected by the hazardous events (131 by one event, 12 by two) (Fig. 15a, b, Table 3).

- Before the events, the growing stock of affected plots was above average compared to all measured plots (Δ = + 10.3 m^3/ha = 354.1 m^3/ha–343.8 m^3/ha). In 2018, these plots fell below the average (Δ = -35.5 m^3/ha = 336.5 m^3/ha–301.0 m^3/ha).
- In the period 2012–2018, the change in growing stock on the damaged plots was estimated to be -53.1 m^3/ha. The difference was 7 times greater than the mean of all plots measured consecutively (702 plots), whose difference was -7.3 m^3/ha. Because of negative differences on all plots, the overall growing stock decrease was estimated at -4.3 m^3/ha (2012–2018).
- Similarly, the decrease in the increment on affected plots was much larger (increment difference -2.04 m^3/ha year) compared to unaffected plots. During the period 2012–2018, the increment decreased everywhere.
- The felling on the damaged plots doubled compared to the plots without damage. The average felling was almost 2 m^3/ha higher in the period 2012–2018 than in the period 2007–2012.



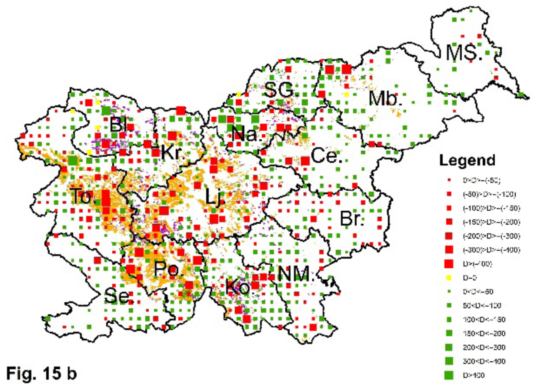


Fig. 15: Growing stock changes (D–difference from the mean growing stock) between 2012 and 2018 and damaged areas (ice storm, bark beetles, windthrows; Pregledovalnik ..., s. a.) by ecoregions (a) and by forest regions (b)

Slika 15: Spremembe lesne zaloge (D–razlika od povprečne lesne zaloge) med letoma 2012 in 2018 ter prizadete površine (žledolom, podlubniki, vetrolom; Pregledovalnik ..., b. l.) po ekoregijah (a) in po gozdnogospodarskih območjih (b)

Table 3: Data for the plots measured consecutively (2007–2012–2018)

Preglednica 3: Podatki za zaporedno izmerjene ploskve (2007–2012–2018)

Event	n[1]	Growing stock			Growing stock difference		Gross increment[2]		Felling[3]		Ingrowth		Mortality	
		2007	2012	2018	2007/12	2012/18	2007/12	2012/18	2007/12	2012/18	2007/12	2012/18	2007/12	2012/18
		m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha y	m^3/ha y	m^3/ha y	m^3/ha y	m^3/ha y	m^3/ha y	m^3/ha y	m^3/ha y
NO	559	311.6	341.1	345.6	29.5	4.7	7.90	7.04	4.15	5.05	0.40	0.33	0.99	1.78
O	143	318.8	354.1	301.0	35.3	-53.1	8.03	5.99	3.55	10.41	0.32	0.21	1.03	4.07
(NO+O)[4]	702	313.1	343.8	336.5	30.7	-7.3	7.93	6.83	4.02	6.14	0.38	0.31	1.00	2.25
SLO		313.7	333.9	329.6	20.2	-4.3	7.92	6.85	4.10	5.94	0.38	0.33	0.99	2.23

Remark: [1]n = 724 in 2007, n = 760 in 2012, n = 759 in 2018; NO = event did not occur; O = event did occur; [2]growing stock gross increment (without ingrowth and half increment of cut trees); [3]felling (without half increment of cut trees); [4]all plots measured consecutively.

Opomba: [1]n = 724 leta 2007, n = 760 leta 2012, n = 759 leta 2018; NO = dogodek se ni zgodil; O = dogodek se je zgodil; [2] bruto prirastek lesne zaloge (brez prirastka in polovice prirastka posekanih dreves); [3] posek (brez polovice prirastka posekanih dreves); [4] vse ploskve izmerjene zaporedno.

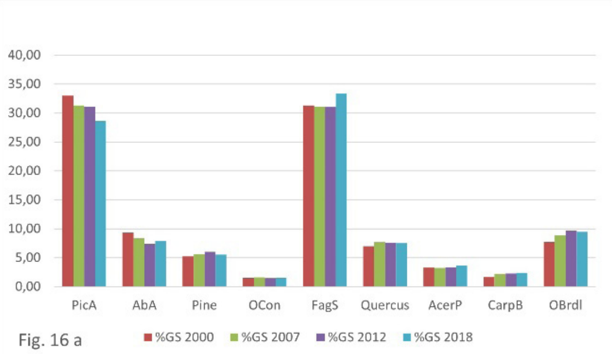
- A general increase in felling and the decrease in increment should be considered the main reasons for the average growing stock decrease.

3.4 Diversity of tree species, species mixtures, forest regeneration, naturalness and deadwood

3.4 Različnost drevesnih vrst, mešanost sestojev, pomlajevanje, naravnost in odmrla drevnina

The most abundant (in volume) tree species in 2018 were beech (33.4%) and spruce (28.6%), followed by fir, sessile oak and all others with substantially lower volume shares (Fig. 16a, b). While beech's share increased, the share spruce and fir decreased. All changes were significant (Z_{spruce} = 6.94; Z_{beech} = 3.27; Z_{fir} = 3.73; all Z values > 1.96 => $P < \alpha/2 = 0.025$). In general, between 2000 and 2018, the tree composition of Slovenian forests changed slowly. While the share of beech increased only recently, the share of spruce began declining between 2000 and 2007 and again after 2012. The dynamics of the change for fir were less clear. In the case of all other species, the changes were small. A detailed data analysis revealed that the shares of fir, pine sp., sessile oak, sycamore maple, and many species with much smaller shares (e.g. larch, ash, wych elm, part of Ocon and Obrdl) have not increased despite their ecological, economic and environmental significance (Dakskobler et al., 2013a; Dakskobler et al., 2013b; Dakskobler et al., 2016). Conversely, the share of other broadleaves (Obrdl) increased.

The 2018 distributions of species count by diameter classes were more informative. As shown in Fig. 17a, b, only the distribution of beech individuals was balanced, while fir, sycamore maple, sessile oak and



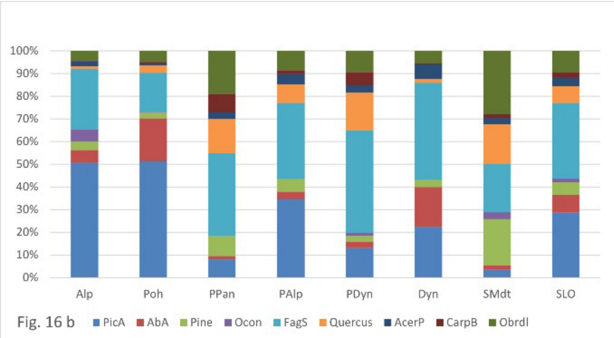


Fig. 16: a) Tree species abundance in SLO forests expressed in volume shares (% GS) between 2000 and 2018. PicA = *Picea abies*, AbA = *Abies alba*, Pine = *Pinus* sp., Ocon = other conifers, FagS = *Fagus sylvatica*, Quercus = *Quercus* sp., AcerP = *Acer pseudoplatanus*, CarpB = *Carpinus betulus*, OBrdl = other broadleaves; b) Tree species abundance by ecoregions.

Slika 16: a) Številčnost drevesnih vrst v slovenskih gozdovih izražena v prostorninskih deležih lesne zaloge (% GS) med letoma 2000 in 2018. PicA = *Picea abies*, AbA = *Abies alba*, Bor = *Pinus* sp., Ocon = drugi iglavci, FagS = *Fagus sylvatica* , Quercus = *Quercus* sp., AcerP = *Acer pseudoplatanus*, CarpB = *Carpinus betulus*, OBrdl = drugi listavci; b) Številčnost drevesnih vrst po ekoregijah.

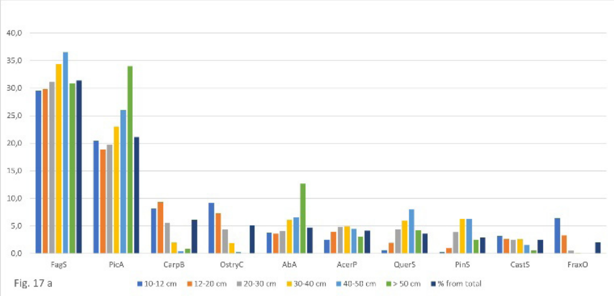
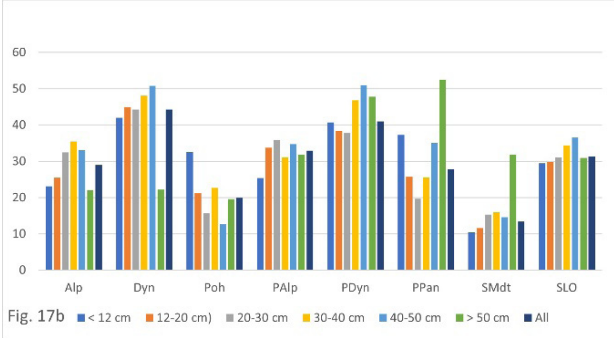


Fig. 17: a) Percentages of tree species (based on counts) by diameter classes (every DBH class is 100%). Of all ingrown trees in 2018, the percentage of fir trees was 3.8%. FagS = *Fagus sylvatica*, PicA = *Picea abies*, CarpB = *Carpinus betulus*, OstryC = *Ostrya carpinifolia*, AbA = *Abies alba,* AcerP = *Acer pseudoplatanus*, QuerS = *Quercus* sp., PinS = *Pinus* sp., CastS = *Castanea sativa*, FraxO = *Fraxinus ornus*; b) Relative percentages of beech trees by diameter classes in ecoregions (ex: No. of beech species with DBH = 10–12 cm / all species with DBH = 10–12 cm).



Slika 17: a) Odstotki drevesnih vrst (na podlagi števila) po razredih premera (vsak razred DBH je 100 %). Od vseh vraslih dreves v letu 2018 je bil delež jelk 3,8 %. FagS = *Fagus sylvatica*, PicA = *Picea abies*, CarpB = *Carpinus betulus*, OstryC = *Ostrya carpinifolia*, AbA = *Abies alba*, AcerP = *Acer pseudoplatanus*, QuerS = *Quercus* sp., PinS = *Pinus* sp., CastS = *Castanea sativa*, FraxO = *Fraxinus ornus*; b) Relativni odstotki bukev po razredih premera v ekoregijah (npr.: št. vrst bukve z DBH = 10–12 cm / vse vrste z DBH = 10–12 cm).

Scotch pine lacked saplings (ingrowth) and trees with diameters below 30 cm. Conversely, hornbeam, sweet chestnut and some other species exhibited shortages in larger diameter classes. The counts of spruce trees also differed, with the reduction in ingrowth largely attributed to hazardous events and an intentional reduction in share.

The distributions of the proportions of beech, fir and spruce by diameter classes in ecoregions (Fig. 18a, b) were even more insightful. Beech exhibited higher ingrowth rates of over 20% in all ecoregions except the Submediterranean. On the other hand, the ingrowth of fir remained balanced and retained significant shares only in the Pohorje ecoregion. The largest decline in fir occurred in the Dinaric ecoregion, where its share was sustained by the presence of abundant large trees. In the Alpine ecoregion, the share of fir also was relatively stable, maintaining an average share of 5% across all DBH classes.

The percentage of spruce in diameter classes also varied greatly. In contrast to the species mentioned earlier, this variation is not worrisome, as spruce in Slovenia largely inhabits secondary forest sites (Levanič et al., 2020).

Forests were primarily classified as seminatural (Forest Europe, 2020). Forest regeneration was mostly natural and lagged behind the required demographic shares. Given that i) the average share of regenerated area between 2000–2018 was 45,300 ha (3.85%) and that ii) young growth needs ca. 20 years to overgrow the first developmental phase, it would take more than 500 years to regenerate all shelterwood forests in the country.

In 2018, the volume of deadwood amounted to 24.2 ± 2.39 m^3/ha. It increased significantly after 2012 (P = 0.0002) when it was estimated at 19.83 ± 1.93 m^3/ha. The 2018 deadwood volume also differed significantly between ecoregions (P = 0.003). The highest mean

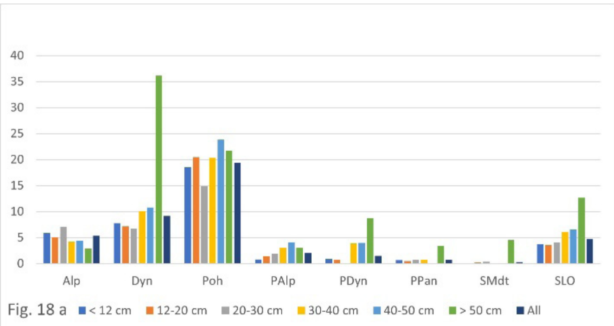
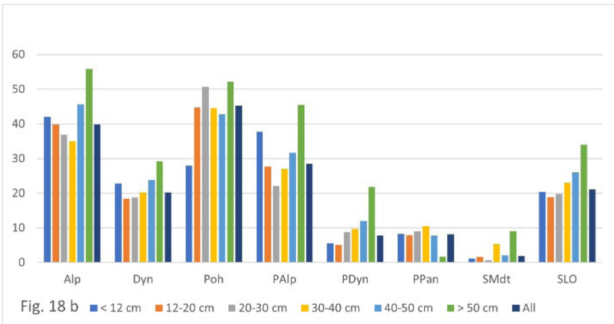


Fig. 18: Relative percentages of fir (a) and spruce (b) trees by diameter classes in ecoregions. The peak of fir in the Dinaric ecoregion (36%, DBH > 50 cm) serves as a reminder of once common fir-beech forests.



Slika 18: Relativni deleži jelke (a) in smreke (b) po razredih premera v ekoregijah. Izrazit vrh jelke v dinarski ekoregiji (36 %, DBH > 50 cm) spominja na nekoč pogoste jelovo-bukove gozdove.

volumes were found in the Alpine (31.4 m^3/ha) and the Dinaric ecoregions (30.5 m^3/ha), while the lowest were in the Prepannonian (18.5 m^3/ha) and Submediterranean (20.4 m^3/ha) ecoregions. The increased mean values reflected the intensity of disturbances and were the largest in the Dinaric (7.9 m^3/ha), Alpine (5.7 m^3/ha) and Pohorje ecoregions (4.7 m^3/ha). It is worth noting that, according to the 2020 Forest Condition report (Forest Europe, 2020), Slovenia belongs to the group of countries with the highest average deadwood volume in its forests.

3.5 Evaluation of sustainability with selected indicators

3.5 Ocena trajnostnega razvoja z izbranimi kazalniki

Apart from forest area and deadwood, the statuses of the other indicators were found to be unfavourable (Table 4). The most critical issues were the demographic portrayal of stands and tree species composition. Both factors also affect forest biodiversity and the conservation status of forest habitat types (Kutnar and Dakskobler, 2014; Grošelj et al., 2015; Kovač and Grošelj, 2018). Another concern in the long run was the felling/increment ratio. While underharvesting helped raise growing stocks, it contributed to forest ageing. As already shown (Ch. 3.1), ca. 29% of sawlogs 2,3 had considerably low SDIs (< 500; low stocked stands) and could be treated similarly to overaged stands. Tree species and regeneration also were determined to be unfavourable. The shares of spruce were quite high, while the shares of pine and fir declined (Dinaric, Predinaric ecoregion). By contrast, the data for beech clearly indicated that this species was making a comeback, while the share of fir declined (only ca. 4% in ingrowth; Fig. 18a, SLO). Lastly, the regenerated forest area was low and should have amounted to about three times the size of its current area.

The differences in factors between the current and desired values of indicators range from 0.33 for regeneration area (min.) to 1.6 for deadwood (min). In the case of tree species, the factors range between 0.05 for Austrian pine (current = ingrowth), 0.075 for oak and 0.9 for beech. The future outlook seems especially discouraging when the discrepancies between the current and the desired values are expressed in the time in years needed to reach the desired states. Considering the current change dynamics, it may take decades to significantly improve the present forest conditions (e.g. regeneration; if increased by 33% every 10 years, it would take more than 60 years). Based on the presented facts, the current direction of national forest development is discouraging and may be considered as a departure from sustainable forest development.

3.6 Estimation of the suitability of the 4 x 4 km systematic sampling grid

3.6 Ocena primernosti sistematične vzorčne mreže 4 x 4 km

The mean growing stock values of differently ori-

Table 4: Assessment of sustainability (current values as of 2018)

Preglednica 4: Ocena trajnosti (sedanje vrednosti iz leta 2018)

Indicator	Current value	Desired value	Condition	Reference/compared values
Forest area	1,214,400 ha (60%)	50–60%	Favourable	The EU27 forest cover is ca. 40%.
Growing stock (GS)	Unbalanced = 329.6 m^3/ha	325–350 m^3/ha	Unfavourable	Current normal = 297 m^3/ha, optimal = 325–350 m^3/ha.
Area Young/ swl 1,2,3 /uneven aged	29% : 68% : 3%	41% : 52% : 7%	Unfavourable	Lack of young stands, many sawlogs overaged; ca. 40 years needed to improve the portrayal.
Felling/increment	2018/2000 average R = 63% R_{2018} = 88%	90–110%	Unfavourable	Beech SI_{28} = increment 7.2 and felling 7.2 m^3/ha; R = 100% Spruce SI_{28} = increment 7.7 and felling 7.7 m^3/ha; R = 100%
Tree species	[1]Spruce 28.6% (20.4%) Fir 7.9% (3.8%) Pine (0.3%) 5.5% Beech 33.3% (29.5%) Oak 7.5% (0.6%) Maple 3.7% (2.5%) Other 13.5% (15.8%)	[2]Spruce 25–29% Fir 8–15% Pine 6–10% Beech 33–40% Oak 8–15% Noble brdl. 4–10% Other 10–15%	[3]Unfavourable Unfavourable Unfavourable Favourable Unfavourable Unfavourable Favourable	[1]Values in brackets refer to ingrowth [2]All desired values refer to the total share. [3]Reference values in Fig. 17 and 18. Apart from beech and spruce, the shares of the other tree species in the ingrowth are unfavourable.
Regenerated area	Area ca. 4%	12–14%	Unfavourable	
Deadwood	24 m^3/ha	15–25 m^3/ha	Favourable	

Table 5: Mean growing stock values of differently oriented odd and even 20 km wide strips

Preglednica 5: Povprečne lesne zaloge izračunane iz ploskev ležečih na lihih in sodih 20 km širokih različno orientiranih pasovih

stripp	[1]Combination a 1, 2		[2]Combination b 1, 2		Combination c1, 2		Combination d1, 2	
	n	mean GS m³/ha	n	mean GS m³/ha	n	mean GS m³/ha	n	mean GS m³/ha
	N-S odd	N-S even	E-W odd	E-W even	NE-SW odd	NE-SW even	SE-NW odd	SE-NW even
Odd	386	320.90	376	333.06	367	325.92	361	334.92
Even	373	339.39	383	326.25	392	333.10	398	324.83
All	759	329.63	759	329.63	759	329.63	759	329.63

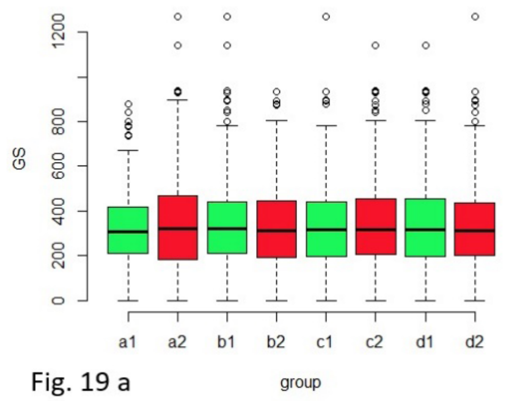
Remark: n = number of plots; GS = growing stock; Combination (see Fig. 2); [1] = largest differences; [2] = smallest differences
Opomba: n = število ploskev; GS = lesna zaloga; kombinacija (glej Sliko 2); [1] = največje razlike; [2] = najmanjše razlike

ented odd and even data strips from 2018 ranged between 320.19 and 339.39 m³/ha and differed from the national mean growing stock (329.63 m³/ha; 2018) by less than 3% (Table 5). While the differences between the variances in the strips were significant (Levene; df = 7, F = 2.53, P = 0.0134), the differences between the mean growing stocks were not significant (4 cardinal directions x 2 strips; ANOVA; df = 7, F = 0.416, P = 0.893; Fig. 19a). Conversely, the same analysis carried out with the 2012 data revealed no significant differences between the variances or means (Levene; df = 7, F = 1.82, P = 0.078; min-max. differences in s.d. = ± 1.5 % to ± 8.3 %; ANOVA; df = 7, F = 0.25, P = 0.971). An erratic pattern was also exhibited in the spatial continuity. Instead of showing decreasing correlations by distance, the correlations of the four km lags of selected west-east segments were in the range of + 0.39 to -0.78, while the values of the eight km lags were in the range of +0.57 to -0.74. Considering all the means and variances, we concluded that the estimates were not affected by cyclic periodicity. As shown, the differences between the variances in 2018 were due to the hazardous events.

3.7 Completeness of indicators for the purpose of SFM analyses and reporting

3.7 Popolnost kazalnikov za potrebe presojanja TGG in poročanja o njem

Out of the 34 complex indicators of SFM (Forest Europe, 2022), between 15 and 19 of them are supposed to be collected by NFIs. Considering the many possible combinations generated by stratification factors such as other wooded lands and forests available for wood supply, the number of sub-indicators increases significantly. Regarding the available data in 2018, we conclude that the FFECS database made it possible to derive incomplete estimates on eight SFM indicators. It also did not allow for estimates to be derived for different reporting processes, which differ in area thresholds and indicator definitions (e.g. national vs Forest Europe definitions).



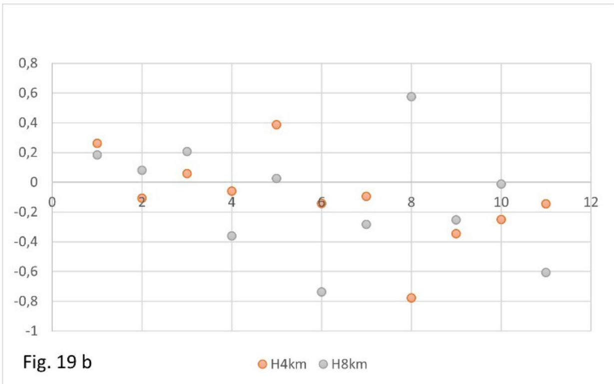


Fig. 19: a) Growing stock 2018 (m³/ha) in 20 km wide strips; b) Average correlations for the 4 km and 8 km lag for 11 segments (each dot pair viz. orange and grey, represents one line segment).

Slika 19: a) Lesna zaloga 2018 (m³/ha) v pasovih širine 20 km; b) Povprečne korelacije za razpon 4 km in 8 km za 11 segmentov (vsak par pik, tj. oranžna in siva, predstavlja en segment črte).

Table 6: Completeness of SFM indicators (as of 2018)

Preglednica 6: Popolnost kazalnikov TGG (stanje leta 2018)

SFM	Indicator name (shortened)	Availability of estimates	Demanded	Source
1.1	Area of forest and other wooded land, classified by…	A: forest area	FE + LU	NFI
		N/A: AWS, OWL, PFL, FTy, OLWT		
1.2	Growing stock (GS) …, classified by…	A: GS of forest area	FE + LU	NFI
		N/A: GS of OWL, AWS, PFL, FTy and OLWT		
1.3	Age structure and/or diameter distribution of, by …	A: diameter distribution, developmental phases; forest area	FE	NFI
		N/A: diameter distribution, developmental phases; OWL, OLWT		
		P/A: age structure; different methods, inconsistent data		
1.4	Carbon stock and carbon stock changes in …	A: carbon pools (living wood biomass, litter, deadwood, soil) for forest area	FE + LU	NFI
		N/A: PFL, OWL, OLWT, change		
2.1	Deposition and concentration of air pollutants on forest and …	Not NFI	FE	ICP
2.2	Chemical soil properties (pH, CEC, C/N, organic C, base sat.)	A: forest area (pH, C/Nm organic C)	FE	NFI
		N/A: CEC and base saturation, change, soil type, OWL, OLWT		
2.3	Defoliation of one or more main tree species on …	N/A: FTy, FPL, OWL	FE	NFI-ICP
2.4	Forest and other wooded land with damage classified by …	N/A: tree level, PFL, FTy, OWL, FTy	FE	NFI
		N/A: damaged area of PFL, FTy, OWL, FTy		
2.5	Trends in forest land degradation ...	NEW	FE	NFI
3.1	Balance between … Increment/felling of wood …	A: forest area	FE + LU	NFI
		N/A: PFL/AWS, OWL, OLWT		
3.2	Quantity and market value of roundwood	Not NFI	FE	FSTAT
3.3	Quantity/market value non-wood	A: game; P/A: honey; not collected by NFI	FE	FSTAT
		N/A: quantity in forests, OWL		
3.4	Value of marketed services	N/A: services in forest area, OWL	FE	FSTAT
4.1	Tree species	A: share in GS in forest area	FE	NFI
		N/A: species area in forests, OWL; exotic, invasive, other species in forests and OWL		

4.2	Forest regeneration/expansion	A: forest regeneration in even-aged forests (determined as developmental phase)	FE	NFI
		N/A: forest expansion, regenerated patches in uneven-aged stands and older sawlogs (2 and 3), regenerated patches in OWL, composition and sapling densities of regenerated patches, damage on saplings		
4.3	Area of forest and other wooded land by class of naturalness	A: forest area	FE	NFI
		N/A: OWL		
4.4	Area of forest and other wooded land dominated by introduced tree species. …	N/A (sparse grid): forest area	FE	NFI
		N/A: OWL, density of species, % of area		
4.5	Volume of standing and lying deadwood	A: forest area	FE + LU	NFI
		N/A: OLWT, change in OWL		
4.6	Genetic resources	Not NFI	FE	EUFORGEN
4.7	Area of continuous forest and patches of forest separated by	NEW	FE	NFI
		N/A: forest area, OWL, forest habitat type		
4.8	Number of threatened forest species, classified	Not NFI	FE	BM
4.9	Area of forest and other wooded land protected to conserve ...	N/A: forest area, OWL	FE	BM-NFI
4.10	Common breeding bird species	NEW	FE	BM-NFI
5.1	Protective forests–soil, water and other ecosystem functions	N/A: forest area, OWL	FE	NFI
		Not NFI		
6.1-9	Maintenance of other socioeconomic functions and conditions	Not NFI	FE	FSTAT
6.10	The use of forests and other wooded land for recreation in ..	N/A: forest area	FE	NFI, FSTAT

Remark: SFM = No. of SFM indicator; A = estimate available; N/A = estimate non-available; P/A = estimate partly available (for some variables); AWS = area available for wood supply; OWL = other wooded lands; PFL = productive forest land; FTy = forest type; OLWT = other lands with trees; GS = growing stock; CEC = cation exchange capacity; FE = Forest Europe; LU = LULUCF = land use, land use change and forestry; EUFORGEN = Forest genetics monitoring; BM = biodiversity monitoring; FSTAT = forest statistics.

Opomba: SFM = št. indikatorja TGG; A = ocena na voljo; N/A = ocena ni na voljo; P/A = ocena delno na voljo (za nekatere spremenljivke); AWS = območje, ki je na voljo za oskrbo z lesom; SOVA = druga gozdnata zemljišča; PFL = produktivno gozdno zemljišče; FTy = vrsta gozda; OLWT = druga zemljišča porasla z drevesi; GS = lesna zaloga; CEC = kapaciteta kationske izmenjave; FE = Gozdovi Evrope; LU = LULUCF = raba zemljišč, sprememba rabe zemljišč in gozdarstvo; EUFORGEN = Forest genetics monitoring; BM = spremljanje biotske raznovrstnosti; FSTAT = gozdna statistika.

4 DISCUSSION
4 RAZPRAVA

Slovenia's forest area is stable and Slovenia ranks third in the EU 27 (Forest Europe, 2020). The average growing stock is also the third highest at approx. 330 m^3/ha (Forest Europe, 2020). The balanced growing stock is slightly lower at 297 m^3/ha, a value similar to the calculation from 2012, which was 290 m^3/ha (Bončina, 2017).

However, after several years of continuous growth, the average growing stock started to decrease after 2012 in all developmental phases. These phases remained relatively homogeneous and were characterized by unsuitable tree densities and average growing stocks. Compared to neighbouring Austrian (of Carinthia, Styria and Burgenland states only) and the Swiss forests, our developmental phases had lower mean growing stocks (viz. sawlogs1 by 10–30%; sawlogs2 by 10–70%; sawlogs3 by 19–90% (Österreichische … s. a; WSL, 2022)). The Slovak yield tables (Kotar, 2003) also predict a more distinctive stand heterogeneity.

Several decades of an inadequate felling increment ratio affected the developmental phase structure, leading to a deficit of young forests. While the ratio of young and older stands in our forests was estimated at R_{SLO} = 0.29:0.71, the same ratio in the forests of the Austrian states is R_{AT} = 0.45:0.55, and in the Swiss forests it is R_{CH} = 0.34:0.66 (Österreichische … s. a; WSL, 2022). Based on the results and these comparisons, we argue that only demographically balanced seminatural forests can develop sustainably and provide essential ecological ecosystem services (e.g. erosion protection, water purification, wood) to societies. In our view, SFM should always seek a balance between forest structure and the diverse ecosystem services it provides, without undermining the forest structure itself. While searching for acceptable options, shifts from the demographic balance are possible and often necessary (e.g., planned increase of the growing stock, restoration of damaged areas, addressing imbalances in the market). However, such shifts should be spatially and temporally limited, justified and agreed upon with forest owners.

The felling/increment ratio between 2000 and 2018 was estimated at 0.63, the lowest among the three compared nations and quite low in Europe (Forest Europe, 2020). The gross increment decreased in all ecoregions and in most forest regions, apart from Tolmin, Sežana and Murska Sobota. Similarly, a decrease in growing stock was observed. Both facts, partly affected by the natural events, play a significant role in carbon management. The decrease in increment and growing stock, along with a non-optimal SDI (Hladnik and Žižek Kulovec, 2014), suggest that the present Slovenian forests, at given stand densities, are already saturated with wood (carbon) biomass, similar to European forests (Nabuurs et al., 2013). Consequently, as the country cannot increase the carbon sink by establishing new forest areas, it must regulate it within existing forest boundaries. As a result, alternatives for a higher carbon sink should be sought in newly established stands (future generations) and prompt forest management capable of performing timely management actions. If these new stands have site-suitable tree species compositions (Pardos et al., 2021) and balanced demographic portrayals, they will also be more resilient to disturbances and less risky to manage (Brang et al., 2013; Thom and Seidl, 2016; Levanič et al., 2020; Kauppi et al., 2022). There is a larger potential for storing carbon in optimal developmental phase stocking (higher SDIs) and a more balanced felling-increment ratio. Notably, recent simulations suggest that optimal carbon storage can only be achieved through sustainable felling (Thürig and Kaufmann, 2008; 2010; Jevšenak et al., 2020). Similarly, our simulation with balanced growing stocks shows that if the developmental phases of Slovenian forests had growing stocks as high as the forests of Burgenland or Switzerland, the Slovenian balanced growing stock would amount to 347 m^3/ha and 322 m^3/ha, respectively. However, if the areas of developmental phases remained unbalanced (as they are), the unbalanced growing stock would reach 408 m^3/ha or 356 m^3/ha.

The existing tree species composition is facing many challenges. Among the three main species, the share of spruce has declined due to many hazardous events. Regardless, the share of spruce continues to remain high in the ecoregions of Pohorje and the Alps and in the lowlands. The future of fir is much more questionable. Although its current share is still significant due to many large trees (Fig.19b) in the stands, its proportion in the ingrowth does not exceed 4%. Fir regenerates normally only in the Pohorje ecoregion, and its share is declining in the Dinaric and Predinaric regions, where it once formed large-scale fir-beech-spruce forests. Although the FFECS has not provided evidence about the drivers of its low share, it is very likely that the carrying capacities of fir-mixed and some other forests are undermined by game browsing (Klopčič et al., 2010). Beech, the third dominant species, is slowly reclaiming sites from which it was once wiped out and is becoming the dominant species on many sites where it was previously admixed (Poljanec et al., 2010; Gozdnogospodarski načrt …, 2012; Kovač et al., 2018). This process has also been observed in some other EU countries (Mölder et al., 2014). The shares of other tree species such as pine sp., noble broadleaves, larch, willow, alder and poplars continue to remain very low and should be increased in different forest types to improve the general forest and their forest habitat type biodiversity.

Also insufficiently large is the average regenerated forest area, totalling ca. 4%. In neighbouring Austrian forests, the regeneration area totals ca. 21–26 %, while in Swiss forests it is 9% (Österreichische … s. a; WSL, 2022). The share of regenerated forests ranks Slovenia among the countries with the lowest share of regeneration in Europe (Forest Europe, 2020). The problem of extremely slow forest rejuvenation has been observed for a long time. Pipan, who attributed this issue to great inertia in the state forest management, reported that ca. 1,873 ha of forests were regenerated annually between 1947 and 1967 (Pipan, 1967). Alongside forest rejuvenation, some beneficial actions such as the local reduction of game and stand fencing need to be considered to improve the conservation status of forest habitat types. Many of them (some covering large areas, e.g., 91K0-Illyrian beech forests, 91L0–Illyrian oak-common hornbeam forests) are changing their portrayals and slowly turning into homogenous stands due to the suppression of their dominant species such as fir, sessile (and pedunculate) oak, maple and ash, causing the depletion of their natural biodiversity (Kutnar and Dakskobler, 2014; Kovač et al., 2016)

Regarding very limited possibilities for deriving the complete set of SFM indicators and suggestions for improvements (Bončina, 2017; Kovač et al., 2019a; Kovač et al., 2019b), the Slovenian national forest inventorying should undergo significant improvements, especially in terms of the amount of collected variables and inventory integration.

5 CONCLUSIONS – HOW TO MOVE FORWARD

5 SKLEPI – POGLED V PRIHODNOST

As assumed, the intensive regeneration of forests, coupled with prompt management in existing stands, is a reliable approach for Slovenian forestry to break free from management standstill. The series of consecutive and connected hazardous events between 2000–2018, and especially since 2012 (salvage cutting in some regions reached 70% or more; (Zbirka osnutkov …, s. a), should be considered a wake-up call and a warning that sustainable forest development and management cannot tolerate insufficient management activity or delays in the execution of actions. If natural processes are disregarded for an extended period, forest development may spiral into a management crisis, with economic consequences potentially amounting to tens of millions of euros. Additionally, because many of the earlier highlighted issues (e.g. stand homogenization, undermined demographic structure, felling increment ratio, long rotation periods) cannot be explained solely by natural disturbances and the knowledge and recommendations of forest science, nor can credit for some SFM indicators (e.g. high average growing stock due to low felling) be attributed to successfully planned and executed forest management actions, the forest sector as a whole should engage in a wide-ranging discussion about the appropriateness of the present management strategies. This discussion should also address the suitability of the present, highly rigid state forest planning and forest management system (GIS, 2006–2016). The basic idea that all national forests must be regulated by a set of forest management plans, designed exclusively by governmental institutions, originates from the early 1960s, when Slovenia was still part of the Socialist Federal Republic of Yugoslavia (Kovač, 2018). Therefore, a comprehensive discussion is necessary given the predominance of private forests whose owners must have a say about whether the present forest management concept should be continued or modified. These forest owners will also play an important role in the implementation of future forest conservation actions. Close collaboration among forest owners, forest practitioners, forest science and the administration in resolving such issues is also envisioned by the new EU forest strategy (New EU Forest …, 2021). This collaborative effort will be essential in shaping a sustainable and resilient forest management approach for Slovenia's future.

6 SUMMARY

6 POVZETEK

V prispevku smo predstavili stanje in razvoj slovenskih gozdov, ocenjena s podatki velikoprostorskega Monitoringa gozdov in gozdnih ekosistemov (MGGE), pridobljenimi na sistematični vzorčni mreži 4 x 4 km. Meritve so bile opravljene v letih 2000, 2007, 2012 in 2018, na ca. 760 trajnih vzorčnih ploskvah.

Stanje in razvoj slovenskih gozdov z vidika trajnosti smo preverili z naslednjimi kazalci trajnostnega gospodarjenja z gozdovi (TGG): površina gozdov, temeljnica, lesna zaloga, indeks sestojne gostote (SDI), starostna struktura/porazdelitev prsnih premerov, ravnotežje razvojnih faz, optimalna lesna zaloga, prirastek, sečnja, različnost drevesnih vrst, mešanost sestojev, pomlajevanje, naravnost in odmrla drevnina. Obračuni so bili izdelani na ravni države, dveh višinskih pasov (pod/nad 600 m nmv), sedmih ekoregij ter štirinajstih gozdnogospodarskih območij (GGO).

Površina gozdov je od l. 2012 stabilna in znaša ca. 1.214.000 ± 54.663 ha (gozdnatost 60 %). Pod 600 m nmv je bilo 52 % gozdov, nad to mejo pa 48 %. Med ekoregijami so bile z gozdovi najbogatejše Dinarska, Alpska in Predalpska, med GGO pa Tolmin, Ljubljana, Novo mesto in Kočevje.

Povprečna temeljnica je med l. 2000 in 2012 narasla z 29,4 m^2/ha (± 1,1 m^2/ha) na 32,2 m^2/ha (± 1,1 m^2/ha), se potem znižala in je l. 2018 znašala 30,7 m^2/ha (± 1,1 m^2/ha). V pasu nad 600 m nmv so bile njene povprečne vrednosti za ca. 17 % višje od temeljnic v nižinskem pasu. Razslojevanje temeljnice po razvojnih fazah je neizrazito. Najvišje temeljnice so v Pohorski ekoregiji (40 m^2/ha), najnižje pa v Submediteranski (24 m^2/ha). V opazovanem obdobju ima skoraj 50 % gozdov temeljnice nižje od 30 m^2/ha. V istem času pa je delež površin z visokimi temeljnicami (nad 40 m^2/ha) narastel.

Zarast sestojev smo ocenili z indeksom sestojnih gostot (SDI), ki nam omogoča podroben vpogled v sestojno strukturo. V opazovanem obdobju je povprečni SDI naraščal od 576 ± 21 v letu 2000, na 619 ± 21 v letu 2012, nato pa se do l. 2018 zmanjšal na 592 ± 21. V l. 2018 sta najvišja povprečna SDI v GGO Slovenj Gradec (744 ± 112) in Kranj (701 ± 99), najnižji pa v Sežana (512 ± 77) in Ljubljana (516 ± 55). Podobno so najvišji povprečni SDI v Pohorski (615 ± 48) in Alpski (653 ± 62) ekoregiji, najnižji pa v Submediteranski (494 ± 60) in Preddinarski (552 ± 54). Razporeditev gozdnih površin, razvrščenih po razredih SDI v ekoregijah, je pokazal, da deleži površin s SDI nad 800 ostajajo večinoma pod 20 % (izjemi sta bili Pohorska in Alpska ekoregija). Poleg tega je podroben pregled debeljakov pokazal, da ima približno 31 % (pribl. 261.000 ha) SDI nižje od 500 in 24 % višje od 800. Raztros SDI v drogovnjakih in tanjših debeljakih je velik. V precejšnjem deležu sestojev so bili SDI nižji od normalnih vrednosti. Precej drugačne so bile strukture sestojev v Pohorski in Dinarski ekoregiji. Medtem ko so bili sestoji v Pohorski ekoregiji polnozarasli, je v sestojih v Dinarski ekoregiji primanjkovalo dreves (predvsem v debeljakih).

Lesna zaloga je od l. 2000, ko je znašala 299,3 ± 13,8 m^3/ha, naraščala. Najvišjo vrednost je dosegla l. 2012, in sicer 333,9 ± 13,7 m^3/ha, zatem se je l. 2018 znižala na 329,6 ± 13,71 m^3/ha. L. 2018 so bile najvišje zaloge v GGO Slovenj Gradec (450 ± 60 m^3/ha), Nazarje (422 ± 83 m^3/ha), najnižje pa v Sežani (199 ± 35 m^3/ha) in Ljubljani (275 ± 33 m^3/ha). Izmed ekoregij je imela najvišjo povprečno zalogo Pohorska (469 ± 54 m^3/ha), najnižjo pa Submediteranska (199 ± 28 m^3/h). Razen v Predpanonski in Submediteranski, so bile v vseh preostalih lesne zaloge v zgornjem višinskem pasu višje (največ za ca. 20 %). Med l. 2012 in 2018 se je lesna zaloga zmanjšala v vseh razvojnih fazah.

Do l. 2018 so bile prevladujoče oblike sestojev (97 %) skupinsko postopno gospodarjeni in raznodobni gozdovi. Njihovo demografsko stanje med l. 2000 in 2012 je bilo stabilno. Prehode med razvojnimi fazami, ki so postali izrazitejši po l. 2012, je v veliki meri sprožil niz naravnih dogodkov, kot so žledolom leta 2014, kasnejši napadi podlubnikov ter občasni snego- in vetrolomi. Čeprav so ti obsežni naravni dogodki vplivali na gozdne strukture, so bile spremembe na nacionalni ravni nepomembne; majhen delež mlajših sestojev (mladovje in drogovnjaka) je l. 2000 znašal 32 %, l. 2018 pa je padel na 29 %, medtem ko se je delež zrelih sestojev (debeljaki) povečal z 68 % na 70 %. Podobna je bila tudi porazdelitev razvojnih faz v višinskih pasovih. Premeri dreves so bili pozitivno zamaknjeni v vseh razvojnih fazah in so kazali na njihovo pomembno neenakomernost.

Kar zadeva razlike v površinskih deležih razvojnih faz med ekoregijami ali GGO, je nabor podatkov za l. 2018 pokazal, da so velike in pomembne. V Dinarski, Pohorski in Predalpski ekoregiji je bilo več kot 70 % zrelih sestojev. Nasprotno pa so precej ugodnejšo, čeprav neuravnoteženo, demografsko podobo izkazovali gozdovi v Submediteranski ekoregiji (ca. 50 % debeljakov). Podobno je bilo v GGO Kranj, Kočevje, Nazarje in Maribor več kot 75 % zrelih gozdov, v Tolminskem in Sežanskem pa približno 53 %.

Neuravnotežena demografija sestojev je bila prikazana z modelom normalnega gozda za skupinsko postopno gospodarjenje. Model je razkril pomanjkanje mladih in presežke zrelih sestojev. Čeprav je ta demografski problem poznan že nekaj časa, se je stanje po l. 2012 poslabšalo. Omeniti velja naslednje ugotovitve:

Slovenskim gozdovom je v l. 2018 primanjkovalo 169.152 ha mladih sestojev (110.835 ha mladovij in 58.417 ha drogovnjakov). Hkrati je bil v enaki količini presežek zrelih sestojev.

Neuravnotežene razvojne faze in njihove povprečne lesne zaloge so povzročile uravnoteženo lesno zalogo 296 m^3/ha (skupinsko postopno gospodarjenje) in 297 m^3/ha v kombinaciji z raznodobnimi sestoji. Za gozdove pod 600 m nadmorske višine je bila izračunana vrednost 276 m^3/ha in 303 m^3/ha za gozdove nad njo.

Uravnotežene vrednosti so bile bistveno nižje od optimalnih lesnih zalog, izpeljanih iz švicarskih in slovaških donosnih tablic, ki so bile postavljene na 319 m^3/ha oziroma 421 m^3/ha. Nižje so bile tudi od vrednosti, izračunanih s simuliranjem adekvatnih vrednosti gozdov dežele Gradiščanske in Švice, ki so znašale 347 m^3/ha oz. 322 m^3/ha.

Bruto prirastek z vrastjo in polovičnim prirastkom posekanih dreves je l. 2018 znašal 7,86 ± 0,32 m^3/ha in se je v primerjavi z l. 2012 (8,60 m^3/ha) zmanjšal. Bruto prirastek brez vrasti in polovičnega prirastka posekanega drevja je bil med l. 2012 in 2018 ocenjen na 6,85 ± 0,30 m^3/ha in je nižji od vrednosti med l. 2000 in 2007, ki je znašala 7,92 ± 0,32 m^3/ha (bruto prirastek z vrastjo in polovičnim prirastkom posekanih dreves je v l. 2018 znašal 7,86 ± 0,32 m^3/ha, v l. 2012 pa 8,60 ± 0,33 m^3/ha).

Z izjemo Alpske ekoregije se je v vseh drugih ekoregijah bruto prirastek najprej povečal, nato pa zmanjšal. Podoben trend je mogoče zaslediti v GGO. Precej drugačen trend je bil v GGO Bled, kjer se je bruto prirastek stalno zmanjševal, in v Murski Soboti, kjer se je stalno povečeval. V GGO Tolmin je bruto prirastek skozi leta ostal stabilen.

Med l. 2012 in 2018 je bil povprečni letni posek brez polovičnega prirastka posekanih dreves ocenjen na 5,94 ± 1,18 m^3/ha (s polovičnim prirastkom 6,27 ± 1,2 m^3/ha) in je bil višji kot med l. 2007 in 2012, ko je znašal 4,03 ± 0,80 m^3/ha. Od l. 2000 je povprečni letni posek naraščal v vseh ekoregijah, razen v Predpanonski, kjer se je zmanjšal.

V obdobjih 2000–2007, 2007–2012 in 2012–2018 sta se bruto prirastek in letni posek razvijala z različnimi trendi. Medtem ko se je bruto prirastek najprej povečal v večini ekoregij in tudi GGO kljub naraščajočemu letnemu poseku, se je ta smer po l. 2012 obrnila. To dejstvo je omembe vredno, ker naravni dogodki in povečani posek niso prizadeli vseh ekoregij in GGO.

Od l. 2000 do 2012 je povprečni letni posek v razvojnih fazah v veliki meri zaostajal za bruto prirastkom. Od l. 2000 do 2007 je bilo razmerje med posekom in prirastkom 47 % in je med l. 2007 in 2012 doseglo 52 %. Njegova nizka vrednost se je obrnila po l. 2012, ko je vrsta zaporednih naravnih dogodkov prizadela gozdove in ga potisnila na 88 %.

Razen gozdov v Subpanonski ekoregiji (R = 0,29) so naravni dogodki prizadeli vse gozdove. V Dinarski, Submediteranski in Pohorski ekoregiji je razmerje doseglo 1,05 oziroma 1,12. V drugih ekoregijah se je gibalo med 0,83–0,97. Od vseh GGO se je posek najbolj povečal v Postojni (za faktor 2,20), Ljubljani (1,50), Nazarjah (1,29) in Kranju (1,07).

L. 2018 sta bili v gozdovih najpogostejši drevesni vrsti bukev (33,4 %) in smreka (28,6 %), ki so jima z bistveno nižjimi volumenskimi deleži sledile druge vrste. Deleža smreke in jelke sta se med l. 2000 in 2018 znižala. V zadnjem obdobju je izrazito narasel delež bukve. Na splošno se je v zadnjih 18 letih drevesna sestava slovenskih gozdov počasi spreminjala. Medtem ko je delež bukve močno narasel šele v zadnjem času, je delež smreke začel upadati že med l. 2000 in 2007 ter ponovno po l. 2012. Manj jasno dinamiko spreminjanja je zaznati pri jelki. Pri vseh drugih vrstah so bile spremembe majhne. Podrobna analiza podatkov je pokazala, da se deleži jelke, rdečega bora, macesna, gorskega javorja in velikega jesena kljub njihovemu ekološkemu, gospodarskemu in okoljskemu pomenu niso močno povečali. Spremenila se je tudi mešanost sestojev.

Več informacij nam da porazdelitev drevesnih vrst po debelinskih stopnjah l. 2018, kjer je bila uravnotežena le porazdelitev osebkov bukve, medtem ko jelka, gorski javor, hrast in rdeči bor nimajo zadostnega števila mladik (vrasti) in dreves s premerom pod 30 cm. Nasprotno pa pri belem gabru in velikem jesenu primanjkuje dreves večjih premerov. Neuravnotežena porazdelitev je tudi pri smreki, do te spremembe je prišlo zaradi naravnih dogodkov in morebitnega namenskega zmanjšanja deleža smreke.

Še lepše se to vidi na porazdelitvi deležev bukve, jelke in smreke po debelinskih razredih v ekoregijah. Medtem ko je bil delež bukve v vseh ekoregijah višji od 20 %, se je v Submediteranski ekoregiji delež jelke zmanjšal in je ostal uravnotežen le v Pohorski ekoregiji. Največji upad je bil zabeležen v Dinarski ekoregiji, kjer je jelka obdržala svoj delež (v lesni zalogi) zaradi še vedno velikega števila debelih dreves. Kljub temu pa je od vseh jelk le 5 % takšnih, ki jih je mogoče šteti za vrasle. Tudi delež smreke v debelinskih razredih je bil zelo različen. V nasprotju s prej omenjenimi vrstami ta variabilnost ni zaskrbljujoča, saj smreka v Sloveniji večinoma raste na sekundarnih rastiščih.

Večina sestojev je polnaravnega nastanka. Obnova gozdov je pretežno naravna in zaostaja za potrebnimi demografskimi deleži. Če upoštevamo, da je povprečni delež površin v obnovi v obdobju 2000–2018 znašal 45.300 ha (3,85 %) in da potrebujejo sadike najmanj 20 let, da prerastejo prvo razvojno fazo, bi bilo potrebnih več kot 500 let, da bi obnovili vse gozdove v državi.

V l. 2018 je količina odmrle drevnine znašala 24,2 ± 2,39 m^3/ha. Znatno se je povečala po l. 2012, ko je bila ocenjena na 19,83 ± 1,93 m^3/ha. Tudi količina odmrlega lesa v l. 2018 se je med ekoregijami pomembno razlikovala. Največje količine so bile ugotovljene v Alpski in Dinarski ekoregiji (> 30 m^3/ha), najmanjše pa v Predpanonski in Submediteranski (> 18,5 m^3/ha). Povečane vrednosti so kazale na intenzivnost naravnih motenj in so bile največje v Dinarski (7,9 m^3/ha), Alpski (5,7 m^3/ha) in Pohorski ekoregiji (4,7 m^3/ha).

Glede na poročilo o stanju gozdov 2020 (Forest Europe, 2020) sodi Slovenija v skupino držav z največjo povprečno količino odmrle drevnine v svojih gozdovih.

Razen kazalcev površine gozdov in odmrle drevnine so bila stanja drugih kazalnikov z vidika trajnostnega razvoja ocenjena kot neugodna. Najbolj kritična sta bila neuravnotežena zgradba razvojnih faz (demografska podoba) sestojev in drevesna (vrstna) sestava. Oboje vpliva tudi na biotsko raznovrstnost gozdov, predvsem na stanje ohranjenosti gozdnih habitatnih tipov. Dolgoročno neugodno je bilo tudi razmerje posek/prirastek. Čeprav je premajhna sečnja pomagala povečati lesne zaloge, je prispevala tudi k zastaranju gozdov.

Neugodno sta bila ocenjena tudi znaka drevesna (vrstna) sestave in obnova. Previsoki so bili deleži smreke, upadajo pa deleži rdečega bora in jelke (Dinarska, Preddinarska ekoregija). Nasprotno pa je podatek za bukev jasno pokazal, da je ta vrsta ponovno zavzela svojo površino, jelka pa jo izgubila.

Razlike faktorjev velikosti med ocenjenimi in želenimi vrednostmi indikatorjev so se gibale med 0,33 (pomladitvene površine) in 1,2 (odmrla drevnina), v primeru drevesnih vrst pa med 0,08 (hrast) in 0,8 (bukev). Stanje postane zelo nespodbudno takoj, ko se izrazi v času, ki je potreben, da se gozdovi vrnejo ali približajo normalnemu stanju. Glede na sedanjo dinamiko sprememb bo potrebnih več desetletij za približanje zaželenim vrednostim kazalnikov. Na podlagi dejstev in predpostavk lahko sedanjo usmeritev razvoja nacionalnih gozdov štejemo za odmik od trajnostnega razvoja gozdov.

Ocenili smo tudi ustreznosti sistematične mreže 4 x 4 km, ki se je uporabljala do l. 2018, in ugotovili, da periodičnost v populaciji ni bila zaznana.

Od 34 kompleksnih kazalnikov SFM (Forest Europe, 2022) naj bi jih ca. –5 - 19 pridobivali z nacionalno inventuro. Ob upoštevanju številnih možnih kombinacij (ki jih ustvarjajo stratifikacijske spremenljivke, kot so druga gozdnata zemljišča, gozdovi, ki so na voljo za oskrbo z lesom), se število podrejenih kazalnikov močno poveča. Glede na razpoložljive podatke v letu 2018 ugotavljamo, da je zbirka podatkov MGGE omogočila izpeljavo nepopolnih ocen osmih kazalnikov SFM. Prav tako ni omogočila izpeljave ločenih ocen za različne postopke poročanja, ki se razlikujejo glede na mejne vrednosti območij in v nekaterih drugih definicijah kazalnikov.

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