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A Five-Step Framework for Creating Forests for the Future

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Abstract: Changing environmental conditions, disturbances, and escalating demands for forest ecosystem services require foresters to restore present forestlands with new forest generations that will exhibit ecological integrity, diversity, high adaptive capacity, and the ability to provide essential ecosystem services. Establishing such forests requires careful consideration of the forest landscape and site dynamics. In pursuit of these requirements, we developed a novel framework that enables the restoration of forest sites and promotes the desired features of the forest complex at the same time. This framework was designed with the methods of system engineering and was organized in the same way as the forest planning process. It was tested in the habitat type of Illyrian *Fagus sylvatica* forests belonging to the Natura 2000 network. The environmental, vegetation, and site conditions were investigated via field inspections, available forest management plans, and simple GIS analyses. Additionally, we established a seminatural stand composed of European beech, sessile oak, sycamore maple, silver fir, and some wild fruit tree species. The survival of planted species was assessed using census and simple random sampling, the performance of provenances by the Student's test, while microhabitat factors were explored by a one-way ANOVA. The survival rate of key species was estimated to be 55.6%, while that of fruit species was estimated to be 94.5%. Our framework demonstrated satisfactory performance and contained sufficient benchmarks to facilitate consistent decision-making. In the discussion, we elucidate the framework's primary features and attributes of the mixed stand, where we also expose some open issues to be addressed in the future.

Keywords: restoration; forest habitat type; indigenous species; planting; mixed stand; key species; fruit species

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1. Introduction

Forests are indispensable elements of European landscapes. In 2020, they covered approximately 227 million ha of land, harbored ca. 35 billion m^3 of wood, and generated ca. €30.39 billion in gross value added [1]. Millions of residents also enjoy the privilege of free access to national forests and share their many forest uses [2]. Finally, the EU27 alone is building the Natura 2000 biodiversity network, in which forests represent a significant part [3].

European forests are regulated by national and EU27 common policies. Joint policy documents include the EU Biodiversity Strategy for 2030 and the New EU Forest Strategy for 2030 [4,5], both highlighting their health, resilience, adaptivity, diversity, and provision of ecosystem services. The EU27 forestry is also part of the Land Use, Land Use Change and Forestry sector (LULUCF), from which it is anticipated that it will contribute to the reduction of CO_2 [6–8]. Yet, the latest carbon sink target, set at 310 Mt of CO_2-eq by 2030, gives many countries little room for maneuvering. The first option, demanding to reduce the rate of harvesting and increase the net forest sink [9,10], is not appreciated by many key stakeholders because it changes the current concept of sustainable forest management [11], forest use, and bioeconomy, and introduces a variety risks (e.g., forest aging, proneness to natural hazards, and reduced wood quality). In contrast, the second option is grounded on increasing mean forest growing stocks and sustaining them at high levels for a longer period [12]. Like the first option, this option is not risk-free. The last alternative is to increase the share of forest plantations [13].

Despite growing concern, the future of European forests is not free from worry. The ICP Forest monitoring program reveals that their health is deteriorating. Since 2000, the mean tree defoliation of key tree species in temperate forests, such as Norway spruce (*Picea abies*), European beech (*Fagus sylvatica*), Scots pine (*Pinus sylvestris*), and sessile oak (*Quercus petraea*), has risen from 2.5 to 4.5 percentage points and attained even higher rates in Central European countries [14]. Also growing is the number of disturbances, generating an annual average salvage timber volume of 43.8 million m^3. The most common agents are wind, snow, ice, drought, bark beetle outbreaks, and fire [15,16]. Although disturbances disrupt forest functioning, they are a driving force of forest development and diversity [17].

It has been known for a while that natural regeneration, indigenous tree species, and mixed stand structures reduce the susceptibility of forests to diseases and disturbances and increase their adaptive capacity [18–22]. Regardless, 82% of present European forests are composed of one to three tree species and 18% of more than three [1]. Central European forestry is also occupied with the problem of overspread spruce [20,23,24], which accounts for the second largest share of all European species (23%, after pine sp. with 29.6%) and causes severe management problems at many sites inside and outside of its natural range [25,26]. Despite much advice against its overspread, this species is often used in establishing new monospecific forest generations [27]. In connection with forest regeneration, it is worth noting that natural regeneration is not always the best choice. For example, sites neighboring heavily modified forests almost always reflect the species compositions of parent stands and prolong the existence of undesirable compositions. In such cases, it is meaningful to renew them artificially with genetic material from other provenance regions [28]. The same holds true for large open areas, affected by large-scale disturbances, where waiting for natural regeneration often results in weeds that cease natural regeneration and prolong the regeneration period.

Numerous hazardous events in recent decades have sparked intense research in the field of establishing future forest generations. Its outcomes suggest that future forests need to be created by considering past, present, and future ecological and disturbance factors and genetics to reduce risks and improve the delivery of ecosystem services [29–33]. They also imply that forest owners and managers should relinquish traditional reforestation practices, based on simplified regeneration, low tending costs, and expected financial revenues, and should begin renewing forests systematically. If a forest renewal process is systematic, it typically provides answers to questions regarding site and neighboring ecological conditions, common agents affecting its development, and the potential suitability of species to grow in a forest landscape.

To uphold the forest renewal process, science and forest practices have also developed a lot of frameworks, supporting plantation forestry, regular stand renewal, and restoration due to different disturbances [34–38]. The latest concepts in row are forest landscape and ecological restoration. Although both of them have probably been inspired by large-scale forest clearings and forest degradation, they both strive to spark the recovery of stands in view of their health, ecological integrity, and sustainability [39–41].

From the hierarchical point of view, seminatural forests are composed of forest types and stands. To sustain them, the creation of their new generations must be based on considering landscape and stand spatial level. Only if the tree species composition at these two levels are harmonized can future forests develop as a whole in the long run. Such an understanding of forests (see Section 2.4 for details) is consistent with ecosystem management [42] and with the paradigm of closer to nature management [43].

The objectives of this study were (a) to develop a five-step framework to be used for the creation of new generations of seminatural forests, regardless of the nature of their renewal; (b) to test the framework in ecologically demanding conditions; and (c) to design and create a seminatural stand whose attributes would match ecological and management demands and recommendations. We argue the main features of the framework and the established stand in the discussion, where we also expose some open issues to be addressed in forthcoming studies.

2. Materials and Methods

2.1. Study Area

This study was conducted in the FMU of Vrbovec (84% forest cover) in the region of Kočevje (Slovenia, Figure 1). The study area encompassed a pilot area (ca. 6 ha) and the surrounding area (defined by a circle with a diameter of 2000 m/1256.6 ha/, with the center in the pilot area; see Section 3.1 for details). This FMU was chosen because it has been exposed to several disturbances in the last thirty years. It is also characterized by harsh ecological conditions (high karst), overspread spruce in its lowlands, and many totally or partially destroyed forest sites.

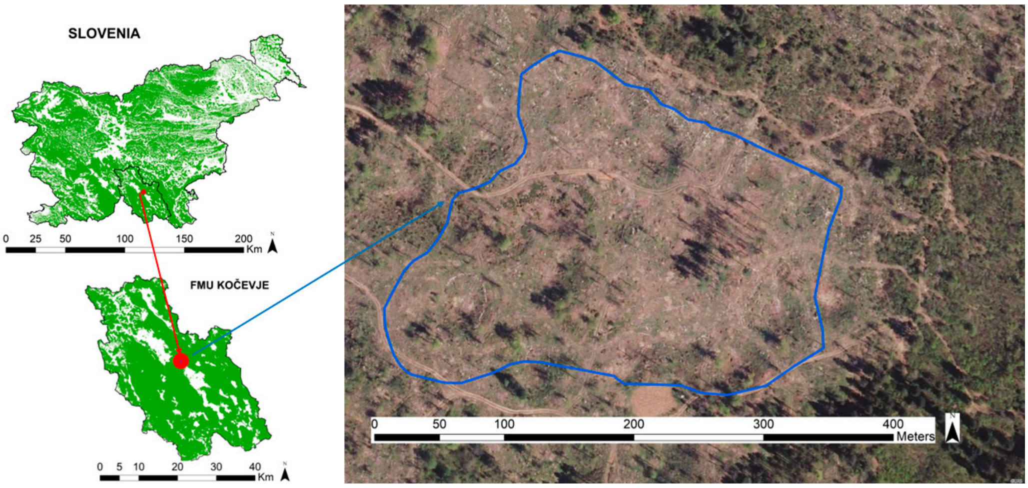

Figure 1. Study area location and the pilot area.

2.2. Forest Disturbances and Damages

Forest disturbances were explored within the FMU and the surrounding area. All plans from the 1990s onwards were checked. The surrounding area, located at the intersection of the FMU of Vrbovec and two neighboring FMUs (Stojna and Velika gora), was analyzed with geocoded data. To obtain damaged areas, the stand maps of all three FMUs were overlayed with layers of forest disturbances. With the support of attributes, such as developmental phase, tree species composition, vegetation community, stand vegetation change, and cause of felling, we performed simple GIS and statistical analyses.

2.3. Site Conditions, Tree Species Compositions of Stands, and Habitat Types

Slovenia's forest management is influenced by the Braun-Blanquet plant sociology approach [44] and the Tuxen concept of potential natural vegetation (PNV). This concept (similar to Natural range of variability, used in North America) is defined as an imaginary natural state of vegetation, potentially expected under given environmental constraints and the absence of human intervention and natural hazards [45]. Despite its limitations in heavily changed forest environments, large-scale vegetation mapping and detailed site investigations are usually informative enough to infer what tree species once grew in a region, what their susceptibility to disturbances is, and what forest types and species mixes would best fit the region's sites.

The tree species to be planted in the surrounding area (forest types and forest habitat types, respectively) were determined by a two-dimensional scheme, connecting different forest uses (e.g., forest management, forest conservation, and plant science) with two contrasting spatial levels. Depending on the use (Figure 2), an organizational unit at the landscape level may be considered a forest type, forest habitat type, or a group of sites [46].

Regardless of the use, at the detailed spatial level these units represent the mosaic of more or less homogeneous plant communities (also named forest associations) that interact with each other and develop their joint ecological integrity [44]. Since it is usually known to which forest type or habitat type a particular plant community belongs (either PNV or others), the portrayals of forest types, habitat types, and stands can be defined straightforwardly.

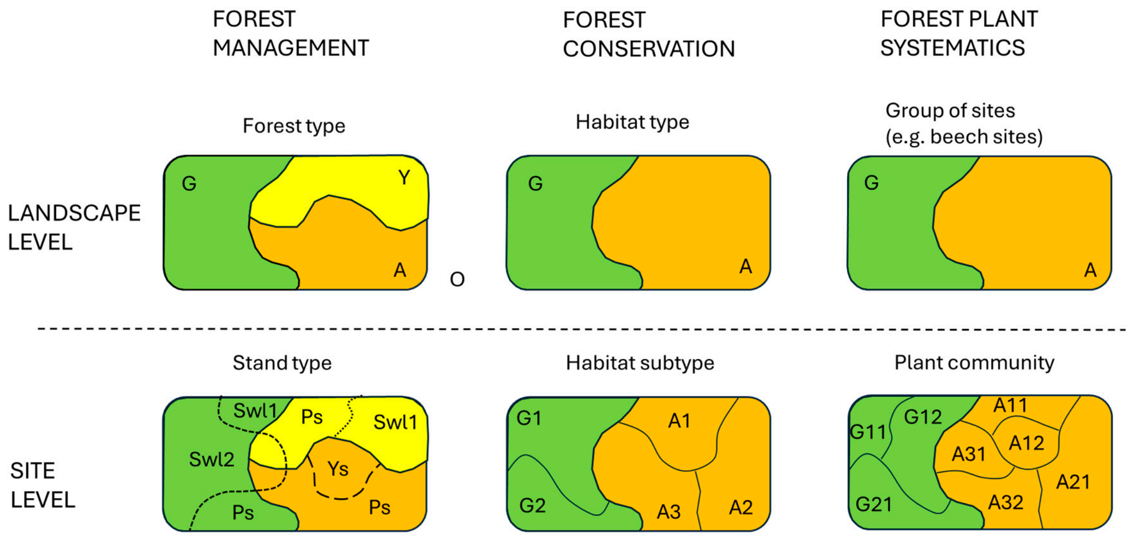

Figure 2. Schematic representation of organizational entities at a landscape and site level (Abbrev.: A, G, Y = forest type or habitat type or a group of sites; Swl = sawlog; Ps = pole stand; Ys = young stand). Plant community is the most detailed plant unit and is the basis for aggregation. Habitat type A: for instance, 91KO Illyrian *Fagus sylvatica* forests; Habitat subtype A1= *Haquetio-Fagetum*; A2 = *Hedero-Fagetum* sin. *Querco-Fagetum.*

To gain the necessary information, site conditions were investigated at two spatial levels. The pilot area (the site to be restored) underwent a detailed phytosociological and soil investigation. The first study suggested [47] that the site could belong to the group of pre-Dinaric-Dinaric submontane beech forests, while PNV could be classified as a community of beech with dwarf masterwort (*Haquetio-Fagetum*). However, the same datasets enabled the classification of the site to the group of sessile oak with beech on leached soils, while PNV could belong to the community of beech and common ivy (*Hedero-Fagetum*, sin. *Querco-Fagetum*). This study also provided a list of present tree species (Table 1) to be favored in the pilot area and beyond, and the information that site vegetation was changed significantly.

Table 1. Site conditions in the pilot area of Dolnje Ložine, FMU Vrbovec, Forest region of Kočevje [47,48].

Observed Variables	Observed Value/Attribute
Mean annual temperature	8.3 °C
Annual precipitation	1520 mm
Elevation above sea level	470–490 m
de Martonne aridity index	82 (=extremely humid)
Plant community	*Haquetio-Fagetum*; *Hedero-Fagetum* sin. *Querco-Fagetum*
Soil depth	0–60 cm
Soil type	Shallowest soils—rendzinas; Deeper soils—calcareous brown soils (Chromic Cambisols); bottom of sinkholes—leached brown soils (Luvisols)
Soil pH	4–5.5

Soil organic carbon stock	40–80 t C ha^{-1}
Presence of deadwood	On 7%–70% of the area
Presence of invasive species	In some parts: giant goldenrod (*Solidago gigantea*), annual fleabane (*Erigeron annuus*)
Present tree species	*Picea abies, Abies alba, Pinus strobus, Acer pseudoplatanus, Acer campestre, Betula pendula, Carpinus betulus, Fagus sylvatica, Fraxinus excelsior, Fraxinus ornus, Malus sylvestris, Ostrya carpinifolia, Populus tremula, Prunus avium, Quercus petraea, Tilia cordata, Tilia platyphyllos, Salix caprea, Sorbus aria, Sorbus aucuparia*

Considering both PNV communities, the fact that beech was systematically suppressed in neighboring stands (see Section 3.1 for details) and afterwards was totally destroyed, and soil data (Table 1), we suggested that the pilot area should be reforested with a mix of key species (Table 2), such as beech, oak, sycamore maple (*Acer pseudoplatanus*), and silver fir (*Abies alba*). As broadleaves in this area were suppressed for a considerable length of time, we also suggested that beech and oak should be genetically improved with known provenances from this and other regions. Lastly, to improve the wildlife habitat conditions, we proposed that the tree species mix should be enriched with selected wild fruit species. In connection with these decisions, it is worth noting that a likely occurrence of naturally regenerated spruce offspring (due to easy seed dispersal from remaining neighboring stands and its competitiveness in open spaces) would not be beneficial for the site as it would prolong the undesirable forest development trajectory that had been shifted from its natural course long ago.

Table 2. Planted forest reproductive material.

Forest Reproductive Material *	Species and Provenance **	No. of Seedlings	Share (%)
Key species	European beech (*Fagus sylvatica*); Gorjanci-Strmec, pre-Dinaric	2760	24
	European beech (*Fagus sylvatica*); Rog, Dinaric	717	6
	Sessile oak (*Quercus petraea*); Pokoše, Pohorje	2858	25
	Sessile oak (*Quercus petraea*); Pasji rep, sub-Mediterranean	1780	16
	Sycamore maple (*Acer pseudoplatanus*); Pernice, pre-Pannonian	1735	15
	Silver fir (*Abies alba*); Jelovški boršt, pre-Dinaric	241	2
Fruit species	Wild cherry (*Prunus avium*); Zidanšek, pre-Alpine	417	4
	Rowan (*Sorbus aucuparia*); Plešivec, Pohorje	225	2
	Crab apple (*Malus sylvestris*); Zidanšek, pre-Alpine	268	2
	Wild pear (*Pyrus pyraster*); Zidanšek, pre-Alpine	364	3
	Common hawthorn; (*Crataegus monogyna*)	100	1

* Seedlings outside the fence were protected five times with Kemakol and Trico repellent in the period from November 2020 to October 2023. ** The seedlings of beech and oak were 2 years old (2 + 0), of sycamore 3 (1 + 2), and of fir 4 (2 + 2) years old. Apart from sycamore (height ca. 80 cm), most seedlings were less than 50 cm tall.

Because of the availability of geocoded data on PNV and stands' species compositions, the surrounding area underwent a GIS analysis. The spatial distributions of both attributes played an important role in considering suitable species mixes.

2.4. Planting Design and Survival Assessment

Planting (Figure 3b,c) was performed in species-homogeneous clusters [49] that formed larger oak and beech patches, admixed with sycamore and fir. Sycamore was mixed with oak, while fir was mixed with both species. This pattern was chosen because beech and oak are competitive species [50]. With regard to microrelief gradients, oak was planted in the plateaus, beech was planted in the bottom of sinkholes and in the transient areas between the sinkholes, and sycamore was planted in existing initial spruce patches (spruce height < 0.5 m) and fir under the shelter of oak remnants and in the bottom of the deepest sinkhole. Fir was planted solely within the fenced part of the pilot area. Existing beech and spruce patches of good quality were kept but were underplanted with seedlings. Already existing spruce patches were suggested to be left in place and merged with the patches of other species. Oak provenances were planted on different microsites. Seedlings from the Pohorje region were planted in deeper soils, while seedlings from the sub-Mediterranean region in shallower ones. Similarly, fruit species were planted in clusters of five seedlings. Their clusters were established in the interspaces between key species clusters (Figure 3a).

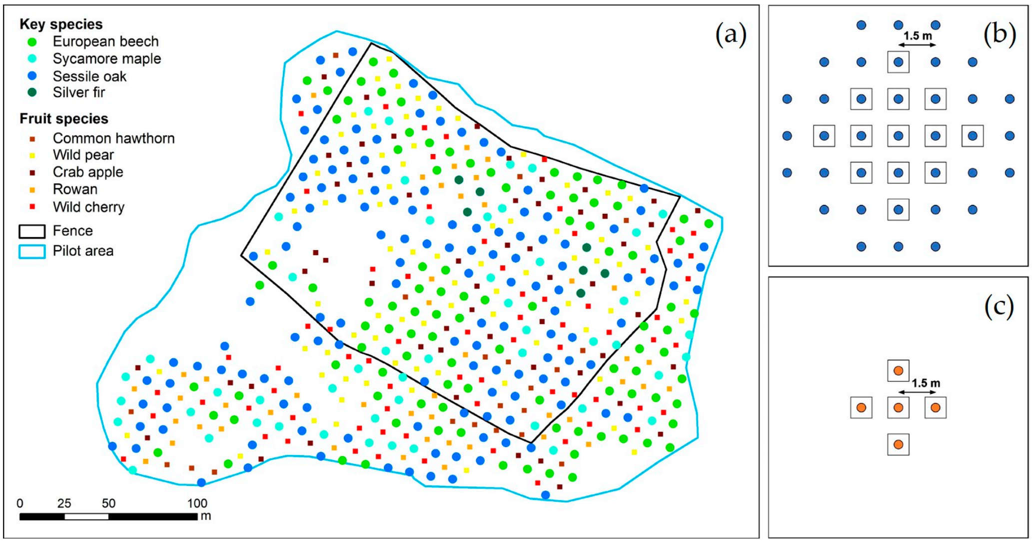

Figure 3. Pilot area. (**a**) Planting blueprint. (**b**) Planting order in the key species cluster (blue dots: the full cluster containing 37 seedlings; squares: the scheme of sampling survival status). (**c**) Planting order in the fruit species cluster (orange dots: the full cluster containing five seedlings; squares: the scheme of sampling survival status).

The survival assessment was performed twice. During the first campaign (May 2021), a census (full enumeration) was used (10,091 key species and 1374 fruit species). In the second campaign (October 2021), a census was used for fruit species (1374 seedlings) and systematic random sampling (precisely: estimation of population proportion) for key species (3545 seedlings). All clusters were revisited, but only 13 of 37 individuals were checked for survival status (Figure 3b,c). These two assessment strategies were chosen because of irregular cluster distributions that did not allow any reasonable stratification. A constituent part of the survival assessment was a provenance test, performed with Student's *t* test. Furthermore, as planting was not performed in terms of experimental design (treatments + control stand), relationships between survival rates (higher or lower cluster rate compared to the mean survival rate) and microecological factors were explored with a one-way ANOVA. The attributes of factors (e.g., location = plain, slope, bottom of sinkhole; protection from game = inside, outside of fence) were used as grouping variables.

2.5. Framework

A five-step framework was developed by summarizing the actions needed in establishing a future stand. To organize it in a logical order, we used the system engineering approach [51] and the forest planning process [52]. If the framework steps are used in a consecutive order, they help to define and establish stands and forests, and suggest how to manage them over time.

- Step one—a situation analysis (environmental scan) collects ecological and other data on sites to be restored and in their surrounding areas (potential and real plant communities and changes, site conditions and their potentials, and ecosystem services). This step also requires the investigation of historical events and shaping of future scenarios, such as which type of disturbances prevailed and what species shifts are expected due to climate change.
- Step two—desired future portrayal defines tree species compositions and structures of new forest generations. To promote forest integrity, stability, adaptive capacity, and the ability to deliver ecosystem services (including biodiversity), the portrayals of new forest generations must be defined at landscape and site levels. This step includes thorough considerations about long-term goals and desired ecosystem services for they are, to a certain degree, dependent on tree species compositions and structures.
- Step three—generic and functional pathways support set goals and objectives. Generic pathways typically support goals and need to be understood as long-term directions. They refer to a forest complex (e.g., keeping forest types and habitat types compact by maintaining their core zones [53] and sustaining tree species compositions). In contrast, functional pathways, always specific in terms of location, type of action, and time frame, support medium-term objectives (e.g., weed control and forest tending in different development stages).
- Step four—the implementation of the restoration plan is about the execution of actions. Prior to planting, a detailed blueprint with necessary information must be finalized (e.g., planting order and density, weed control, seedling treatment and protection, and area fencing).
- Step five—survival and stand development monitoring is essential in creating new forest generations. In addition to assessing seedling survival, this action helps assess the effectiveness of a regeneration technique, the suitability of provenances, and stand development over time [22].

3. Results

3.1. Disturbances and Damages

Between 1991 and 2000, the FMU was affected by the fir-dieback; between 2001 and 2006, by the bark beetle infestation; and between 2014 and 2018, by the nationwide ice storm and consecutive bark beetle attacks [54,55]. The same held true for the surrounding area (Table 3; Figure 4), where the majority of forests (ca. 90%) are located below 600 m a.s.l. Although it lies within the spruce natural range, its lowlands were excessively planted by spruce. Consequently, all stands, except for those with low shares of spruce, were affected by a series of disturbances.

Table 3. Basic information on forest damages in the study (and surrounding) area.

Indicator		Area, ha (%)	Damaged Area, ha (%)
Lowland forest	<600 m a.s.l.	941 (90)	
Young stands	10 cm < DBH < 30 cm	335 (32)	215 (64)
Saw log stands	DBH > 30 cm	660 (63)	338 (51)
Bush forest	/	50 (5)	42 (84)
Spruce share	<30%	188 (18)	35 (19)
	>30%; <70%	143 (14)	104 (73)
	>70%; <90%	279 (27)	137 (49)
	>90%	388 (37)	308 (79)
	n/a	47 (4)	

The pilot area was affected multiple times (by the 2014 ice storm, bark beetle outbreaks in 2015 and 2016, and windthrow in 2017). The last event finally destroyed its tree cover.

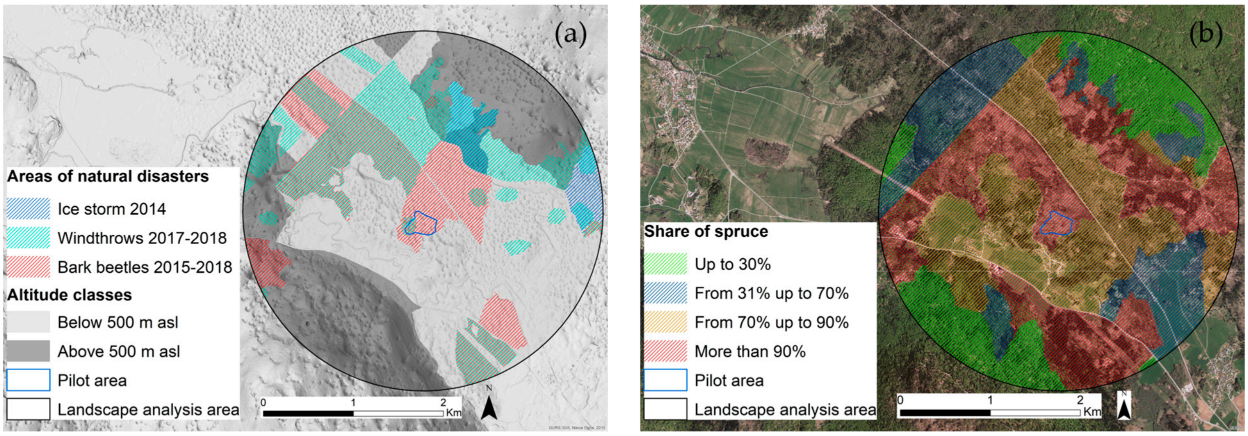

Figure 4. (**a**) Locations and areas of natural disturbances occurring between 2014 and 2018. (**b**) Changes in tree species composition in the forests around the Dolnje Ložine pilot area; the analyzed area encompassed a forest area of 1267 ha (a circle with a radius of 2 km with the pilot area in the center).

3.2. Future Portrayal of the Surrounding Area

Three of the most common PNV communities in the surrounding area were oak with beech (ca. 66% of the area), located in the northeastern part; fir-beech (ca. 25%) in the extreme southwestern slopes; and sub-mountainous beech forest (5.3%), also present in the extreme southern slopes. Considering management recommendations on overspread spruce [56] and the fact that all three plant communities may constitute the same habitat type, we suggested that damaged areas should be restored with species compositions supporting the 91K0 habitat type of the Illyrian *Fagus sylvatica* forest [3]. This forest habitat type is heterogeneous in nature and allows the establishment of ecologically different habitat subtypes (e.g., pure beech, fir-beech-spruce, and oak-beech communities) [46].

3.3. Seedling Survival, Provenances, and Site Factors

The first winter survived 77% of seedlings (Table 4). The highest survival percentages were observed for fir (92%), sycamore (82%), beech from the pre-Dinaric provenance region (82%), and oak from the pre-Dinaric provenance region (79%). On average, of all planted seedlings in the cluster, 27 survived. The second assessment revealed that the mean survival rate was ca. 56%. Of the 13 sampled individuals in the cluster, 7 survived. The highest survival rates were detected for fir, oak, and beech. In the whole population, 5611 ± 131 seedlings ($p = 0.05$) survived. The highest mortality was recorded for oak from the Pohorje provenance region.

Table 4. Survival of key species during fall 2020–October 2021.

Tree Species	Seedlings	Survived	Dead1 *	Dead2 **	Dead1 + 2	Dead, %	Alive, %
E. beech, pre-Dinaric	1021	606	166	249	415	40.6	59.4
E. beech, Dinaric	245	148	48	49	97	39.6	60.4
S. maple, pre-Pannonian	606	352	90	164	254	41.9	58.1
S. oak, Pohorje	1026	455	250	321	571	55.7	44.3
S. oak, sub-Mediterranean	640	392	97	151	248	38.8	61.3
S. fir, pre-Dinaric	91	65	6	20	26	28.6	71.4
Total	3629	2018	657	954	1611	44.4	55.6

* Dead at the 1st monitoring campaign; ** dead at the 2nd monitoring campaign.

The survival of species coming from different provenance regions differed (Figure 5). Significant differences were found between the oaks ($t = 4.19$; $p = 0.000$) that came from the contrasting provenance regions of Pohorje (northern Slovenia, poorly adapted) and sub-Mediterranean (southern Slovenia, adapted). Although seedlings from the Pohorje region were taller (and morphologically better developed), their survival rate was lower due to a much lower adaptive capacity. In contrast, no significant differences were detected between the beech species that came from the ecologically similar Dinaric and pre-Dinaric provenance regions.

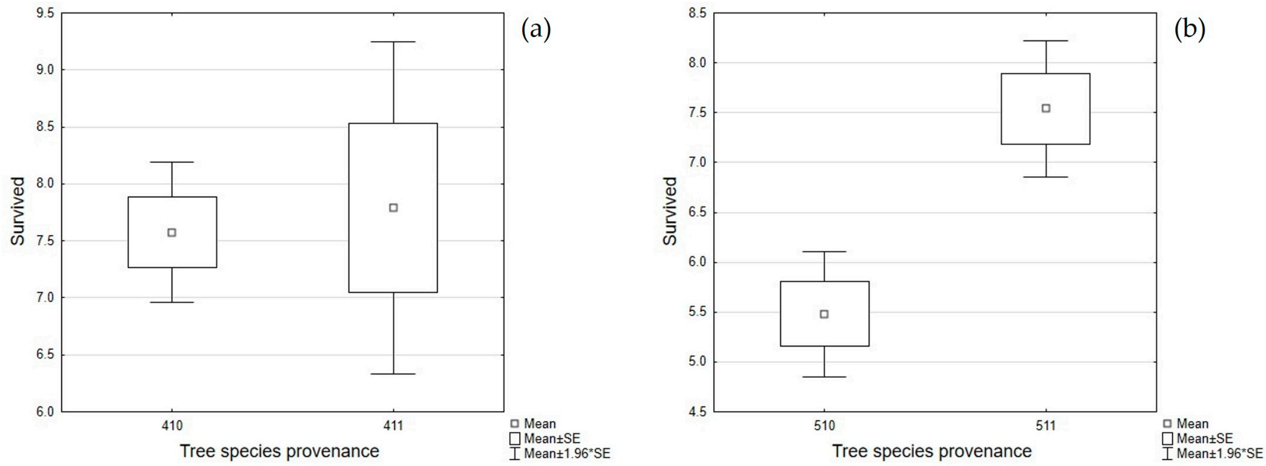

Figure 5. Survival of seedlings from different provenance regions (y-axis: average number of survived seedlings in the cluster): (**a**) European beech from the pre-Dinaric provenance region (410) and Dinaric region (411). (**b**) Sessile oak from the Pohorje provenance region (510) and sub-Mediterranean region (511).

Much longer survival rates were observed for fruit species. During the first winter, only 24 of 1374 seedlings died (survival = 99.98%). Most of them (14) were wild pears. Over the summer, the number of dead seedlings increased by 51 and resulted in a total of 75 dead individuals. The overall survival rate was 94.5% (1299 seedlings remained alive).

The spatial survival pattern exhibited patchiness (Figure 6) that had no close relationship with microecological factors. Similarly, the survival of seedlings inside and outside the fence showed no differences.

Figure 6. Distribution of key species clusters by site location and survival rate (above or under the average). Legend: outer squares; light green = plateau; orange = slope; dark green = bottom of a sinkhole; inner circles; red = no. of survived seedlings smaller than average; and light green = no. of survived seedlings larger than average.

3.4. A Five-Step Framework

The five-step framework is displayed in Table 5. In addition to the step name, the table suggests the spatial level at which each step should be applied, justifies its purpose, and presents the basic methods to be used and activities to be carried out. The steps in this order are needed to make decisions and arrive at desired stands and forests.

Table 5. Five-step framework for forest restoration.

Step Name	Spatial Level	Purpose	Method	Activities
1 Situation analysis	Region, landscape	Defining planning area	GIS, field inspection	Defined planning area.
		Vegetation, acquainting with forest habitat types and damages	Field inventory, GIS	Distribution of forest habitat types and plant (also PNV) communities, distribution of damaged stands and volume, ecosystem services.
		Disturbance analysis	GIS, FMU plans and archives	Historical analysis of hazardous events (agent, frequency, damage extent, regeneration dynamics), assessment of threats and opportunities.
		Landscape plan	GIS	Suitability maps for forest habitat types.
	Site, stand	Site exploration	Site inventory	Investigating site and stand features, defining suitable regeneration types, presence of browsing and diseases.
		Available resources	Accounting	Availability of planting and sowing material, financing, work force.
2 Desired future portrayal	Region, landscape	Habitat type future portrayal	PNV, real vegetation, desired values	Defining desired portrayal of a landscape (forest habitat types, vegetation communities, other features). Exploring the possibilities for amalgamating stands. Setting conservation targets (buffers,

				corridors, prevention from fragmentation, excessive browsing, nature conservation sites). Ecosystem services check.
	Forest type, stand	Defining goals and restoration types	PNV, real vegetation, desired values	Desired mix of tree species, vertical structure, species mingling, regeneration technique, amelioration technique (e.g., underplanting, planting in patches).
	General	Conflict resolution	Ranking, decision support	Assessing the effects of disturbances on desired portrayals, reliability of reaching set goals.
3 Generic & functional pathways	Region, landscape	Developing pathways for a landscape	GIS modeling, means to ends analysis, desired values	Generic pathways: Establishing initial patches of forest types across the forest region. Maintaining the sizes of forest core areas, maintaining buffers.
	Forest type, stand	Pathways for partially damaged and nondamaged forest types	GIS, means to ends	Generic pathways: Browsing control and regulation, balancing ecosystem services, suggestions for merging isolated forest patches into forest types, prevention from fragmentation. Functional pathways: Maintaining core areas, defining actions for ecosystem services.
	Site, stand	Pathways for newly established stands	Means to ends	Functional pathways: Site preparation, planting density, seedling/seed treatment, seedling protection from animal and insect herbivory or site protection (fencing), scheduling weed control, regular stand tending.
4 Implementation	Forest type, site	Execution of plans and blueprints	GIS, elaborating the material	Implementing actions in forest types. Elaborating planting blueprints, planting.
5 Monitoring	Forest type, site	Forest development and seedling survival	Forest inventory, plot inventory	Collecting data on forest stands and sites. Seedling survival survey.
	General	Monitoring the success of pathways	Indicators	Defining differences between past and present states. Evaluation of sustainability status and survival.

4. Discussion

4.1. Framework Contribution to the Creation of Future Forests

Recent decades have been stirring times for Europe's forests. Because of many pressures, ranging from natural disturbances to human demand for ecosystem services, forest management has experienced occasional difficulties in providing these services concomitantly and sustainably. Currently, the greatest demand is for carbon storage [57–59], which calls for sustainable sequestration and new forest generations, characterized by ecological traits. The presented framework is one of many to be used for their establishment [34,36,60]. Its main features are stepwise decision making, equitable promotion of sustainability components, and a holistic approach to the creation of future forests.

Stepwise decision making is assured by five successive steps that must be performed, such that each step is the means to arrive to the next step.

- A situation analysis (step one) provides basic information for shaping a future forest landscape portrayal. As climate change is underway, this step must take into account likely plant successions and predicted vegetation shifts [61].

- Desired future portrayal (step two) is about making trade-offs among ecological possibilities, human wants, and conservation requirements. Once the portrayal is defined, a set of long-term forest management goals is to be set. This step requires forest managers to understand how forest ecological integrity works. For example, while portrayals at the landscape level help sustain the existence and distribution of forest habitat types, portrayals defined at stand levels guarantee that specific tree species compositions of new forest generations (stands) fit site conditions and form the plant communities (subtypes) of these forest habitat types.
- Generic and functional pathways (step three) are needed to meet goals and objectives. While generic pathways control the main course of forest (or habitat type) development, functional pathways are essential for sustaining forest diversity as they help establish stands that fit specific site conditions and the provision of forest services because they control all actions in the field (e.g., protection against erosion needs a specific tree structure, berries grow in stands with variable light, safe recreation is preferable in mature and well-tended forest complexes, and quality wood can be produced by tending trees and stands). At both spatial levels, generic pathways and actions support the integrity of forest habitat types and subtypes by maintaining their core areas. If their minimum sizes are not secured, habitat types and subtypes may no longer sustain themselves and they blend with neighboring stands. Furthermore, generic pathways should also address disturbances sparked by humans (e.g., game management). The problems of fir, pedunculate oak, and some rarer species that are becoming extinct in their native range and habitat types are well documented [12,62]. This issue is not trivial because these species are the key species of the Natura 2000 forest habitat types and need to be monitored, assessed, and conserved.
- The implementation of a restoration plan (step four) and survival monitoring (step five) are the final steps of forest establishment. Apart from detailed action planning, no decision making about future forests is needed. To pursue the main pathways, survival monitoring must gradually evolve into continuous stand development monitoring [63].

As demonstrated, this framework demands consistent decision making at every step. If it is performed in this manner, it leaves little room for errors.

The second trait of the framework is equitable promotion of all sustainability components. The ecological component is best reflected by juxtaposing real forest vegetation with potential natural vegetation. This comparison is meaningful, despite limitations and climate change predictions, because it prevents taking questionable decisions. The ecological component is also reflected through the promotion of indigenous species, stand structures, and ecological factors, which continue to hold, despite changing environment [19,64]. Similarly, social and economic components are exhibited through social and economic ecosystem services, which need to be managed by target-oriented actions. Such actions include thinning and cutting to support high-quality timber production, keeping stands open enough to promote forage for animals, and safe recreation.

The last trait, a holistic approach, is best reflected by combining the landscape and site-specific goals, objectives, and actions. Its power lies in the ability to integrate individually established stands (that act as building blocks) into forest habitat types and make them function as a whole.

Although the presented framework shares many similarities with ecological restoration, we believe it can be used universally in any forest restoration. The main reason for this are changed demands for future stands coupled with the precautionary principle.

4.2. Site Restoration

The established mixed stand, presented in this study, differs from monospecific planting experiments in many ways. First, it supports the idea of mixed forests that likely prevailed in large parts of European forestlands in the past [65]. Second, it promotes indigenous, site-suitable species, resembling natural vegetation and site traits, and thus complies with the principles of ecosystem forest management and nature-based forestry. Thirdly, it has the potential to become the cornerstone of the forest habitat type and assists in strengthening its ecological integrity and adaptive capacity. These attributes are no longer required by only some specific forests but by all seminatural forests used by societies. Finally, the concept of mixed stands introduces tree species with controlled provenances that will likely assist in creating healthy and adaptable forest stands in the future and in improving their wood quality.

Reports from provenance and afforestation trials reveal that seedling survival in the natural environment generally ranges between 60 and 95%, and heavily depends on local conditions, treatment against diseases and pests, and planting quality [66,67]. Similar survival rates have been reported for trials with coated seeds [68]. With the exception of poorly adapted seedlings from the Pohorje provenance region, the survival of seedlings from all other provenance regions was close to 60% or higher. Thus, an important take-home message is that harsh ecological conditions cannot be beaten by high-quality seedlings, but rather by their high adaptative capacity.

Hence, in view of harsh karstic conditions, bare root planting, no specific treatment, and the upper mentioned survival rates, we consider the success of our restoration from low to moderate. Additionally, we expect that an ongoing natural ingrowth will fill gaps and that early mix regulation will assist in establishing a model stand.

4.3. Open Issues and Future Work

Contemporary forest restoration is presently supported by many methods assisting in meeting specific objectives [69]. On the other hand, much less is known about their success. As Europe is about to experience vegetation shifts that might change the distributions and shares of present-day tree species [70,71], it is vital for European forestry to gain fresh knowledge on establishing and managing mixed and pure broadleaved stands that will likely prevail in some of its parts in the future. Although some of this knowledge is already available [72–74], especially appreciated would be information regarding the costs and techniques of their establishment (combined vs artificial and containers vs bare root), resistance to particular disturbances, ways of species mixing, mortality, and yield. All these tasks should also be performed in this area and many other pilot areas in Slovenia that underwent artificial and natural regeneration in the past 5 to 10 years.

The answer regarding which potential (indigenous and foreign) tree species could replace present key European species, whose habitats might become significantly reduced due to climate change and accompanying events (insurance hypothesis), is also urgent. The current strategy, based on the principle "it goes as long as it goes with the present species", is not the best choice and may not work well for forestry or for forest conservation and societies.

5. Conclusions

Rapidly changing environmental conditions and a variety of disturbances demand the creation of forests with high ecological integrity, adaptive capacity, and the ability to provide all sorts of ecosystem services. Because of extremely diverse ecological and social demands, the creation of future generations of seminatural forests will probably have to be grounded on trading off integrity and adaptivity for social benefits, as these traits represent the grounds of wellbeing.

To meet at least the most important ecological traits, restoration of future forests will have to relinquish simplified regeneration concepts. This includes planning compact forests at the landscape level, instead at the stand level; establishing forests with site-adequate species, instead of with species; and maximizing yield with targeted tending and protection against loose tending and frequent diseases and infestations. Also worth mentioning is the improvement of gene pools, which are often depleted due to the systematic suppression of commercially less desired species and unsuitable thinning practices, such as high grading. Since much of the present knowledge on forest establishment and management (ways of forest renewing, planting, yield assessment, and competition) applies to homogeneous and pure forests, more research is needed in mixed coniferous-broadleaved and mixed broadleaved species. With regard to stand establishment, the most needed knowledge should deal with species interactions, species site-adaptivity, costs of stand establishment, and tending to produce high-quality timber. Also needed is an improved education system that will spread new knowledge and the paradigm of future forests.

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