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Review

Deep Ecology, Biodiversity and Assisted Natural Regeneration of European Hemiboreal Forests

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Abstract: Climate change and the associated disturbances have disrupted the relative stability of tree species composition in hemiboreal forests. The natural ecology of forest communities, including species occurrence and composition, forest structure, and food webs, have been affected. Yet, the hemiboreal forest zone of Lithuania is the least studied in the country for climate change risks and possible management adaption techniques. This problem is further complicated by the fact that Lithuania uses a traditional centralised forest management system. Therefore, this work proposes assisted natural regeneration (ANR) of tree species as a more viable means of building hemiboreal forest resilience to cope with future climate change risks. The ANR model implies that forest management is localised in local communities, to provide opportunities for the local people to participate in forest management based on local knowledge, thereby facilitating the transition from cultural diversity to biodiversity. Further, ANR is grounded on an ethical framework—deep ecology—to provide ethical justification for the proposal to transit forest management in Lithuania from the traditional centralised segregated system to a community-driven practice. The work combines the theories of ANR, deep ecology, and hemiboreal forest knowledge systems to provide complementary information that builds on gaps in the existing literature. This study is unique in that no previous work has linked ANR and deep ecology in the context of Lithuania's forest ecosystems.

Keywords: hemiboreal trees; assisted natural regeneration; deep ecology; climate change; forest sustainability; forest management; Lithuania; forest disturbances

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Citation: Petrokas, R.; Ibanga, D.-A.; Manton, M. Deep Ecology, Biodiversity and Assisted Natural Regeneration of European Hemiboreal Forests. *Diversity* **2022**, *14*, 892. https://doi.org/10.3390/d14100892

Academic Editors: Jian Lin, Qin Ma, Jingyu Dai, Weichao Guo and Yang Ju

Received: 23 September 2022
Accepted: 19 October 2022
Published: 21 October 2022

1. Introduction

Natural recurring forest processes are often self-organised and implicate sustainability processes in environmental changes. Niche construction, ecological engineering, and biosemiotics processes are different forms of indirect, background interaction and communication of organisms in the environment [1]. Self-organisation of an ecosystem includes all the diversity that cannot be reduced to the properties of an individual system's components, such as molecules, genes, populations, and species in both time and space [2]. Meaning is generated across all the organisational levels [3]. The strategy of life expansion is realized through the spread of life in space—the proliferation and collaborative construction of ecosystems and the biosphere by organisms. Forests are multi-scale, multi-species networks that constantly evolve toward the successional processes and patterns of natural regeneration which cannot be reached at an individual tree species level. In this direction, our work focuses on the super-organism approach of forest communities that considers succession as a comprehensive ecological process of multiple events where the forest vegetation communities are directly related to environmental condition with regard to climate change [4].

The life history traits of species are controlled by natural patterns and processes recurring over time and space at multiple scales [5,6]. Natural selection has matched trees to site and environmental conditions for millennia [7] and is considered a key evolutionary process that can increase the adaptation rate of species to environmental change [8]. Natural selection can be confirmed through field observations of ecological communities and their development towards self-organisation. Tree species' life histories, reproductive character, regeneration times, mode of dispersion, and other evolutionary phenomena are interconnected in the immense and complex system of self-sustaining interactions of forest communities [9]. The ecology of a forest never ceases to evolve. The probability of seed germination, tree growth, development and recruitment is dependent on a species' genetic profiles and life history traits to cope with the changes in environmental conditions [10–12]. Dynamics in forest communities are driven by a wide range of factors, including species' invariable life history strategies [4].

However, traditional forest management, climate change and increased disturbances have disrupted the relative stability of tree species composition in combination with the edaphic site conditions in European hemiboreal forests [13,14]. This is a key problem. The natural ecology of forest communities, including species occurrence and composition, forest structure, and food webs have been affected [15]. Developing knowledge about natural forest disturbance dynamics and their relationship to anthropogenic impacts and management practices is essential towards the mitigation of impacts on forest ecosystems in the light of climate change [16]. This warrants the basis for proposing the assisted natural regeneration (ANR) strategy as an alternative adaptive model for forest management in Europe.

The aim of the review was to provide complementary information that builds on the topics of deep ecology and ANR within the context of hemiboreal forest management. First, we proposed a conceptual framework for hemiboreal tree dynamics based on Lithuania as a case. Second, we discussed the benefits of ANR of trees in the context of hemiboreal ecology. Finally, ANR was overlaid on deep ecology—an ethical framework—to highlight how it can promote diversity in forest management.

2. European Hemiboreal Tree Species: The Case of Lithuania

We focused on the European hemiboreal forests of Lithuania because it is one of only two countries (Latvia and Lithuania) that falls completely within the hemiboreal forest zone in Europe [17]. The hemiboreal forest zone is the flux zone between the temperate forest zone to the south and boreal zone to the north. Unfortunately, the forests of the hemiboreal zone are often overlooked in climate impact and adaption studies, while attention is focused on the other two zones [14].

Lithuania's hemiboreal forest site types (as well as the 13 Natura 2000 forest habitat types of European Community) can be classified into three main forest habitat types based on the concept of potential vegetation and soils [14,18,19]: (1) mixed broadleaved forests on rich sites; (2) mixed species forests on mesic sites dominated by Norway spruce; and (3) Scots pine (*Pinus sylvestris*) forests on poor sites. Soil moisture and fertility of Lithuania's forests are considered the main drivers of forest disturbances and succession [17]. As such, Lithuania's forests have been classified by the Food and Agriculture Organisation (FAO, Rome, Italy) soil classification system [20,21] based on soil typological groups (Figure 1).

The main tree species of mixed broadleaved forests in Lithuania are *Quercus robur, Tilia cordata*, *Acer platanoides, Fraxinus excelsior,* and *Ulmus glabra*, along with *Alnus incana* and *Alnus glutinosa* [18]. Other individual non-dominant tree species can also be found here—Norway spruce and birch are the most common, the least common being Scots pine [22]. Mixed Norway spruce forests in Lithuania usually consist of *Betula pendula*, less commonly *Populus tremula* or *Pinus sylvestris*, and on richer sites *Quercus robur, Tilia cordata,* *Acer platanoides* and *Carpinus betulus*. Eurasian aspen and birch stands are mostly mixed, as well as English oak and European ash stands [22]. Scots pine forests grow on highly oligotrophic, strongly acid- to base-rich soils, on very shallow and dry substrates to wet and oxygen-poor mires, on mineral and peat wetlands. Within peatland forests, vegetation communities show that a high-water table and nutrient poor environment affects tree growth [17]. The species composition of Lithuanian hemiboreal pine forests is often a mixture of species from various vegetation formations but can be remarkably similar to boreal pine forests (especially on infertile sites).

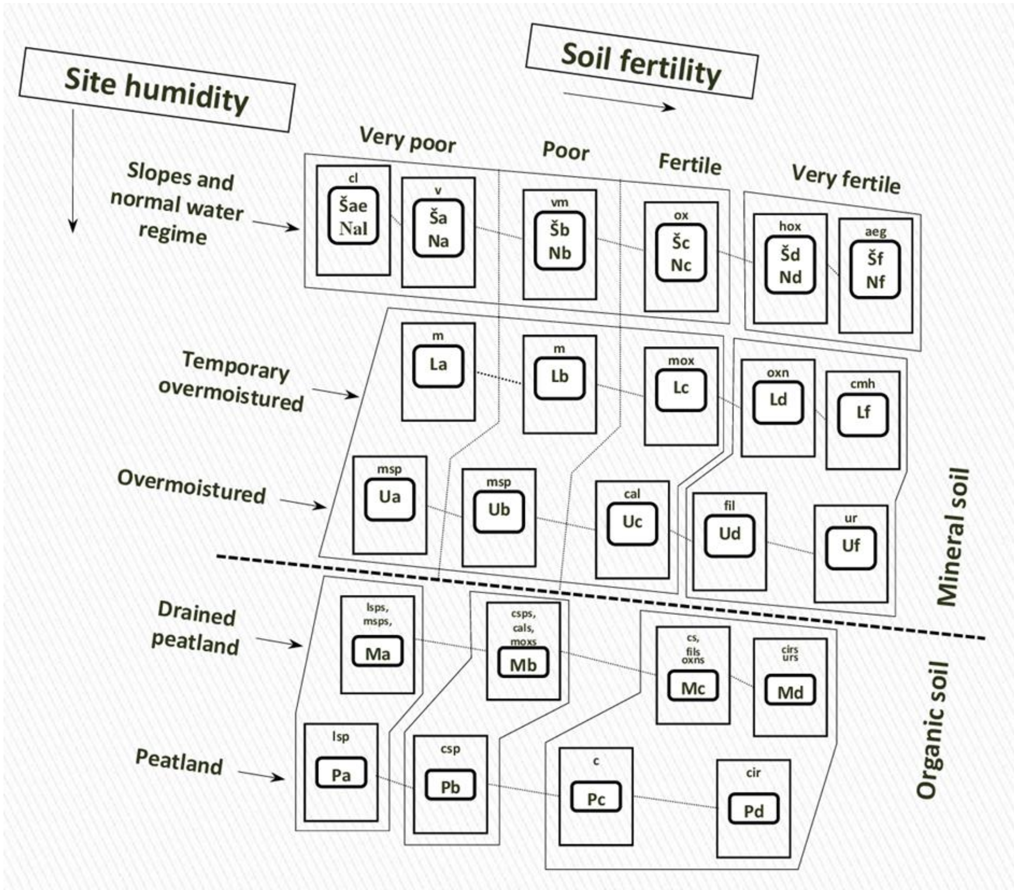

Figure 1. Lithuania's forest site type scheme. The bold codes refer to Lithuanian's forest site types based on soil fertility and moisture, and the small non-bold letters refers to the forest vegetation type series [18,20,23]: N—normally moist, L—temporarily over moist, U—over moist, P—peatland, and f—very eutrophic soils, d—eutrophic soils, c—mesotrophic soils, b—oligotrophic soils, a—very oligotrophic soils; aeg—*Aegopodiosa*, c—*Caricosa*, cal—*Calamagrostidosa*, cir—*Carico-iridosa*, cl—*Cladoniosa*, cmh—*Carico-mixtoherbosa*, csp—*Carico-sphagnosa*, fil—*Filipendulo-mixtoherbosa*, hox—*Hepatico-oxalidosa*, lsp—*Ledo-sphagnosa*, m—*Myrtillosa*, mox—*Myrtillo-oxalidosa*, msp—*Myrtillo-sphagnosa*, ox—*Oxalidosa*, oxn—*Oxalido-nemorosa*, ur—*Urticosa*, v—*Vacciniosa*, vm—*Vaccinio-myrtillosa*.

3. Hemiboreal Tree Dynamics

3.1. Tree Regeneration Strategy

Forests are characterized by the development of contiguous communities of trees that are relatively uniform in composition, structure, age, size, class, distribution, spatial arrangement, site quality, condition, and location to distinguish them from adjacent communities created by human intervention [24–26]. The absence of structural legacies at multiple scales is one of the most distinguishing features of modified forests subjected to intense and frequent anthropogenic disturbances [27,28]. Species' life history traits are interrelated with natural disturbances and associated site conditions, and these account for the interactions (patterns and processes) in species distribution [14,29]. There is also increasing evidence that the intrinsic influences of disturbance susceptibility are phylogenetically inherited, implying that species-level traits are constrained by developmental, genetic, or other correlated limitations [30]. Being the primary species of forest ecosystems, long-lived trees are pivotal in providing associated organisms with a combination of resources and habitats that range from beneficial to detrimental [31]. Therefore, the forest development and growth dynamics of tree species follow relatively fixed patterns and can be difficult to modify in the light of the interactions of both biological and physical processes. This is also the case with hemiboreal trees' natural regeneration.

There are four tree natural regeneration strategies, i.e., the establishment and growth of trees in forest gaps [32–36]: (i) colonization; (ii) occupation; (iii) invasion; and (iv) expansion (Table 1). These are inter-intuitive with Clark and Clark's [37] tree species regeneration groups (A–D), Whitmore's [38] tree species groups, having an increasing "pioneer index" (1–4), and Grime's [39] four types of secondary ecological strategies in trees that are derived from the theoretical triangular scheme of competitor (C), stress-tolerant (S) and ruderal (R) primary plant ecological strategies—stress-tolerant ruderals (S-R), competitive stress-tolerant ruderals (C-S-R), competitive ruderals (C-R), and competitive stress-tolerators (C-S). Colonization (D, 4, S-R) implies that even-aged seedlings are being established after gap formation and grow only in gaps. This relates to stress-tolerant species that possess a ruderal strategy without advanced regeneration. Juveniles have the highest growth potential. A ruderal strategy is a characteristic of many species that never become established in ruderal habitats. Ruderal species are plants that grow only in habitats that have been completely disturbed and damaged by human activity [40]. Occupation (C, 3, C-S-R) relates to the competitive stress-tolerant ruderal strategy species occurring as gap makers. Their seeds germinate better in gaps with intermediate canopy openness than in the understorey or large gaps, saplings can survive in closed forests. Invasion (B, 2, C-R) implies that trees regenerate from saplings recruited before gap or stand formation. This type involves competitive species with a ruderal strategy of advance regeneration, allowing already established juveniles to survive in newly created gaps. Expansion (A, 1, C-S) implies that trees in the forest regenerate as advanced regeneration under shade. This usually involve competitive stress-tolerant species. Juveniles have average growth rates.

3.2. Natural Regeneration of European Hemiboreal Tree Species

Multiscale recovery dynamics analysis of community typology is measured to determine the impact of change in forest ecology. Usually, it ranges from tree genetic variation characteristics (in terms of regeneration vs. canopy compositions) to multi-population structures reflected in disturbance and management regimes. To enhance the adaptive potential and associated ecosystem services of forests, we proposed a conceptual framework for hemiboreal tree dynamics based on a dynamic typology of forest communities [13,14,18,19,41–46] and forest sites defined by field layer-canopy dominants, on-site soil fertility and moisture [18,47], and four types of tree regeneration strategies [33–35,37–39,48] (Table 1). It follows the Lithuanian classification of forest types and the layer dominants: forest site type, forest type series (field flora), and dominant and secondary tree species [18]. The three dynamic forest habitat types in our conceptual framework represent general descriptions of plant community types that reflect the dynamics of vegetation cover that occur in the course of natural disturbances [13]. In hemiboreal forests, there are three main types of natural disturbance regimes that determine the success of natural selection: (1) gap dynamics caused by the death of individual trees or small groups of trees in the absence of fire; (2) successional development after severe stand-replacing disturbances, such as crown fires, large windthrows, pest outbreaks, etc.; and (3) multi-cohort dynamics related to partial disturbances, such as low-intensity surface fires [41–46].

Hemiboreal forests may be legacies of biological and physical disturbances [6,24]. Disturbance regimes are classified by the type, magnitude and duration of environmental variation as well as community (ecosystem) and individual species resilience [42–44,49].

Tree species regeneration in hemiboreal zone is generally rapid after large-scale short-term disturbances (e.g., forest fire) but slower after longer term disturbances such as repeated logging or forest conversion to monoculture plantations [48]. Restoration of the original forest ecosystem via natural regeneration can take several centuries as succession begins with early-successional herb, shrub, and tree species, and culminates with late-successional species. In order to understand forest regeneration processes following a disturbance, one needs to be knowledgeable in forest dynamic typology, which can provide a first insight into the status of vegetation cover (i.e., basal, canopy, foliar, or ground cover) and warn us if it is facing decline or an unwanted trajectory. As such, we have allocated each hemiboreal tree species to a dominant regeneration strategy (Table 1).

Table 1. Conceptual framework of hemiboreal tree dynamics in Lithuania [32,48,50]. Capital letters indicate the main tree species that form forest stands in gap dynamics (G), successional development (S), or multi-cohort succession (M), whereas small letters (g, s, and m) indicate secondary ones which are a valuable admixture in these stands.

Regeneration Strategy: C—Colonization O—Occupation I—Invasion E—Expansion		Forest Habitat Types (NATURA 2000 Codes)/Codes of the Lithuanian Forest Type Series * and Forest Site Types **																	
		Mixed Broadleaved Forests							Norway Spruce Mixed Forests				Scots Pine Forests						
		(9020 9080 91F0 91E0)							(9050 9160 9180 9190 9070)				(9010 9060 91D0 91T0)						
		aeg * Nf **	cmh Lf	cal Uc	Fil Ud	ur Uf	cir Pd	c Pc	ox Nc	mox Lc	hox Nd	oxn Ld	cl Nal	v Na	vm Nb	m Lb	msp Ub	csp Pb	lsp Pa
C	*Alnus glutinosa*		G	G	G	G	G, S	G, S				G							
C	*Alnus incana*	G	G	g	G				s, g	s, g	G	G							
C	*Betula pendula*	G	G	g	G	g			S	S	S	S		s	s	S			
C	*Betula pubescens*	G	G	S	S	g	G	S									s	S	
C	*Larix decidua*								S		s								
C	*Pinus sylvestris*							s, m	M	M			M	M	M	M	M	M	M
O	*Fraxinus excelsior*	G	G		G	g						G							
O	*Populus tremula*	G	G		G				S	S	s	S				S			
O	*Quercus robur*	G	G						G		G	g							
O	*Ulmus laevis*	G	G									g							
I	*Acer platanoides*	G									g								
I	*Carpinus betulus*	G									G								
I	*Picea abies*			g	G				S	S	S	S			s	s	s		
I	*Ulmus glabra*	G																	
E	*Fagus sylvatica*								G		G								
E	*Tilia cordata*	G								g	G	g							

* Field layer codes of the main types of forest plant communities, i.e., forest type series (forest site types): aeg—*Aegopodiosa* (Nf), c—*Caricosa* (Pc), cal—*Calamagrostidosa* (Uc), cir—*Carico-iridosa* (Pd), cl—*Cladoniosa* (Nal), cmh—*Carico-mixtoherbosa* (Lf), csp—*Carico-sphagnosa* (Pb), fil—*Filipendulo-mixtoherbosa* (Ud), hox—*Hepatico-oxalidosa* (Nd), lsp—*Ledo-sphagnosa* (Pa), m—*Myrtillosa* (Lb), mox—*Myrtillo-oxalidosa* (Lc), msp—*Myrtillo-sphagnosa* (Ub), ox—*Oxalidosa* (Nc), oxn—*Oxalido-nemorosa* (Ld), ur—*Urticosa* (Uf), v—*Vacciniosa* (Na), vm—*Vaccinio-myrtillosa* (Nb). ** N—normally moist, L—temporarily overmoistured, U—overmoistured, P—peatland, and f—very eutrophic soils, d—eutrophic soils, c—mesotrophic soils, b—oligotrophic soils, a—very oligotrophic soils (see Figure 1).

However, a forest stand that is subject to a larger-scale disturbance can also be subject to smaller-scale disturbance thus the scale of disturbance is also a factor that needs be considered and discussed. For instance, in mixed Norway spruce forest, disturbance can range from a single tree (gap/small patch (G)) to a stand or forest (large patch (S)) sized disturbance. Thus, there is no certain rule on regeneration. Another factor to consider is the type of disturbance. For instance, Scots pine is fire tolerant, and fire stimulates regeneration. Conversely, Norway spruce is fire intolerant and thus is often eliminated together with its seed bank. So, fire creates multi-cohort pine stands and eliminates spruce. Also, the different disturbance regimes of forests undergo generate different age profiles [27]. For instance, successional development (S) of spruce-dominated mixed forests varies across all age classes. Multi-cohort stand succession (M) generally has older age classes mixed with some younger age classes [27]. Another important aspect is that natural forests have multiple ages structures due to the different regeneration modes of each tree species. For instance, birch and aspen are pioneer species with fast regeneration but spruce is much slower and needs time to be invasive and form the dominant stand species in a mixed forest ecosystem.

4. Concept of Assisted Natural Regeneration of Trees

The regimes and dynamics of forest disturbances are forecast and shown to be altered significantly by the impact of climate change [51]. Vegetation models show us that climate change is of such magnitude and speed that tree species currently present in our forests will not have time to adapt or acclimatize to predicted climatic conditions [52]. By the end of the century, the native tree species that currently populate Lithuania's forests may succumb to climate change under traditional forest management practices and the species that may be able to adapt to the future conditions may not have had time to naturally evolve and adjust. This would stifle the current biodiversity. This highlights the need for knowledge and development of sustainable forest management that imitates the natural patterns and processes of forest ecosystems, and the development of a conceptual framework to mitigate the barriers to natural regeneration under a changing environment.

In the context of global climate change and disturbances, the adaptive potential of forests lies in assisted natural regeneration (ANR) in the contiguous communities of trees. It ensures that the physical and biological conditions of the forest ecosystem can continue to self-regulate while supporting natural selection and native biodiversity [48]. ANR is applied to forest resources after harvesting with the aim to accelerate, rather than replace, natural successional processes by removing or reducing barriers to regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g., fire, grazing and wood harvesting) [53]. Therefore, we call for the application of ANR in the adaptative management of forest disturbances and succession to sustain tree species and promote forest self-organisation. ANR is very relevant in the context of hemiboreal forests. It lays the groundwork necessary to consider the life-cycle features of trees that affect the organic relationships between individual species and ecological communities indirectly via their effects on growth, reproduction, and survival, such as tree regeneration strategies that correspond to the various trade-offs in the adaptations to competition, stress, and disturbance [54,55]. The self-organisation of an ecological community is a highly ordered non-random process based on information written in the genomes of participating species and it can play a major role in providing resilience to future climate change [56–58] but must be accelerated with ANR strategies.

ANR works where local people intervene to help local plants and wildlife naturally recover, leaning on their knowledge of native habitats and on ancestral traditions [59]. The practice of ANR is not centralised to a given global hegemonic knowledge but varies from place to place. Despite this, the most fundamental practices of ANR are protecting and facilitating the growth of parent trees inherently present in the area and their regeneration, and inextricably linked to natural disturbance regimes and site conditions [60]. The emphasis is on sustainability of diversity in the tree community. In fact, many studies indicate that ANR enhances tree growth, biodiversity, and forest productivity [61]. Also, there is a likelihood that ANR will contribute to carbon sequestration vis-à-vis slowing or mitigating the effects of climate change [62]. The fact is that the adverse effects of the phenomenon of global climate change can undermine the resilience of forest ecology in terms of its capacity for natural regeneration to occur successfully on the scale of the expected time. In other words, climate change can slow the reproductive regime of the European hemiboreal tree species, leading to delays in the turnover of tree populations and to sustain their resilience. Therefore, with the concept of ANR, the natural powers of forest ecology in Lithuania can be revitalized and fast-tracked to keep up with the pace of global climate change or even overtake it ahead its disruptions.

5. Grounding Assisted Natural Regeneration on Ethical Framework

Assisted natural regeneration (ANR) encourages non-anthropocentric intervention in the forest ecology. This makes it necessary to anchor it on a sound ethical foundation to guide the human–environment interactions anticipated in the model. Deep ecology is an ethical framework that provides excellent guidelines for non-anthropocentric human-environment interaction on the scale that can support the ANR programme. It provides a set of ethical principles complementary with the institutional attributes of ANR, which urges for deliberate and non-anthropocentric intervention in the ecology of trees to fast-track it against the growing threats of global climate change. Deep ecology provides an ethical grounding for human beings to participate in nature and explore forest ecosystems by sharing in their pleasures and challenges, benefits and needs, and awakening a persons' ecological consciousness [63]. Ecological consciousness presupposes humans' freedom of action in their organic relationships with the earth and with the plants and animals that grow on it. Participation in forest ecology must be based on the recognition of the intrinsic worth of tree species and other nonhuman components in the natural community. Deep ecology places an emphasis on the recognition of intrinsic worth in trees and in the nurturing of diversity in the management of the ecosphere [64,65].

The idea of the intrinsic worth of trees is formulated to scale down on anthropocentric interference in the natural community. Anthropocentric interference has dominated the history of human–environment relations, resulting in large-scale environmental degradation, climate change-related global warming, and biodiversity depletion [66]. Human beings placed themselves at the centre of nature to the neglect of the interests of nonhuman beings—in the belief that the environment and its resources (trees, animals, minerals, etc.) do not have value beyond the human interests they serve [63,64]. This trend in human thinking negatively impacted the biological and ecological diversity of the natural community [66]. So, the emphasis placed on the recognition of the intrinsic worth of nonhuman nature (trees, animals, ecosystems, etc.) is aimed at restoring the richness and diversity of life forms [63,64]. Diversity—biological, ecological, cultural, and cognitive diversities—is at the heart of the deep ecology. It is recognized as the necessary ingredient that contributes to the sustainability and flourishing of the ecosphere [65]. But the recognition of the intrinsic worth of trees does not annul human interest in nature. Deep ecology recognizes that human needs must be satisfied in the context of the environmental resources [63–65]. In meeting their vital needs, human beings must replenish the environment in terms of taking active and deliberate steps to restore it to its richness and diversity to ensure its continued survival and flourishing [63].

The philosophy of deep ecology places emphasis on diversity as the bastion of sustainability. This is inter-intuitive with the ANR model in forest management. ANR emphasizes human intervention in forest ecology based on the local knowledge of the people [59]. In other words, ANR encourages ecological and cultural diversity. Epistemic diversity is an integral part of the effort to restore, preserve and sustain diversity in forest ecology via ANR. The emphasis on epistemic diversity is based on the understanding that 'many of the paths to [ecological] stabilisation run straight through our daily lives' [67]. Further, cultural communities have embodied diverse historical knowledge about their environments and will readily act within these contexts [65]. In this direction, while ANR embraces local knowledge in the management of forest ecology, deep ecology recognizes epistemological pluralism as a major ingredient that contribute to survival and flourishing of the biodiversity. In line with this view, Lithuania must shift away from centralized management of its forests while putting more responsibilities in the hands of individuals and communities—to harness the cognitive diversity of Lithuanians to revitalize and reposition the forest ecology ahead of the increasing negative impacts of global climate change. This does not mean that scientific knowledge should be jettisoned. Science is crucial to understanding the genome of trees, make quantifiable projections of the natural regeneration processes, support communities to ground strategies in evidence, and adapt the ecosystems to environmental change via technology [66,67]. Yet, in talking about science, the hegemonic knowledge of North

America and western Europe is often promoted without regards to differences in cultural contexts in the process, marginalising other ways of knowing and limiting opportunities for inputs from local knowledge systems. In making allowance for collaborations between core scientific and local knowledges, ANR, consistent with deep ecology, facilitates the transition from epistemic and cultural diversities to biodiversity.

6. Concluding Remarks

This paper discussed the inadequacy of natural regeneration of tree species in the context of climate change. We observed that the environmental disturbances associated with climate change are monumental, very disruptive and that the evolution of certain tree species will not be able to adapt in time with climate change, especially in the hemiboreal context of Lithuania. Hence, we argue that ANR of tree species in the hemiboreal forest ecology should be applied to keep the forest resilient in the face of climate change. Importantly, ANR must be based on the idea of diversity. This implies that the ANR processes must be localised in community-based knowledge systems, which necessitates the introduction of the concept of deep ecology to demonstrate this importance. Deep ecology also provides an ethical justification for the proposal to transit forest management in Lithuania from the traditional centralised system to a community-driven practice. ANR, embedded in the principle of deep ecology, is very relevant in the context of hemiboreal Lithuania where there is an increasing need to maintain forest biodiversity, while at the same time enhancing the cultural diversity of Lithuania. Adopting ANR will not only promote local participation in forest management in Lithuania but will make the forests resilient to future climate change.

Author Contributions: Conceptualization, R.P., D.-A.I. and M.M.; writing—original draft preparation, R.P., D.-A.I. and M.M.; writing—review and editing, D.-A.I., M.M. and R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The review presents research findings that have been obtained through the long-term research programme "Sustainable forestry and global changes", implemented by the Lithuanian Research Centre for Agriculture and Forestry.

Conflicts of Interest: The authors declare no conflict of interest.

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