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Analysis of the Environments Where Natural Regeneration Is Established in the Absence of a Wildfire in the Open *Pinus brutia* Forests in the Middle Elevations of the Central Part of Cyprus

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Abstract: The objective of this research was to analyze the *P. brutia* natural regeneration and the environments where it was established in the absence of a wildfire in the open formations of the species in the middle elevations of the central part of Cyprus. Forty-eight rectangular plots of 0.1 ha were established in three site productivity types. Individuals of the species with a height from 0.1 m to 1.5 m were considered regeneration plants. Within each plot, various measurements and estimations were made. Moreover, 480 hemispherical photographs were taken. Additionally, hemispherical photographs were taken above each of the recorded naturally regenerated *P. brutia* plants. In all the site productivity types, the most regeneration plants were established and grew under the process of facilitation. In each of the site productivity types, there were no differences in the light condition diversity between the environments where the regeneration plants grew and the existing light conditions. Regeneration exhibited a small number of plants and constituted only a very small proportion of all trees in the three site productivity types. To achieve sustainability in *P. brutia* forests, forest practices must develop strategies for the enhancement of *P. brutia* regeneration in the studied area and in analogous environments.

Keywords: absence of wildfire; facilitation; light regime; natural regeneration; *Pinus brutia*

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1. Introduction

Pinus brutia Ten. is the dominant tree species in Cyprus. Its formations constitute 65% of the area of forests on the island [1].

Pinus brutia is a species of the eastern Mediterranean and western Asia [2]. It is a site-insensitive, light-demanding species [2,3] that can be found on most types of parent materials [4,5]. Also, it has the ability to grow in dry, barren, and stony soils [2]. Although *P. brutia* is considered a drought-tolerant species, its water requirements are generally greater than those of *Pinus halepensis* [4,6–8].

The wood from *P. brutia* forests is used in construction, industry, furniture, as firewood, for charcoal production, and as pulp for paper production [9–12]. Other products besides wood, which are extracted from the forests of the species, have a great economic contribution, such as honey, mushrooms, resin, and aromatic and medicinal plants [13–16]. According to [17], the indirect benefits that *P. brutia* forests offer are many and summarized in the following: protection of soil and water resources, support of agricultural production, sequestration of carbon dioxide from the atmosphere, and mitigation of climate change. Additionally, *P. brutia* forests are important for biodiversity protection [18].

Ecosystems in the Mediterranean region are characterized by dry and long summers with solar radiation of high intensity, little or no precipitation, and high temperatures [19]. According to [9], even though *P. brutia* exhibits notable resistance to long periods of high temperatures and drought, in some cases, these climatic elements cause the deaths of trees of the species.

In Cyprus, forest fires are the main threat to forest ecosystems [9]. According to the 2018 National Risk Assessment of the Republic of Cyprus, forest fires present the highest risk compared to other natural disasters, such as earthquakes, coastal erosion, floods, etc. [20]. Nowadays, forest fires are the greatest threat to Mediterranean forests [21]. Over time, their incidence has increased, even in areas of central and eastern Europe [22]. The problem is growing worse since both the number of fires and the burned area are increasing [23]. The occurrence of pines and conifers is related to fires that influence large areas [24]. Both harsh abiotic conditions and forest fires might be extremely dangerous for the survival of the *P. brutia* formations in many areas. One of them is the middle elevation area in central Cyprus, which is the study area of this research.

In recent decades, a decrease in the density of *P. brutia* natural regeneration plants has been observed [25–27].

The annual timber yield from *P. brutia* forests in Cyprus for the periods 1988–1992, 1998–2002, and 2003–2007 was 56,100 m^3, 27,633 m^3, and 14,384 m^3, respectively [28]. This wood is used as firewood, to produce charcoal, and by local industries for the production of some building timber products [9].

The significant degradation of *P. brutia* forests in Cyprus, expressed both through the drastic reduction of the annual yield and the low density of regeneration, has mainly been due to two factors, which are: (1) the silvicultural treatments of the previous decades, and mainly (2) the unfavorable climate and soil conditions prevailing on the island [25,26,29,30].

Natural regeneration of *P. brutia* has been extensively studied, mainly in post-fire conditions [31–44]. In contrast, the natural regeneration of the species in environments undisturbed by forest fires has received limited study [29,43,45,46].

To achieve sustainability in the management of *P. brutia* forests in Cyprus, there is an immediate need for a better understanding of *P. brutia* ecosystem processes in adverse environments in order, in the first phase, to stop their degradation and, in the second phase, to reverse the downgrading course in order to conserve them and, if possible, to expand their area. Achieving these goals is particularly difficult since climate conditions are expected to continue to deteriorate.

Moreover, as time passes, climate change will make many *P. brutia* ecosystems in northern areas resemble the Cyprus ecosystems and make them more vulnerable to degradation factors.

Open *P. brutia* formations dominate in the middle elevations of the central part of Cyprus. In these "open" stands, there is a rather low ground cover from the projection of the tree canopy. On the other hand, dense *P. brutia* stands with large areas appear in very few cases [47].

The objective of this research was to analyze the *P. brutia* natural regeneration in the open formations of the species and the environments where it was established in the absence of a wildfire in the middle elevations of the central part of Cyprus.

2. Materials and Methods

2.1. Study Area

Middle elevations of central Cyprus (34°56′35.68″ N, 33°17′12.25″ E) were the study area of this research. As middle elevations are considered areas with altitudes from 300 to 750 m above sea level. This area is 14,000 ha (Figure 1). According to the meteorological station in Kornos, the mean yearly temperature is 18.4 °C, and the rainfall annually is 477.1 mm (for 1991–2000). The substrate of the study area belongs to volcanic sequence diabase dykes with pillow lava screens [48]. The soil texture is from sandy loam to sandy clay loam, and the soil pH is from slightly acidic to slightly alkaline [49]. *Pinus brutia* is the dominant tree species in the area, and its forests in the study area were mainly established in abandoned olive yards and vines [50].

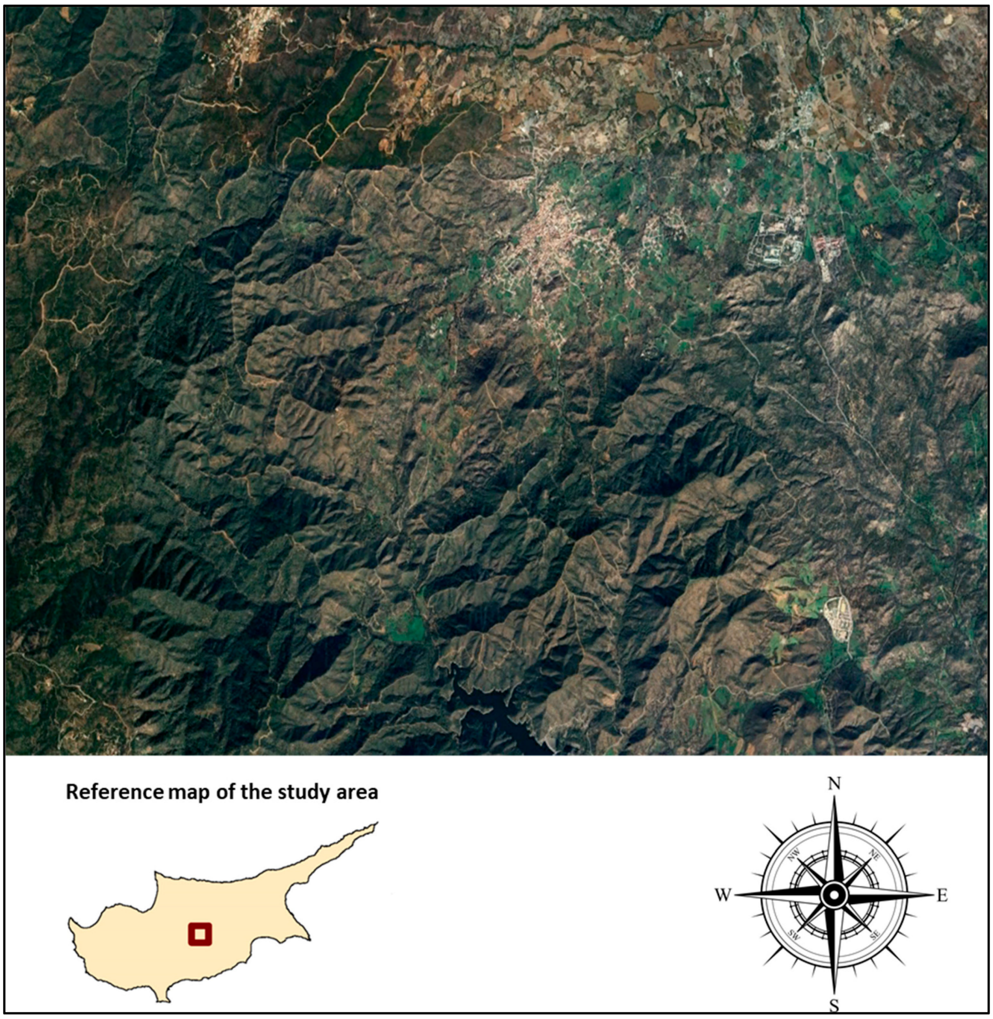

Figure 1. Map of the study area.

A *P. brutia* formation is considered as "open" when the projection of the tree canopy covers the ground of the formation in a percentage lower than 75% [47].

Based on site productivity, Petrou [49] refered to three site productivity types in the *P. brutia* formations. The distinction of the types was based on soil depth and on the mean annual height increment of dominant and codominant trees calculated by the ratio of total tree height to the total age of the tree [51]. The age of trees was determined using cores taken from stump height (30 cm) [49]. The three types of sites were: good productivity sites, where soil depth was over 100 cm; medium productivity sites, having a soil depth of approximately 40–80 cm; and bad productivity sites, where soil depth was approximately 5–30 cm. The classification of sites using the above characteristics was verified by *P. brutia* site index curves made for central Cyprus by [52]. In good productivity sites, open *P. brutia* formations have small areas and appear scattered, while the landscape is dominated by *P. brutia* formations growing in medium and bad productivity sites [47].

About 1000 animals graze in the area (850 goats and 150 sheep) (data from Cyprus Department of Forests). Grazing is practiced unevenly, and animals follow relatively the same routes on a systematic basis. This results in some areas being intensively grazed, while others hardly at all (personal observations and communication with herders).

2.2. Research Method

To investigate the natural regeneration of *P. brutia* "open" formations in the study area, in 2013, a total of 48 rectangular plots (16 in each type of productivity sites) of 0.1 ha (25 m × 40 m) were established using the stratified random sampling method. The plots in good productivity sites were established in areas where the slope of the ground varied from zero to 10%; in medium productivity sites, from zero to 20%; and finally, in bad productivity sites, from zero to 25%. According to the data provided by the Department of Forests, those areas have not been affected by wildfires since 1960, the year in which data on forest fires began to be systematically recorded [53]. On each plot, the percentage of the area covered by (a) pines, (b) low shrubs, and (c) bare ground (without cover) was estimated. Then, within each plot, the number and species of trees with a height greater than 1.5 m were counted. These trees were considered mature trees. Moreover, the dead trees of *P. brutia* with a height of over 1.5 were counted. Individuals of *P. brutia* with a height from 0.1 to 1.5 m were considered regeneration plants, and their numbers were counted while their height was measured using a tape measure. Seedlings less than 0.1 m tall were not counted as regeneration plants because the aim of the present research was to study already established regeneration plants (seedlings that survived at least two growing seasons) [54].

The *P. brutia* regeneration plants were classified into four categories according to the location where they were established and grown, as follows:

1. "Gap" category (regeneration located on bare ground in the gaps).
2. Category "Pine" (regeneration located below or at the limits of the projection of the crown of mature *P. brutia* trees).
3. Category "Low Shrub" (regeneration located below or within the area defined by the projection of the crown of low shrubs).
4. Category "Pine and Low Shrub" (regeneration located simultaneously below or at the borders of the projection of the crown of mature *P. brutia* trees and below or within the area defined by the projection of the crown of low shrubs).

The regeneration plants belonging to the categories 'Pine', 'Low Shrub', and 'Pine + Low Shrub' are located or established essentially under the facilitation of other plants [46] and belong to a broader regeneration category that is hereinafter referred to as "Facilitation".

Moreover, all *P. brutia* regeneration plants were evaluated based on the degree to which they were grazed and classified into three categories, as follows:

1. Heavily grazed (plants that had strong signs of grazing).
2. Moderately grazed (plants that had signs of grazing but were not heavily grazed).
3. Not grazed (plants that had no sign of grazing).

Additionally, all *P. brutia* regeneration plants were classified into three categories according to their height, as follows:

1. Category of height 10–60 cm (plants that had a height from 10 cm to 60 cm).
2. 60–105 cm height category (plants that were between 60 cm and 105 cm high).
3. 105–150 cm height category (plants that were between 105 cm and 150 cm tall).

In each plot of 0.1 ha of the 48 (16 in each type of productivity sites) established for the study of natural regeneration, 10 points were selected using the simple random sampling method, and at a height of 1.5 m above the ground, hemispherical photographs were taken. In total, 480 photographs were taken. In addition, hemispherical canopy photos were also taken above each naturally regenerated *P. brutia* regeneration plant recorded on the established plots, at a height of 1.5 m above the ground. The photos were taken to determine the light conditions in which the natural regeneration of *P. brutia* was located and to compare them with the available light conditions that exist in each type of productivity sites separately. The photographs were taken under a clear sky (homogeneous sky conditions) before sunrise or after sunset. A horizontally leveled digital camera (a Nikon Coolpix 900 digital camera with a fish-eye lens) was used to take the hemispherical photographs. All the photos were analyzed with Hemiview software version 2.1 [55]. The part of the sky that is visible as a proportion of the total hemisphere when it is observed from a single point is called Visible Sky (VS) (or canopy openness or gap fraction) [56]. The VS value is related to the amount of solar radiation attaining the specific point [55–57]. When the total sky is visible, the VS has the value 1, while the Visible Sky takes the value 0 when the total sky is blocked.

2.3. Statistical Analyses

In the various comparisons of this study, the Duncan test, the Dunnet T3 test, and the Wilcoxon test were used. These comparisons were made using the SPSS v.21.0 software [58].

The Hill Numbers-True Diversity [59,60] was used to investigate the differences in the VS distributions that were compared. The calculations in these processes were made using the template of [61]. The comparisons between the distributions were taken place using the z-test, based on the template of [61], where the proportion of Hill Numbers was defined as the Hill Number divided by the number of classes. The order q refers to the richness and abundance that constitute diversity. As q increases, abundance (i.e., the number of trees per class) has an increased impact on diversity. So, when q is greater than 0, diversity is not only determined by the number of different classes present but also by the uneven number of trees within each class. The higher the value of q, the more weight is given to the uneven Visual Sky distribution in calculating diversity.

3. Results

In good productivity sites, 18.75% of regeneration plants were heavily grazed, 62.5% were moderately grazed, and 18.75% were not grazed. In medium productivity sites, 45.3% of regeneration plants were heavily grazed, 30.2% were moderately grazed, and 24.5% were not grazed. Finally, in bad productivity sites, 16% of regeneration plants were heavily grazed, 30.4% were moderately grazed, and 53.6% were not grazed.

Regeneration plants made up only 2.4% of all trees in the good productivity sites; in the medium productivity sites, they made up 11.2%; and, finally, in the bad productivity sites, natural regeneration plants made up 9.7% of all trees (Table 1). In the good productivity sites, the other species recorded were *Olea europaea* L., *Quercus alnifolia* Poech, *Crataegus azarolus* L., *Acer obtusifolium* Sm., *Pistacia lentiscus* L., *Pistacia terebinthus* L., and *Ceratonia siliqua* L.; in the medium productivity sites, *O. europaea*, *P. lentiscus*, *P. terebinthus*, and *Myrtus communis* L.; and finally, in the bad productivity sites, *O. europaea* and *P. terebinthus*.

Table 1. Density of mature *P. brutia* trees, *P. brutia* regeneration plants, dead *P. brutia* trees, and other species trees.

Site Productivity Type	Density, Rounded to the Nearest Integer (n/ha)				
	Mature *P. brutia* Trees	*P. brutia* Regeneration Plants	Dead *P. brutia* Trees	Mature Other Species Trees	Total
Good productivity sites	383 (87.6%)	10 (2.4%)	8 (1.8%)	36 (8.2%)	437
Medium productivity sites	248 (84.1%)	33 (11.2%)	3 (1%)	11 (3.7%)	295
Bad productivity sites	297 (82%)	35 (9.7%)	2 (0.6%)	28 (7.7%)	362

In the good productivity sites, the 105–150 cm height category showed the highest density ($p < 0.05$) of regeneration plants compared to the densities of plants in the 10–60 cm and 60–105 cm categories, whose densities did not show a difference ($p > 0.05$) between them. In the medium and bad productivity sites, the density of regeneration plants in the 105–150 cm height category was greater ($p < 0.05$) compared to the density of regeneration plants in the 10–60 cm category. The density of regeneration plants in the 105–150 cm height class, although numerically higher, was not statistically significantly different ($p > 0.05$)

from the density of regeneration plants in the 60–105 cm height class. Finally, the density of regeneration plants in the 60–105 cm height category was greater numerically, but without being statistically significantly different ($p > 0.05$) from the corresponding one in the 10–60 cm height category (Table 2).

Table 2. Regeneration plant density means of the three height categories in the three site productivity types.

Site Productivity Type	Height Category (cm)	Regeneration Plant Density (n/Plot)		
		Mean	S.D.	N
Good productivity sites	10–60	0.00 b	0.000	16
	60–105	0.06 b	0.250	16
	105–150	0.94 a	1.340	16
Medium productivity sites	10–60	0.44 b	0.727	16
	60–105	1.31 ab	1.448	16
	105–150	1.56 a	1.413	16
Bad productivity sites	10–60	0.69 b	1.014	16
	60–105	0.88 ab	1.088	16
	105–150	1.94 a	2.048	16

S.D.: standard deviation, N: number of plots. Means, in each productivity site type are statistically different at $p < 0.05$, when they are not followed by a common letter. The comparisons were made using the Wilcoxon test.

In all site productivity types, the plants belonging to the broader category Facilitation (all the plants in the categories Pine, Low Shrub, Pine, and Low Shrub) exhibited greater density ($p < 0.05$) compared to the regeneration plant category Gap (Table 3).

Table 3. Regeneration plant density means of the regeneration plant categories: (a) Gap and (b) Facilitation in each site productivity type.

Site Productivity Type	Regeneration Plant Category	Regeneration Plant Density (n/Plot)		
		Mean	S.D.	N
Good productivity sites	Gap	0.00 b	0.000	16
	Facilitation	1.00 a	1.366	16
Medium productivity sites	Gap	0.00 b	0.000	16
	Facilitation	3.31 a	2.358	16
Bad productivity sites	Gap	0.31 b	0.602	16
	Facilitation	3.19 a	2.428	16

S.D.: standard deviation, N: number of plots. Means, in each productivity site type are statistically different at $p < 0.05$, when they are not followed by a common letter. The comparisons were made using the Wilcoxon test.

In good productivity sites, the percentage of bare ground cover varied from 10 to 25% (Table 4). In the medium productivity sites, the percentage of bare ground varied from 30 to 60%, while in the bad productivity sites, the percentage of bare ground varied from 35 to 60% (Table 4). In the three site productivity types, approximately 40%–50% of the low shrubs were under the crown of *P. brutia* trees, while the remaining percentage was in the gaps between the *P. brutia* trees.

Table 4. Percentages of the area covered by (a) pines, (b) shrubs and the percentages of (c) bare ground (without cover) in the established plots.

Site Productivity Type	Area Covered (%) by		
	P. brutia	Low Shrubs	Bare Ground
Good productivity sites	70–75	40–50	10–25
Medium productivity sites	35–65	15–35	30–60
Bad productivity sites	30–60	10–25	35–60

When comparing the density of the regeneration plant category Pine with the regeneration plant categories Low Shrub + Pine and Low Shrub, in each site productivity type, separately, they did not show a statistically significant difference ($p > 0.05$) between them (Table 5).

Table 5. Regeneration plant density means of the regeneration plant categories: (a) Pine and (b) Low Shrub + Pine and Low Shrub in each site productivity type.

Site Productivity Type	Regeneration Plant Category	Regeneration Plant Density (n/Plot)		
		Mean	S.D.	N
Good productivity sites	Pine	0.38 a	0.500	16
	Low Shrub + Pine and Low Shrub	0.63 a	1.088	16
Medium productivity sites	Pine	2.06 a	2.048	16
	Low Shrub + Pine and Low Shrub	1.25 a	1.125	16
Bad productivity sites	Pine	1.50 a	1.932	16
	Low Shrub + Pine and Low Shrub	1.69 a	1.352	16

S.D.: standard deviation, N: number of plots. Means, in each productivity site type are statistically different at $p < 0.05$, when they are not followed by a common letter. The comparisons were made using the Wilcoxon test.

The density data for all regeneration plant categories in the three site types is given in Table 6.

Table 6. Regeneration plant density data of the four regeneration plant categories in each site productivity type.

Site Productivity Type	Regeneration Plant Category	Regeneration Plant Density (n/ha)	Regeneration Plant Density (n/Plot)		
			Mean	S.D.	N
Good productivity sites	Gap	0.000	0.00	0.000	16
	Pine	3.750	0.38	0.500	16
	Low Shrub	0.625	0.06	0.250	16
	Pine and Low Shrub	5.625	0.56	1.031	16
Medium productivity sites	Gap	0.000	0.00	0.000	16
	Pine	20.625	2.06	2.048	16
	Low Shrub	5.000	0.50	0.730	16
	Pine and Low Shrub	7.500	0.75	0.775	16
Bad productivity sites	Gap	3.125	0.31	0.602	16
	Pine	15.000	1.50	1.925	16
	Low Shrub	9.375	0.94	0.772	16
	Pine and Low Shrub	7.500	0.75	0.931	16

S.D.: standard deviation, N: number of plots.

Good productivity sites show the lowest ($p < 0.05$) density of regeneration plants on average, compared to the density of regeneration plants at medium and bad productivity sites, whose means do not exhibit a difference ($p > 0.05$) between them (Table 7).

Table 7. Regeneration plant density means in the three site productivity types.

Site Productivity Type	Regeneration Plant Density (n/Plot)		
	Mean	S.D.	N
Good productivity sites	1.00 b	1.366	16
Medium productivity sites	3.31 a	2.358	16
Bad productivity sites	3.50 a	2.781	16

S.D.: standard deviation, N: number of plots. Means, in the column, are statistically different at $p < 0.05$, when they are not followed by a common letter. The comparisons were made using the Duncan test.

In Figures 2–4, the VS distributions from the photographs taken in the three site productivity types and from the photographs taken above the regeneration plants in the same site productivity types are presented.

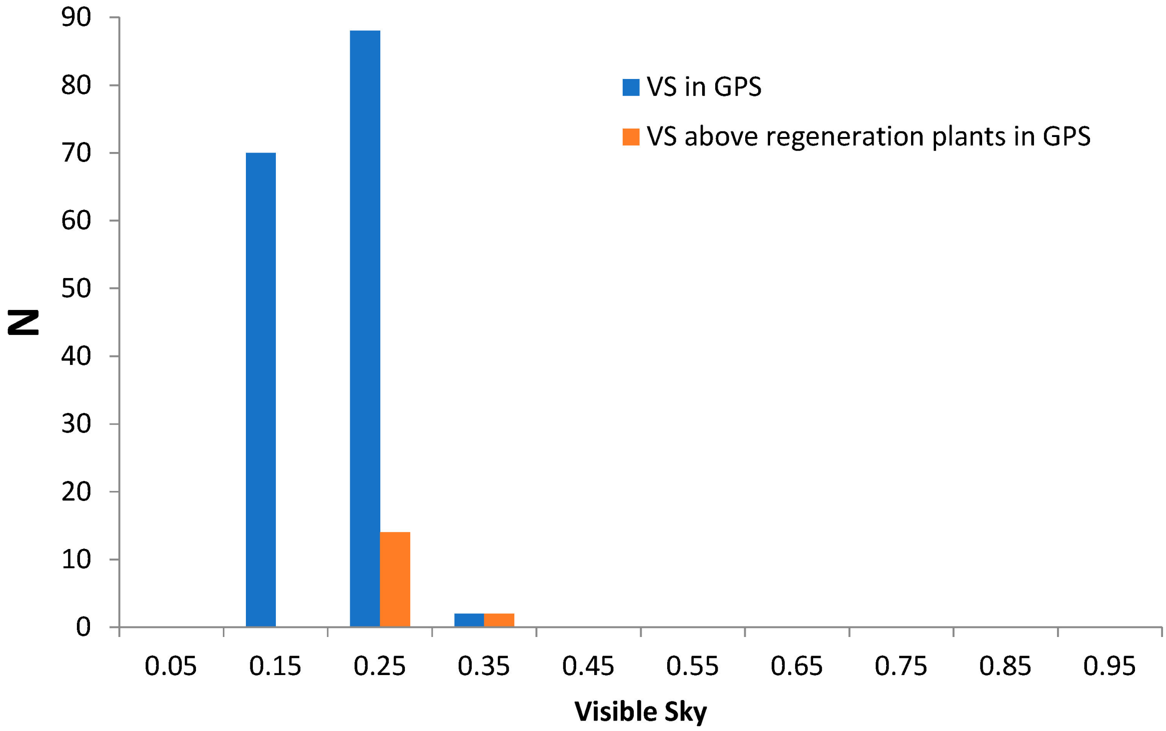

Figure 2. VS distributions from the photographs taken in the good productivity sites (GPS) and from the photographs taken above the regeneration plants in the same sites.

In Figure 5, the distributions of VS values from the photographs taken above the regeneration plants in the three productivity site types are presented.

The bad productivity sites exhibited higher VS values ($p < 0.05$) than those of the medium and good productivity sites on average, while the good productivity sites exhibited lower VS values ($p < 0.05$) compared to the other two types of productivity sites (Table 8). The same pattern was observed in the VS values from the photographs taken above the regeneration plants in the three productivity site types (Table 8).

The Hill Numbers index revealed no significant difference ($p > 0.05$) in VS diversity between photographs taken above the site's regeneration plants and those taken at the site across all three productivity types (Table 9).

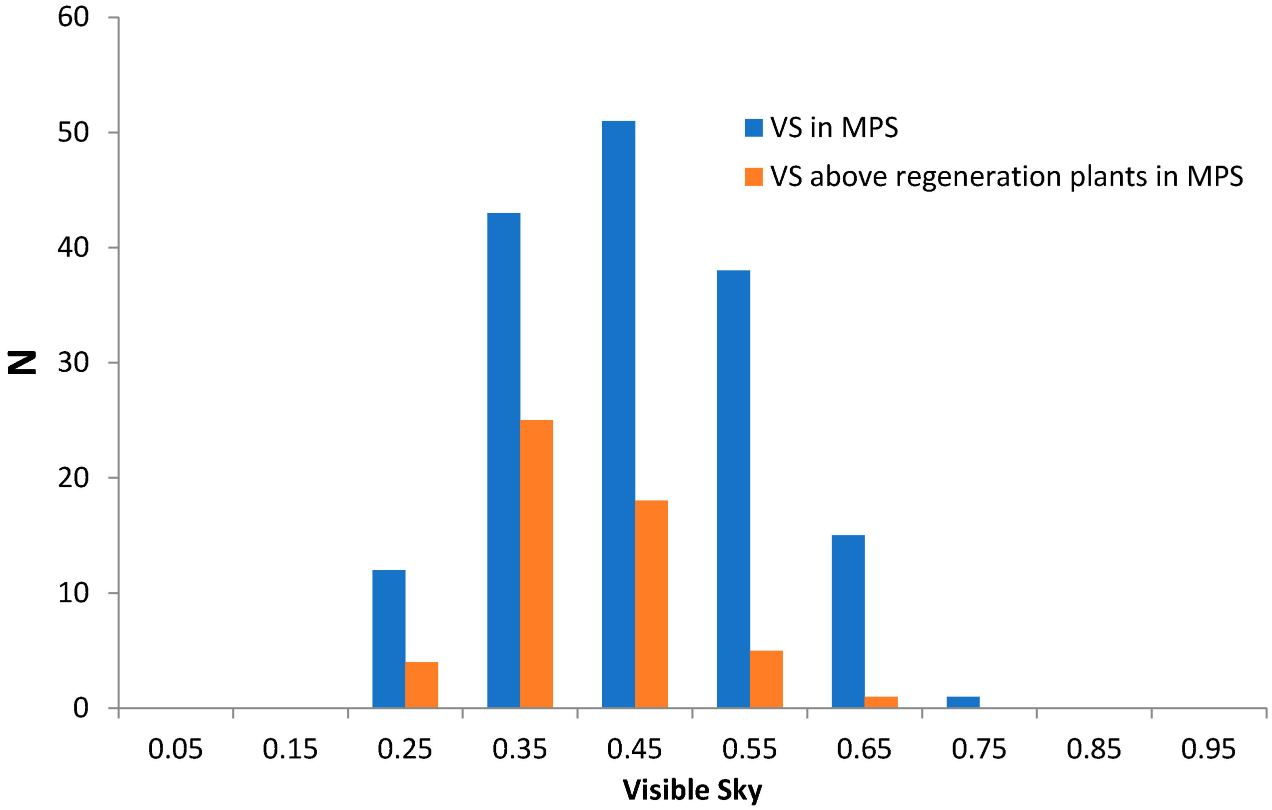

Figure 3. VS distributions from the photographs taken in the medium productivity sites (MPS) and from the photographs taken above the regeneration plants in the same sites.

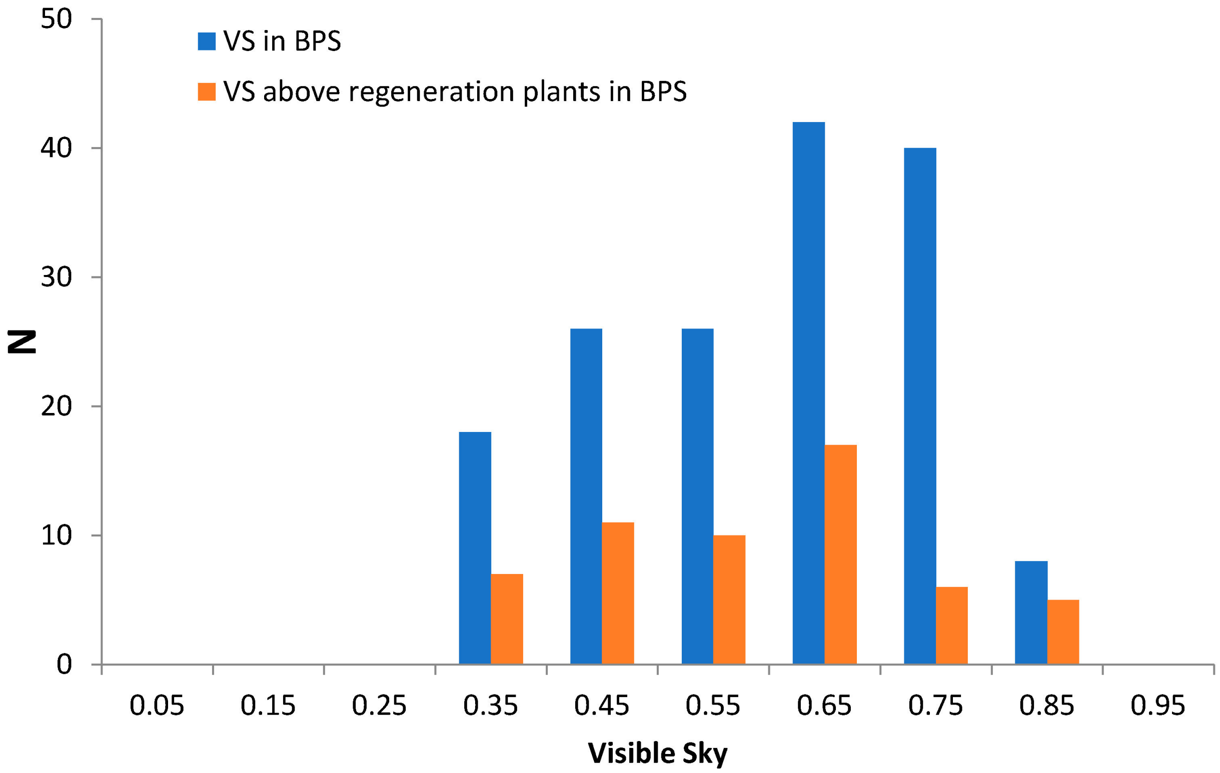

Figure 4. VS distributions from the photographs taken in the bad productivity sites (BPS) and from the photographs taken above the regeneration plants in the same sites.

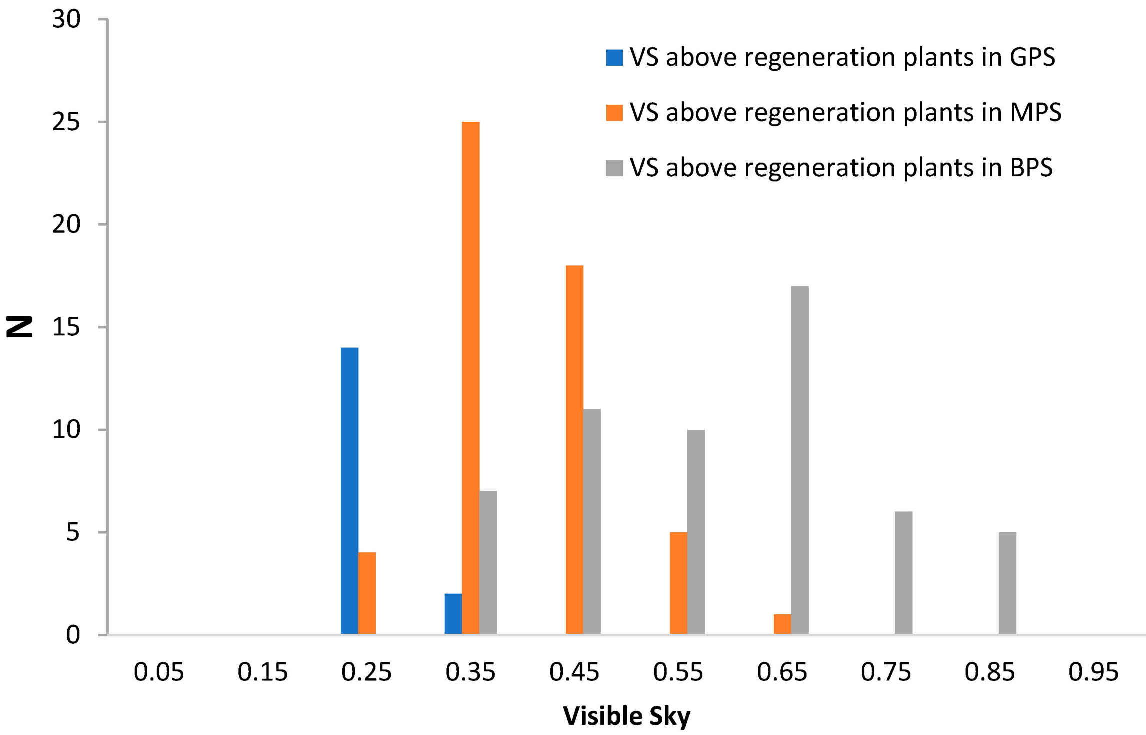

Figure 5. Distributions of VS values from the photographs taken above the regeneration plants in the three productivity site types (good productivity sites—GPS, medium productivity sites—MPS, and bad productivity sites—BPS).

Table 8. VS from the photographs taken in the three productivity sites and from the photographs taken above the regeneration plants in the three productivity sites.

Site Productivity Type	VS Values from the Photographs Taken in the Site			VS Values from the Photographs Taken above the Regeneration Plants		
	Mean	S.D.	N	Mean	S.D.	N
Good productivity sites	0.203 a	0.041	160	0.242 a	0.044	16
Medium productivity sites	0.454 b	0.107	160	0.404 b	0.079	53
Bad productivity sites	0.607 c	0.139	160	0.589 c	0.147	56

S.D.: standard deviation, N: number of photographs. Means, in a column, are statistically different at $p < 0.05$, when they are not followed by a common letter in normal print. The comparisons were made using the Dunnet T3 test.

The VS classes were significantly ($p < 0.05$) fewer in the VS distribution from the photos taken above the regeneration plants in good productivity sites, compared to those of medium productivity sites. The VS classes were significantly ($p < 0.05$) fewer, and there was a significantly ($p < 0.05$) lower diversity in VS values in the VS distribution from the photos taken above the regeneration plants in good productivity sites compared to those of bad productivity sites. Lastly, there was a, to the limit, significantly ($p < 0.05$) lower diversity in VS values in the VS distribution from the photos taken above the regeneration plants in medium productivity sites, compared to those of bad productivity sites (Table 10).

Table 9. Distribution diversity comparisons between VS values from the photographs taken in each site and the corresponding VS values from the photographs taken above the regeneration plants applying the Hill Numbers z-test.

	Good Productivity Site				Medium Productivity Site				Bad Productivity Site			
Order q	**Proportions**	**z-Value**	***p*-Value**	**Diversity of VS Values in the Site, Compared with the Diversity of VS Values above the Regeneration Plants of the Site**	**Proportions**	**z-Value**	***p*-Value**	**Diversity of VS Values in the Site, Compared with the Diversity of VS Values above the Regeneration Plants of the Site**	**Proportions**	**z-Value**	***p*-Value**	**Diversity of VS Values in the Site, Compared with the Diversity of VS Values above the Regeneration Plants of the Site**
0	0.600 / 0.400	1.546	0.124	Non-significantly Decreasing	0.545 / 0.455	1.148	0.253	Non-significantly Decreasing	0.500 / 0.500	0.000	1.000	Not applicable
1	0.421 / 0.292	1.007	0.315	Non-significantly Decreasing	0.410 / 0.306	1.352	0.178	Non-significantly Decreasing	0.449 / 0.458	−0.120	0.905	Non-significantly Increasing
2	0.405 / 0.256	1.163	0.247	Non-significantly Decreasing	0.372 / 0.258	1.513	0.132	Non-significantly Decreasing	0.418 / 0.422	−0.046	0.963	Non-significantly Increasing
3	0.400 / 0.244	1.222	0.224	Non-significantly Decreasing	0.353 / 0.238	1.540	0.125	Non-significantly Decreasing	0.398 / 0.392	0.076	0.940	Non-significantly Decreasing
4	0.397 / 0.239	1.238	0.218	Non-significantly Decreasing	0.353 / 0.238	1.540	0.125	Non-significantly Decreasing	0.384 / 0.370	0.188	0.851	Non-significantly Decreasing
∞	0.364 / 0,229	1.079	0.282	Non-significantly Decreasing	0.285 / 0.193	1.327	0.187	Non-significantly Decreasing	0.317 / 0.275	0.600	0.549	Non-significantly Decreasing

Table 10. Distribution diversity comparisons of VS values from the photographs taken above the regeneration plants between the productivity sites applying the Hill Numbers z-test.

	Proportions	**z-Value**	***p*-Value**	**Diversity of VS Values above the Regeneration Plants of the Good Site Productivity Compared with the Diversity of VS Values above the Regeneration Plants of the Medium Site Productivity**	**Proportions**	**z-Value**	***p*-Value**	**Diversity of VS Values above the Regeneration Plants of the Good Site Productivity Compared with the Diversity of VS Values above the Regeneration Plants of the Bad Site Productivity**	**Proportions**	**z-Value**	***p*-Value**	**Diversity of VS Values above the Regeneration Plants of the Medium Site Productivity Compared with the Diversity of VS Values above the Regeneration Plants of the Bad Site Productivity**
0	0.286 / 0.714	−3.088	0.008	Significantly Increasing	0.250 / 0.750	−3.672	0.002	Significantly Increasing	0.455 / 0.545	−0.949	0.347	Non-significantly Increasing
1	0.208 / 0.481	−1.938	0.072	Non-significantly Increasing	0.182 / 0.687	−3.603	0.003	Significantly Increasing	0.306 / 0.500	−2.058	0.045	Significantly Increasing
2	0.183 / 0.405	−1.629	0.124	Non-significantly Increasing	0.160 / 0.632	−3.337	0.005	Significantly Increasing	0.258 / 0.460	−2.195	0.033	Significantly Increasing
3	0.174 / 0.375	−1.496	0.155	Non-significantly Increasing	0.152 / 0.588	−3.075	0.008	Significantly Increasing	0.238 / 0.428	−2.093	0.041	Significantly Increasing
4	0.171 / 0.359	−1.422	0.175	Non-significantly Increasing	0.152 / 0.588	−3.075	0.008	Significantly Increasing	0.229 / 0.403	−1.959	0.055	Non-significantly Increasing
∞	0.163 / 0.303	−1.102	0.288	Non-significantly Increasing	0.143 / 0.412	−1.986	0.066	Non-significantly Increasing	0.193 / 0.299	−1.291	0.203	Non-significantly Increasing

4. Discussion

In all the site productivity types, a large percentage of regeneration plants was grazed. For many years, human activities have greatly influenced and determined the distribution, composition, and structure of pine forests in various regions of the world [62]. The authors of [63] reported that forests throughout the Mediterranean basin have been disturbed or altered to a great extent by human activities. In addition, [64] pointed out that the forests of the Mediterranean basin countries had been affected for many years by human activities, which ultimately largely determined their present state.

Many animals graze unevenly within the study area, having a greater impact in some areas and less in others. The effect of grazing on young plants is related to the change in the shape and architecture of their crown, thus limiting their growth rates, and in cases where grazing is intense, it can also lead to plant necrosis [65–69].

Within the three site productivity types, regeneration exhibited a very small proportion of all trees, with plant numbers ranging from 10 n/ha in good productivity sites to 35 n/ha in bad productivity sites (Table 1). In successive censuses of both the productive and non-productive *P. brutia* forests of Cyprus, a decrease in the density of the *P. brutia* regeneration plants was found, which, according to the Cyprus Department of Forests, may be the most serious problem of the island's forests [25–27]. Furthermore, [9] stated that the mature individuals of *P. brutia,* which are cut in the productive forests of Cyprus, cannot be replaced by the small number of plants of natural regeneration established in these stands.

There are only a few studies of the density of *P. brutia* regeneration in environments unaffected by forest fires. In a comparative study of the natural regeneration of *P.brutia* forests in Greece and Cyprus, the severe problem of natural regeneration of the island's forests was confirmed [29]. Specifically, in stands that had not been affected by forest fires, the natural regeneration plants (individuals of *P. brutia* up to 3 m in height) on Thassos Island were 1124 n/ha [43]; on Rhodes Island, they were 383 n/ha; and in Cyprus Adelfi Forest, they were only 152 n/ha. According to the results presented by [46], who studied the establishment and survival of *P. brutia* seedlings in the first growth period in partially forested areas in central Cyprus, at the end of the growth period, the total density of seedlings that finally survived was 1180 n/ha. The authors of [45] studied the regeneration plants (individuals of *P. brutia* up to 1 m in height) in mixed stands of *P. brutia* and *P. nigra* on Lesvos Island, which had not been affected by forest fires for at least the last 50 years, and presented their density in three different types of mixtures. In the first type of mixture, where *P. brutia* was the dominant species, the density of *P. brutia* regeneration plants was 220 n/ha. In the second type of mixture, where neither *P. brutia* nor *P. nigra* dominated, the density of *P. brutia* regeneration plants was 240 n/ha. Finally, in the third type of mixture, where black pine was the dominant species, the density of regeneration of *P. brutia* was 50 n/ha.

In all the above cases, the density of the regeneration plants of *P. brutia* was greater than that found in each of the three site productivity types of the present research. Both on Thassos Island and Rhodes Island [29,43], as well as in Lesvos Island [45], the stands of *P. brutia* that were studied grew in areas with more favorable climatic conditions than those prevailing in the region of the present research, i.e., with higher rainfall, lower air temperatures, and a shorter duration of the dry season. In the Adelfi Forest of Cyprus, although the density of the regeneration of *P. brutia* was considered low compared to Rhodes Island and Thassos Island [29], it was nevertheless considerably higher than that of the three site productivity types of the present research. It should be noted that in the research of [29], trees with a height of up to 3 m were considered regeneration plants, while in the present research, regeneration plants were considered trees with a height of up to 1.5 m. Nevertheless, the density of the regeneration of *P. brutia* in the Adelfi Forest of Cyprus, with a height of up to 1 m (and not 3 m), was 88 n/ha, i.e., significantly higher than that of each of the three site productivity types of the present research. The climatic conditions that prevail in the Adelfi Forest of Cyprus do not differ to a great extent from those that prevail in the area of the present research. The main factor favoring the presence of a greater number of regeneration plants in the Adelfi Forest of Cyprus seems to have been the absence of grazing; since 1940, it has been prohibited by law in this area [29].

Ref. [70] found that drought conditions during the summer season, extremely high temperatures, and intense solar radiation could possibly be the main factors that determine the establishment and survival of plants in Mediterranean ecosystems. In addition, Ref. [71] mentioned that the establishment of natural regeneration in Mediterranean ecosystems is very uncertain and faces serious risks, among which is the severity of the summer drought, which is also the main factor in the necrosis of seedlings, as well as the effect of grazing that greatly affects even regeneration survival. The results of the density of *P. brutia* seedlings presented by [46], although they refer to areas that are within the wider study area of this research, are not directly comparable to the values of regeneration densities found in the three site productivity types of the present research. In the above work, the establishment and survival of *P. brutia* seedlings were studied for a single growth period. On the contrary, in the present research, the already-established regeneration plants were studied. It is noteworthy that in all three site productivity types, the 10–60 cm height category of *P. brutia* regeneration plants numerically presented the lowest density, followed by the 60–105 cm height category, while the 105–150 cm height category presented the highest numerical density of regeneration plants of *P. brutia* (Table 2), which was statistically higher ($p < 0.05$) than that of the 10–60 cm height category in all three site productivity types. If we consider that there is a positive correlation between the height of the trees and their age [43], then it is understandable that, in recent years, the number of regeneration plants established in the three site productivity types has been gradually decreasing. Similar results were found by [29] for the regeneration of *P. brutia* stands in the Adelfi Forest of Cyprus, where the regeneration plant density observed in the largest height class (100–300 cm) was greater than that of the two smaller height classes (0–40 cm and 40–100 cm). Ref. [29] also concluded that, over time, there was a decline in the number of regeneration plants in the Adelfi Forest. In addition, Ref. [72] stated that natural regeneration is successful during some periods and occurs in waves, when there is a favorable occasion of biotic and abiotic factors. The decrease in natural regeneration in all the site productivity types in recent years is likely due to the non-existence of these favorable conditions, due to grazing and the deterioration of the climatic conditions taking place in Cyprus [73–77].

Despite the fact that the number of *P. brutia* regeneration plants was low in all the site productivity types, it is clear that the positive effects (facilitation) from the presence of other plants (pines, low shrubs, pines and low shrubs) played a decisive role in regeneration plant density (Table 3) and dominated the regeneration process of *P. brutia* in the area. In all comparisons, for each site productivity type, separately, the density of plants in the "Gap" category was lower with a statistically significant difference ($p < 0.05$) than the density of plants in the broader category of "Facilitation" ("Pine", "Low Shrub", and "Pine + Low Shrub") (Table 3). It should be noted that in all the site productivity types, there was a satisfactory percentage of the presence of all regeneration environments (Table 4). Thus, there is no justification for the absence of regeneration in a category due to the low availability of any regeneration environment.

Ref. [46] studied the establishment and survival of *P. brutia* seedlings during the first growing season in partially forested areas in central Cyprus. The above researchers found that the facilitation provided by the cover of pines, low shrubs, and pines and low shrubs together to *P. brutia* seedlings was crucial for the survival of the seedlings at the end of the growing season since they survived only under the crowns of the previous plants. On the contrary, in the bare ground, no *P. brutia*, out of a relatively satisfactory number initially established in this environment, survived to the end of the growing season. In this study, it was found that the facilitation of the establishment and survival of *P. brutia* seedlings during the first growing season appeared to be influenced by: (a) the lower temperatures of the surface soil and (b) the increased percentages of the surface soil content in organic matter (thus, the existence of a greater amount of nutrients and greater soil moisture) compared to the uncovered soil. Conversely, the minimal to zero precipitation in the summer, combined with the low organic matter content of the topsoil and the extreme surface soil temperatures that prevailed in the bare ground, led to intense drought conditions in this environment, which ultimately resulted in the zero survival of seedlings at the end of the growing season. In addition to the previous ones, another very important factor that led to this result was the necrosis of seedlings from the extreme temperatures of the surface soil. In addition, [50], based on the results of a sowing experiment in natural *P. brutia* stands in the same study area as the present research, mentioned that the facilitation process constitutes one of the main factors that defines the establishment as well as the survival of *P. brutia* seedlings.

Another way of facilitation, in addition to the creation of a favorable microenvironment related to abiotic factors (solar radiation, temperature, soil moisture, nutrients, etc.), is the protection that some plants provide to others from grazing [78–86]. In the present research, the mechanism of facilitation of the *P. brutia* regeneration plants seems to be more related to the creation of a favorable microenvironment regarding abiotic factors than to protection from grazing. The previous conclusion is based on the fact that when comparing the densities of the natural regeneration categories "Pine" and "Low Shrub + Pine and Low Shrub" in each site productivity type separately, they did not show a statistically significant difference between them ($p < 0.05$) (Table 5). In the "Pine" category, there was no protection from grazing for regeneration plants. In contrast, protection from grazing was provided in the initial stages of establishment in the "Low Shrub" + "Pine and Low Shrub" categories. However, later, the *P. brutia* regeneration plants surpassed the low shrubs in height and thus became accessible to animals. So, any protection from grazing can be termed temporary. Conversely, facilitation associated with the creation of a favorable microenvironment regarding abiotic factors has a longer-lasting effect on regeneration plant survival.

The results of this research fully confirm the hypothesis made by [46] that in the middle altitudes of central Cyprus, where adverse climatic conditions prevail during the dry season, facilitation is the dominant process that affects the successful establishment of *P. brutia*. In addition, these results significantly support the concept formulated by [46] that, through the facilitation process, not only the conservation but also the gradual expansion of *P. brutia* in the middle altitudes of central Cyprus is promoted. The favorable conditions created under the canopies of some plants were, in many cases, the cause of facilitation, which led to the survival of a greater number of regeneration plants of various species under the canopies compared to the bare ground [87–96]. Facilitation by the cover of other plants has been shown to be important for the survival of regeneration plants of other pine species in various regions of the world [54,97–109].

Ref. [110] concluded that, in Crete Island, the presence of the phrygana led to the creation of *P. brutia* forest by facilitating the establishment of the regeneration of the species. Ref. [29] reported that in the Adelfi Forest of Cyprus, *Cistus incanus* covered a significant percentage of the regeneration plants of the species (up to 40 cm in height), and thus they concluded that it exerted a partial protective effect on *P. brutia* young seedlings. On the other hand, the results of the same research showed that the regeneration individuals of *P. brutia* (up to 40 cm in height) on Thassos Island and Rhodes Island appeared exclusively on bare ground and not in places where there were shrubs. Thus, the authors concluded that the survival probability of *P. brutia* regeneration was higher on bare ground than at sites where shrubs were present. Ref. [43], in a survey carried out on Thassos Island, also found that regeneration plants of *P. brutia*, in burned and unburned areas, occurred in bare ground in a large proportion rather than in ground covered by shrubs. But they recognized that the *Cistus* spp. during the summer provided protection to the young *P. brutia* seedlings from high temperatures and solar radiation. The results of the research of [29] (Rhodes Island and Thassos Island) and [43] (Thassos Island) were contrary to the results of the present research. The previous ones were fully justified based on the theory that states that competition is dominant when conditions are favorable, while on the contrary, facilitation is dominant when there are adverse conditions [111–114]. In the middle altitudes of central Cyprus, the climatic conditions are much worse than those of Thassos Island and Rhodes

Island, and thus facilitation appears to be the dominant force, while on the contrary, in the other two regions, competition seems to have been the dominant process that determined the establishment of natural regeneration [46].

The range of values of VS in medium and bad productivity sites was large. In medium productivity sites, it varied between the classes of 0.25 and 0.75 (Figure 3), and in bad productivity sites, it varied between the classes of 0.35 and 0.85 (Figure 4). In good productivity sites, the range of VS values was limited almost exclusively between the classes of 0.15 and 0.25 (Figure 2). *Pinus brutia* regeneration plants showed relatively great adaptability in relation to the available light conditions since they appeared in conditions where VS values ranged from 0.2 to 0.9. Thus, no significant difference ($p > 0.05$) in VS diversity between photographs taken above the site's regeneration plants and those taken at the site across all three site productivity types was detected (Table 9). VS values below 0.2 appeared to be prohibitive for the survival of *P. brutia* regeneration plants. Many *P. brutia* regeneration plants in all the site productivity types belonged to the "Low Shrub" and "Pine and Low Shrub" regeneration categories (Table 6). In these categories, the *P. brutia* regeneration plants were initially established in shaded conditions, possibly at VS values lower than 0.2, which were estimated to exist under the canopies of low shrubs. Later, when these plants grew in height, they overtook the low shrubs, allowing them to receive more light. The hemispherical photographs of the *P. brutia* regeneration plants belonging to these categories were taken at a height of 1.5 m above the ground, which, in each case, was greater than the height of the low shrubs. Thus, the VS values of the photographs taken above the plants in these two regeneration categories express the light conditions in which the plants are after they have surpassed the height of the low shrubs. The authors of [50] stated that in the middle elevations of Cyprus, for the artificial regeneration of *P. brutia* formations through sowing, the sowing has to be practiced during December in areas where the VS values must be well over 0.19 up to 0.30. According to [115], the seedlings of *P. pinea* (a light demanding species) in the initial stages of their establishment, showed great resistance to shading conditions, but then their light needs increased. Ref. [3] reported that the light requirements of various forest tree species generally increase with increasing age, but also with increasing competition. Thus, *P. brutia* cannot survive throughout its life in conditions of intense shading [116]. It seems that the availability of light, expressed through the values of the visible part of the sky (VS), was one of the factors that greatly influenced the different densities of *P. brutia* regeneration plants found at each of the site productivity types. The density of *P. brutia* regeneration plants in good productivity sites was statistically lower ($p < 0.05$) compared to those of the other two site productivity types (Table 7). However, there was no statistical difference ($p > 0.05$) in the density of *P. brutia* regeneration plants between the medium and bad productivity types. The VS values of the photographs taken above the regeneration plants in good productivity sites were statistically lower ($p < 0.05$) compared to those of the other two site productivity types. In this case, the photographs taken at bad productivity sites exhibited statistically higher ($p < 0.05$) VS values than those taken at medium productivity sites (Table 8). This result, combined with the absence ($p > 0.05$) of a difference in the density of *P. brutia* regeneration plants between the medium and bad productivity types, leads to the conclusion that the higher light availability in the bad productivity sites did not lead to an increase in the *P. brutia* regeneration plant density. So, VS values around 0.454 (which is the mean value of VS at medium productivity sites) seem to be a factor that does not strongly negatively affect the survival of *P. brutia* regeneration plants. Apart from the differences among the mean VS values of the photographs taken above of the regeneration plants in the different site productivity types, there were also differences in the diversity of VS distributions among them. These differences were in the number of VS classes, in the diversity of VS values in the VS distributions, or in both (Table 10 and Figure 5). Finally, the VS values of the photographs taken at the good productivity sites were statistically lower ($p < 0.05$) compared to those of the other two site productivity types, while the photographs taken at the bad productivity sites exhibited statistically higher ($p < 0.05$) VS values than those at the medium productivity sites (Table 8). This result agreed with the findings of [47] in the same study area. They referred to the VS values in a bad productivity site as statistically greater ($p < 0.05$) than those of a medium productivity site.

Ref. [45] also found that the availability of light in mixed stands of *P. brutia* and *P. nigra* was a very important factor that affected the regeneration plant density of the two species. In the above research, it was found that the *P. nigra* regeneration plants (0.11–0.5 m in height) presented their highest density at VS values between 0.2 and 0.4, while the *P. brutia* regeneration plants had VS values greater than 0.35.

To achieve sustainability in *P. brutia* forests, forest practice must develop strategies for the enhancement of *P. brutia* regeneration in the studied area and in analogous environments. In this context, grazing must be forbidden, and the shelterwood silvicultural system must be applied in order to create the appropriate environment for the establishment and growth of the regeneration plants [50].

5. Conclusions

Regeneration of *P. brutia* exhibited a small number of plants and constituted only a very small proportion of all trees in the three site productivity types. A large percentage of regeneration plants were grazed, and in recent years, their number has been gradually decreasing in the three site productivity types. The density of *P. brutia* regeneration plants in good productivity sites was statistically lower compared to those of the other two site productivity types. Despite the fact that the number of *P. brutia* regeneration plants was low in all the site productivity types, it is clear that the positive effects (facilitation) from the presence of other plants played a decisive role in regeneration plant density and dominate the regeneration process of *P. brutia* in the area. Protection from grazing can be termed temporary. Conversely, facilitation associated with the creation of a favorable microenvironment regarding abiotic factors has a longer-lasting effect on regeneration plant survival. *Pinus brutia* regeneration plants showed relatively great adaptability in relation to the available light conditions since they appeared in conditions where VS values ranged from 0.2 to 0.9. It seems that the availability of light was one of the factors that greatly influenced the different densities of *P. brutia* regeneration plants found at each of the site productivity types. VS values below 0.2 appeared to be prohibitive for the survival of *P. brutia* regeneration plants. The higher light availability in the bad productivity sites, compared to that of medium productivity types, did not lead to an increase in the *P. brutia* regeneration plant density. So, VS values around 0.454 (which was the mean value of VS at medium productivity sites) seem to be a factor that does not strongly negatively affect the survival of *P. brutia* regeneration plants.

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