Analyzing the impact of reforestation on forest fires and the economic outcome in an area in northern Greece. Should we reforest areas with conifers? Yes or No?

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Abstract. The reforestation that occurred in the South Evros region in northern Greece was documented and studied. Our hypothesis is that the economic footprint of reforestation with conifers is negative, and the presence of conifers influences the size of the burned area in forest fires. The reforested area, the species, the amount spent on reforestation and operations to enhance the quality of the forest products, as well as the amount of money spent to protect such areas and prevent fires, were documented. Additionally, the extraction of forest products and the sales income were examined. The numbers of fires, as well as the total burned area, were documented for the fires that occurred in the studied forests between 1980 and 2016. Then, the fire episodes that had burned areas of more than 100 hectares, were examined. In order to compare spending across time, the Consumer Price Index (CPI) was utilized to convert all gathered expense numbers to December 2016 values. The cost of reforestation is significantly greater than the income it produces, and there is a correlation between the size of the burned forest area and the presence of conifers in the burned area. Based on the results of the present study, the use of conifers in reforestations must be avoided in all cases in the studied area, as well as in similar areas regarding their characteristics and ecology.

Key words: conifers; Consumer Price Index; ecological risk; expenses; forest fires; incomes; *Pinus brutia*; reforestation.

1. Introduction

In Greece, reforestations began mainly after 1930 by state organizations (Hatzistathis & Ispikoudis, 1995). Reforestations in the context of restoration of degraded broadleaf forests or of their conversion from sprout origin to seed origin forests using conifers were dominant in the country (Hatzistathis & Dafis, 1989). The use of conifer species in reforestations changes the species composition of the ecosystems. Even in reforestations of peri-urban areas, mainly conifers were used in a very dense spacing of 1m x 1m leading to a dramatic change of the aesthetic characteristics in native vegetation (Hatzistathis & Ispikoudis, 1995). The alteration of species composition through reforestation may have negative impacts on the fauna of an area (Dafis, 1986).

During the decade of 1970 and the first years of 1980's, wood production was the main objective of reforestations in Greece, and thus the planting density was high in all sites, while in the last years of 1980's, the density of planting was reduced since, in many cases, restoration reforestations prevailed as a result of a more ecological approach (Diamantopoulou & Milios, 2010).

Greece cannot be a competitive producer of industrial wood through reforestations mainly as a result of the site productivity of the available for reforestation areas and the cost of wood production (Hatzistathis & Dafis, 1989).

Forest fires can have catastrophic consequences, such as the loss of human lives, ecological degradation, and economic losses (Belomutenko et al., 2022; Vikram & Sinha, 2023). Some of the questions to be answered are whether the use of conifers in reforestations influences the fire regime in an area (Pausas et al., 2004), as well as whether the economical footprint of reforestation with conifers is positive or negative. The answers to these questions will have an enormous impact on the planning and management of reforestation and restoration of degraded ecosystems, especially in the Mediterranean region.

An area where reforestations of conifers dominated in the second half of the twentieth century is the south part of the Evros region (area of Alexandroupolis Forest Service) in the northeastern part of Greece. The main species that were used in the reforestations were: *Pinus brutia* Ten., *P. pinaster* Ait., *P. nigra* J.F. Arnold, *P. silvestris* L., *P. radiata* D. Don, *P. pinea* L., *Pseudotsuga menziesii* (Mirbel) Franco, and *Abies borisii-regis* Mattf.

P. brutia was one of the main species used in the reforestations in the south part of the Evros region (Data from the Forest Service of Alexandroupolis). It spreads in the eastern Mediterranean region and western Asia (Athanasiadis, 1986; Arampatzis, 1998; Korakis, 2015). It is a fast-growing species (Boydak, 2004; Kitikidou et al., 2011; Kitikidou et al., 2012) whose wooden products are valuable and have various uses (Petrakis et al., 2007). *P. brutia* was used in the reforestation of many degraded areas of Greece (Kitikidou et al., 2017). The species regenerates easily after fires (Dafis 1986; Bountis & Milios, 2017).

The aims of this study are to analyze the impact of reforestations with conifers on forest fires and the economic outcome in the southern part of the Evros region in the northeastern part of Greece. Moreover, based on that analysis, the aim is to provide guidelines for the forest practice in relation to reforestations in areas with similar ecological characteristics. Our hypothesis is that the economic footprint of reforestation with conifers is negative, and the presence of conifers influences the size of the burned area in forest fires.

2. Study area

The research concerns the area of responsibility of the Alexandroupolis Forest Service. It is located in the southern part of N. Evros and at the southeastern ends of the Rhodope mountain range. Its exact location is determined by latitude from 40 51' to 40 58' and longitude from 25 59' to 26 02'. The research area has an area of 122,034.31 ha.

Figure 1. Study region location (yellow pin) and its area marked with pink line (Google, n.d.)

The rocks that prevail in the area are from the gneissic series, biotic gneisses and marl schist, while from the phyllite series are the phyllites, ash-colored orthogneisses, amphibolites, and argillaceous schist (YLORIKI EE, 2006; Anthopoulos et al., 2008). The soil varies from clay loam to sandy (YLORIKI EE, 2006; Anthopoulos et al., 2008).

For the area under consideration, data was obtained from two Meteorological stations: the Meteorological Station of Alexandroupolis and the Meteorological

Station of Soufli. The total average annual precipitation for the two stations is: Alexandroupolis, 576.82 mm, Soufli, 668.9 mm. The average temperature is 15.15°C for the station of Alexandroupolis and 13.26°C for the station of Soufli.

The reforestations of conifers in the area of responsibility of the Alexandroupolis Forest Service began in the 1950s. The first reforestation took place in the area of Kirki with 2,000 m^2 and in Iana with 566 m^2 where *P. brutia* was used in both cases. This was followed by a peak in the 1970s when the Forest Service, in order to supply timber to the paper industries of the time (e.g. Softex in Drama), proceeded to extensive afforestation even in areas where there was vegetation (oak, hemlock, hemlock, etc.).

In the next decade of the 1980s, reforestations took place in the spirit of the previous decade, but we also have reforestations that were done for the restoration of burned woodlands. The total area reforested is much smaller compared to the previous decade.

In the 1990s, and specifically in 1997, the last reforestations took place in the area of responsibility of the Alexandroupolis Forest Service. The area of intervention is clearly smaller, and the reasons are now mainly for the restoration of burned areas, but also for filling gaps in forests and for the arrangement of streams. The above information came from the file of the Alexandroupolis Forest Service and from personal communication with employees who served in the Service.

3. Materials and methods

The archive of the Alexandroupolis Forestry Office was used for the research. Data from 1967 to 2016 were found and analyzed. Thus, based on these data, the following were recorded:

I) The annual area reforested.

For the period before 1967, the extent of reforestations was determined from a record of reforestation. In the period 1990-93 the records of the Service did not indicate how much area was reforested per species. Areas were derived from the documents accompanying the seedlings supply based on the number and species of plants used and the main plan spacing for each species.

For the period 1994-1997 there are no detailed data on the area per species planted (Anthia - Loutro area) nor seedling distribution documents, which is why we follow the data of the reforestations plans for the area drawn up in that period.

II) The cost of reforestation.

The specific expenses include tillage, planting, workers' wages, machine hire, fuel for the service's machines, maintenance work, watering, and nursery work.

The expenses for *Populus* plantations and for reforestations before 1967 were not calculated.

III) The expenses for the protection of reforested areas.

In these specific expenses, all projects and works that were directly related to the protection of reforestations were calculated and concerned:

- Opening fire zones.
- Maintenance of fire zones.
- Maintenance of fire roads.
- Construction of dams for fire prevention.
- Construction of tanks.
- Maintenance of tanks.
- Forest clearing works for fire protection.
- Construction of fire stations.
- Construction of prefabricated buildings for firefighting personnel.

The expenses for the opening of fire roads were not calculated because we considered that the cases that existed were not exclusively related to fire protection and covered other needs of the Forestry Service.

Then, the yield in pine wood was recorded.

In addition, the income from the sale of the timber was recorded, were the expenses for the cultivation work done in the reforestation. Production of wood products existed only from pine.

Finally, the fires that took place in the area of responsibility of the Alexandroupoli Forest Service from 1980 to 2016 were registered. The number of fires per year and the area burned were recorded. Then the incidents of burned areas of more than 100 ha were investigated to determine how much conifer reforestations were burned, and how much of it was *P. brutia*. Here we should note that in the big fire of

2011, only the area that concerns the Alexandroupolis Forest Service is calculated and not the total area of the fire.

All expenses collected have been adjusted to December 2016 prices so that comparisons can be made over time. The Consumer Price Index (CPI) was used, which estimates the total cost of both goods and services purchased by the typical consumer (Mankiw, 2002).

The formula used is: $W_{2016} = \dfrac{W_X \cdot CPI_{2016}}{CPI_X}$

where:

W_{2016} is the revised amount of money in Euros for December 2016.

W_X is the amount of money in year X.

CPI_{2016} the CPI for December 2016.

CPI_X the consumer price index for December of year X.

Until the year 2001, the price was divided by 340.75 (equivalent Euro to drachmas) to get the adjusted amount of money in Euros.

For forest products, the revenue from their sale was calculated using their average sales prices for the year 2016, according to the table of forestry products prices for the year 2016 (Ministry of Environment and Energy, 2016). For the cultivation work of the reforestations, the cost price for the Forest Service of Alexandroupolis was used, which in 2016 was €51.76 per hectare, including VAT.

In testing the correlation between the area burned by the fires, where the burned area was greater than 100 ha, and the existence of conifers, the correlation coefficient of Kendall' s tau-b was used (Ho, 2006).

4. Results and discussion

In Figure 2, we have the area that was reforested in the area of Alexandroupolis Forest Service. The first reforestations took place in the 1950s, while the last ones took place in the 1990s. Since then (till 2016), no reforestations have taken place. In each decade, the total area reforested, the area reforested with conifers, and finally the area reforested with *P. bruti*a are presented. We notice that *P. brutia* was used in all decades and that most reforestations (more than half of the area) took place in the 1970s (4,646.70 ha against 7,994.70 ha of the total). Also, the total area of broadleaf reforestation during the 1980s and 1990s was 321.50 ha.

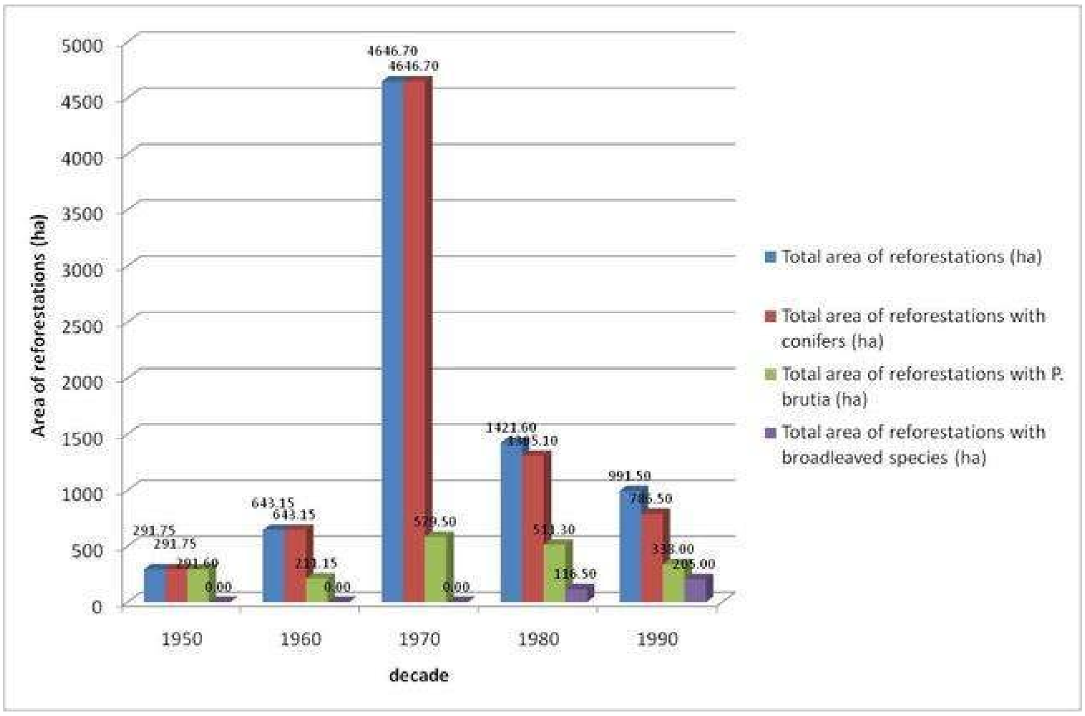

Figure 2. Area of reforestations per decade

In Table 1, we have the total area and the percentage of reforestation that took place (12.83%) in relation to the total forest covered area of the study area.

Table 1. Percentage of reforestations in relation to the forest area of the study area.

Area	ha	Percentage of total
Reforestations	7,994.70	12.83%
Non-reforestations	54,306.04	87.17%
Forest covered area	62,300.74	100.00%

In Table 2, the fires we had in the study area are recorded. Data is available from the year 1980. The number of fires per year and the area burned are shown. It should be noted here that the grassland areas that have been burned are very small. The total burned area is 10,227.15 ha, and almost half of the above area was burned during the two years of 2009 and the big fire of 2011.

Table 2. Number of fires and burned area.

Time period	Number of fires	Burned area (ha)
1980-1984	34	866.65
1985-1989	25	981.50
1990-1994	60	1,704.32
1995-1999	33	140.32
2000-2004	116	779.82
2005-2009	41	3,108.69
2010-1014	42	2,590.07
2015-2016	29	55.78
Total	380	10,227.15

In Table 3, the fire cases where the burned area was greater than 100 ha are presented, along with whether conifers were present in each case. In addition, the total area (reforestation and native) of the conifers and *P. brutia* that burned is given, as is how much of this area is reforestations only. In 1994, the conifers that burned were native pines and not reforestations. In total, we had 18 cases where the burned area was greater than 100 ha.

Table 3. Fire cases with burned area >100 ha.

No of fire case	Year	Burned area (ha)	Presence of coniferous trees	Area of conifers (ha)	Area of *P. brutia* (ha)	Area of reforesta-tions with conifers (ha)	Area of reforesta-tions with *P. brutia* (ha)
1	1980	150.0	Yes	100	100	100	100
2	1981	120.0	No	0.00	0.00	0.00	0.00
3	1982	148.0	No	0.00	0.00	0.00	0.00
4	1985	404.0	No	0.00	0.00	0.00	0.00
5	1987	124.0	No	0.00	0.00	0.00	0.00
6	1988	159.0	No	0.00	0.00	0.00	0.00

7	1991	323.0	No	0.00	0.00	0.00	0.00
8	1992	146.0	No	0.00	0.00	0.00	0.00
9	1994	400.0	No	0.00	0.00	0.00	0.00
10	1994	406.0	Yes	200	200	0.00	0.00
11	2000	494.6	No	0.00	0.00	0.00	0.00
12	2000	130.0	No	0.00	0.00	0.00	0.00
13	2007	570.0	No	0.00	0.00	0.00	0.00
14	2007	110.0	No	0.00	0.00	0.00	0.00
15	2009	2296.0	Yes	326.90	350	326.90	350
16	2011	132.2	No	0.00	0.00	0.00	0.00
17	2011	2179.8	Yes	898.615	604.280	820.37	526.03
18	2011	171.2	No	0.00	0.00	0.00	0.00

Table 4 shows the yield we had in pine timber from 1980 to 2016, every five years. The first year that we had a yield of forest products from reforestation was 1983. The table records the total volume of wood in m^3. The total amount of pine timber we got was 234,014.59 m^3, and of these, 222,212.22 m^3 is chipping wood.

Table 4. Pine wood yield.

Time period	Total pine wood yield (m^3)	Income (Euros)
1980-1984	808.56	24,811.15
1985-1989	4,087.74	121,044.37
1990-1994	4,580.88	132,279.05
1995-1999	28,153.93	869,005.19
2000-2004	11,772.12	344,777.02
2005-2009	54,655.80	1,668,162.88
2010-1014	110,862.00	3,221,425.00
2015-2016	19,093.56	549,139.24
Total	234,014.59	6,930,643.90

In Table 5, the amounts spent on reforestations every five years and per expense category (reforestation, protection, or cultivation) are shown in aggregate. The data ranges from 1967 to 2016. The total expenses are €31,443,988.53, with the largest expense being that of reforestations, which amounts to €24,122,484.68.

Table 5. Expenses per category (in Euros).

Time period	Protection	Reforestation	Cultivation	Total
1967-1969	0.00	2,826,408.95	0.00	2,826,408.95
1970-1974	0.00	8,491,852.67	0.00	8,491,852.67
1975-1979	275,412.07	5,437,386.39	0.00	5,712,798.46
1980-1984	246,178.99	4,120,573.45	13,354.08	4,380,106.52
1985-1989	252,254.26	1,385,300.01	340,684.32	1,978,238.59
1990-1994	617,255.39	1,451,193.64	48,447.36	2,116,896.39
1995-1999	538,671.44	409,769.57	1,187,063.84	2,135,504.85
2000-2004	628,625.34	0	718,325.28	1,346,950.62
2005-2009	610,945.54	0	923,398.40	1,534,343.94
2010-1014	561,908.28	0	190,166.24	752,074.52
2015-2016	130,562.38	0	38,250.64	168,813.02
Total	3,861,813.69	24,122,484.68	3,459,690.16	31,443,988.53

In Table 6, it appears that there is a positive correlation between the size of the burned area and the presence of conifers in this area ($p<0.05$).

Table 6. Correlation coefficient of the variables “burned area from a forest fire” and “presence of conifers in the burned area” for fires that burned an area greater than 100 ha.

Variables		Correlation coefficient Kendall’s tau-b	*p*-value	Number of forest fires
Burned area from a forest fire	Presence of conifers in the burned area	0.411	0.044	18

Reforestation in the study area began in the 1950s and continued until the 1990s. *P. brutia* was used in all decades. Most reforestations took place in the 1970s, with 4,646.70 ha against 7,994.70 ha, which were done in total. According to information from personal communication with Forest Service employees who served at the time, in order to supply wood to the existing paper industries (like Softex in Drama), the Forest Service undertook massive afforestation even in areas where vegetation already existed, so reforestations were essential.

The reforested areas cover 12.83% of the forested area. This percentage is very high. Since the 1980s, broad-leaved species have been used in the reforestation of the area. The area reforested with broadleaf is particularly small (Fig. 2).

The reforestation of conifers resulted in an increase in greenery and economic support for the forest-dwelling settlements in the area (at the time the reforestation took place, the workers came from the nearby populations), while they protected against erosion and flooding (see Dafis, 1986; Hatzistathis & Dafis, 1989). However, the same positive effects appear in the case of reforestation with broad-leaved species.

Apart from the positives of reforestation with conifers, an expense was created for fire protection, which is large. Most of the costs were incurred for the maintenance of fire roads and fire zones. The first expenses are recorded in 1975, a period when the reforestation now exists as stands of conifers. As a consequence of the increase in the need for fire protection, in 1980 the area of the Alexandroupolis Forestry was included in the areas with the highest degree of risk for the occurrence of fire (PD 686/80). Also, we should note that the annual protection expenses for reforestations are high, but the real need is much greater than the expenses given for this purpose.

Apart from the need for more money to be allocated to the protection of reforestations, this work does not include all the costs mentioned and created by the existence of conifer reforestation. For example, the costs of the Fire Department for firefighting and guarding the forest through patrols were not calculated. Also, the costs of reforestation work before 1967 are not mentioned.

In addition, conifer reforestation creates homogeneous stands of conifers that have an increased risk of attack by insects and fungi and are susceptible to damage caused by wind and snow (Kailidis, 1984; Dafis, 1992). This happened with *P.*

pinaster, which had been since the 1970s and was then attacked by bark-eating insects and fungi.

Reforestation also creates large, uniform areas of conifers that help spread the fire and make extinguishing it more difficult. This is because large, homogenous areas are covered by flammable conifer stands that are often colonized by flammable shrubs in the understory, and this has resulted in greatly increasing the likelihood of fire occurrence as well as contributing to large wildfires in previous decades (Pausas et al., 2004). This can also be seen in Table 2, where the number of fires per five years does not change greatly, but there is a large increase in the area that burns. In other words, large fires are created, and as can be seen in Table 3, almost half of the burned area belongs to the two fires of 2009 and the big fire of 2011, where conifers participated.

We reach the same conclusion based on Table 6, where it is proven that there is a positive relationship between the existence of conifers in the burned area and the size of the burned area.

Timber production from conifer reforestation is small, of low quality, and a minimal amount of technical timber is produced. The first year that we had a yield was 1982.

The overwhelming amount of yield comes from chipping wood. 1/3 of the revenue from the sale of the wood of the conifer reforestation came from the sale of the products that came from the two big fires of 2009 and the big one of 2011. This also proves the small yield of pine wood that we have from the reforestation. Furthermore, it shows how easy and likely it is to destroy all the woody capital from the fire event.

In addition, we must notice that common management tactics (a practice applied here as well), such as timber harvesting, reduce burned wood and affect the rich ecological processes associated with its decomposition, while it would be positive to preserve partially or even all trees in situ after the fire (Molinas-González et al., 2017).

Bearing in mind all the above, from an economic point of view, reforestation with coniferous species proves to be unprofitable because the costs are much higher than the incomes. The expenses amount to €31,443,988.53 as shown in Table 5, while the incomes are €6,930,643.90 (Table 4). The expenses started in the 1950s (even if only those after 1967 are mentioned), while the first incomes came in the

1980s. Note that, as mentioned above, the costs resulting from reforestation are much higher than those calculated in this work. Also, although in the future the income from wood derived from reforestation will increase, there is a high probability that fires will break out which will burn a large area, destroy woody volume, and create major ecological problems. Apart from these, any additional income from the wood that will be produced from reforestation will not compensate for the costs already incurred, while there will still be the cost of the fire protection expenses.

The risk of fire in coniferous forests is greater than in broadleaf forests (Núñez-Regueira et al. 2000). On the other hand, broadleaf trees can reoccupy the available growth space after a forest fire through sprouting (Dafis 1986; Bond & Midgley, 2001; Milios & Akritidou, 2003; Milios et al., 2014; Milios et al., 2017). Thus, the conversion of conifer reforestations into a forest of broadleaf trees or into a mixed broadleaf-conifer forest will reduce the risk of a forest fire and increase the ecosystem resilience (Milios et al., 2019). In a warmer climate, probably forest fires will become more frequent, and the use of conifers in reforestations will increase the probability of a large forest fire as well as the subsequent expenses for new reforestations and protection from new forest fires, as shown in the present study. On the contrary, the use of broadleaved trees in reforestations will reduce the costs of the re-establishment of vegetation after a forest fire, since they can resprout (Milios et al., 2019). Moreover, the replacement of the native broadleaf vegetation by planted conifers would be catastrophic. Milios and Akritidou (2003) refer to the fact that in areas where wildfires are frequent and there is degraded vegetation with a relatively satisfactory density of native broadleaf plants, forest practice must not remove them and plant conifers in reforestation aiming for protection from erosion or recreation. On the contrary, through the proper treatments, it has to restore the broadleaf vegetation in order to achieve the management goals.

Based on the results of the present study, the use of conifers in reforestations must be avoided in all cases in the studied area as well as in similar areas with similar characteristics and ecology.

Even in very degraded environments, where site insensitive conifers have an ecological advantage (Oliver & Larson, 1996), forest practices have to find alternatives regarding the species that would be used for restoration. A candidate species is *Robinia pseudoacacia* (Manolopoulos et al., 2022). However, detailed studies have to be conducted in order to determine the dangers of using that invasive species and to eliminate the invasion of the species in adjacent ecosystems (Spyroglou et al., 2021; Manolopoulos et al., 2022). Moreover, in cases where there are native plants in candidate reforestation areas, these have to be incorporated into the restoration process.

Silvicultural treatments can be used in order to mitigate climate change (Mazza et al., 2019; Doukalianou et al., 2019; Doukalianou et al., 2022). Moreover, in the studied ecosystems and in analogous cases, forest practice has to develop special silvicultural treatments for the reduction of the presence of the planted conifer trees based on the characteristics of the specific ecosystem (Milios, 2021; Milios et al., 2021).

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