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Light transmittance and understory junipers influence the survival and growth of seedlings and litter decomposition in black pine forests

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Abstract
Previous studies examining the influence of understory shrubs and light transmittance through the canopy (LT) (%) on seedling establishment of desired species and litter decomposition have reported inconsistent findings. Uncertainty still also remains about the effects of understory junipers (*Juniperus oxycedrus* L. *subsp*. *oxycedrus*) and LT on survival and growth of black pine (*Pinus nigra* Arnold.) seedlings as well as on litter decomposition across species' geographical range. Thus, this study aimed to examine the influence of understory junipers and LT on the growth and survival of black pine seedlings. Moreover, how junipers and LT affect litter decomposition was also monitored for eighteen months. Survival and growth of seedlings were most significantly affected by LT and understory junipers. LT and junipers negatively affected the survival of black pine seedlings. LT increased root-collar diameter (RCD) growth of the seedlings, while the RCD growth rate decreased with the presence of understory junipers. Moreover, the influences of LT and junipers on litter mass loss were mainly statistically significant; the presence of junipers and increasing LT in understory retarded litter decomposition. The findings may help our knowledge of ecological processes such as litter decomposition and seedling establishment in black pine forests. The results would also provide important guidance for evaluating the effects of overstory thinning (i.e., providing light to understory) and removing junipers on the ecological processes associated with litter decomposition and seedling recruitment in a black pine stand.

Keywords Establishment · Juniperus · Mass loss · Pinus · Recruitment · Sustainability

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Introduction

Black pine (*Pinus nigra* Arnold.) is a widespread and economically significant tree species across Europe and Asia Minor (Köseoğlu and Kara 2019). Pure and mixed forests of the species cover vast areas within its natural ranges. However, these forests have been negatively affected due to unfavorable management implications and climate change (Andreu et al. 2007; Sánchez-Salguero et al. 2012). Because of the observed growth decline of black pine in many regions, especially in dry areas (Lenoir et al. 2008; Janssen et al. 2018), the concern over the successful natural regeneration of the species has increased. Light transmittance (LT) (%) through the forest canopy and understory vegetation existence are considered the two main factors that are associated with the successful natural regeneration of black pine forests (Tiscar and Linares 2011). But, our knowledge of the degree of their impact on these forests is still limited, and should be well-understood.

LT can hinder or promote understory seedlings' establishment, survival, growth, and recruitment depending on their light requirements (Petritan et al. 2009; Mediavilla and Escudero 2010; Kara and Topaçoğlu 2018). Seedling establishment and recruitment can be commonly manipulated using silvicultural practices that aim to change the amount of LT by managing canopy cover (Kara et al. 2017; Li et al. 2019). Although black pine is known to be a semi-tolerant species to shade (Genç 2020), the response of black pine seedlings to varying levels of LT in the understory is still poorly understood. The success of the silvicultural treatments in black pine stands would greatly depend on such research that quantifies and understands the interactions between LT and seedlings' growth and survival.

Understory shrubs can also influence the establishment, survival, and recruitment of seedlings of desired tree species (Tiscar and Linares 2011); previous studies examining the effects of understory shrubs on the development of seedlings have cast doubt on this notion. Some studies have documented that understory shrubs can facilitate seedling establishment by providing shade and protecting seedlings against climate extremes (Gómez-Aparicio et al. 2004, 2009). This interaction is essential, especially in forest areas where more frequent and intense drought events commonly occur (Lindner et al. 2010). In contrast, other studies found that understory vegetation may cause reduced seedling survival, growth, and seedling quality due to their competition with the seedlings for resources (Götmark et al. 2011; Jensen and Löf 2017). The discrepancy among previous studies emphasizes the gaps in our understanding of the interactions between understory shrubs and seedlings of desired tree species. Uncertainty also remains about black pine seedlings' response to understory *Juniperus oxycedrus* L. subsp. *oxycedrus* (hereafter, juniper), which is known as an indicator species and typical understory vegetation of black pine stands (Güner et al. 2011; Vilar et al. 2016). Therefore, the impacts of understory junipers on the successful regeneration of black pine stands should also be well-documented.

In addition to their effects on seedling survival and growth, LT and understory shrubs may influence litter decomposition which may consequently impact root development and growth of seedlings in forest stands (Liski et al. 2003; Fujimaki et al. 2004; Prescott 2010; Enez et al. 2015). It should be noted that plants absorb most of the essential nutrients released during the decomposition process (Wang et al. 2022). Moreover, humus, which is the end product of decomposition, also holds moisture that the seedlings can use. Previous research regarding the effects of LT and understory shrubs on decomposition has also published inconsistent relationships. While some previous studies claimed that increasing light in the understory can accelerate litter decomposition (Li et al., 2019; Chen et al., 2014), others revealed that a greater amount of understory light decreased or did not affect decomposition (Son et al., 2004; Bravo-Oviedo et al. 2017). Moreover, while some studies found that understory plants can facilitate litter decomposition in stands (Wang et al. 2016; Li et al. 2021), others reported that understory shrubs can hamper litter decomposition by negatively impacting soil moisture and microorganisms (Sariyildiz and Küçük 2009; Chen et al. 2019). The quantitative knowledge about the relationships among LT, understory junipers, and litter decomposition for black pine forests is essential for the successful regeneration of the species, and such research would help forest managers decide the intensity and frequency of silvicultural treatments that aim to regenerate black pine stands.

The main objectives of this study were to examine (i) the effects of understory junipers on the survival and growth of black pine seedlings, (ii) the influence of junipers on litter decomposition, (iii) the effects of light transmittance through the canopy on pine seedlings' growth and survival, and litter decomposition. It was hypothesized that understory light deficiency and understory junipers would negatively affect the growth and survival of black pine seedlings, and litter decomposition. Novelties include the first models quantifying the relationships among understory light conditions, understory junipers, black pine seedlings, and litter decomposition in black pine forests. Knowledge about the relationships among junipers, black pine seedlings, and the understory light regime would enable forest managers to use silvicultural practices that modify the understory light availability and response of seedlings, as well as regulate understory competing species.

Materials and methods

Study area

This research was carried out in a black pine stand in the city of Kastamonu, northern Türkiye (Fig. 1). This location is a part of the Euro-Siberian phyto-geographic region, which is within the natural distribution of black pine. With cold winters and rainy summers, the research region is representative of the typical characteristics of a continental climate. The average monthly temperature in the study area is 9.7°C, and the average total annual precipitation is 480 mm (Fig. 2). The lowest and highest temperatures are measured in January (− 1°C) and July (20.1°C) on average, while the maximum and minimum monthly precipitation occur in May (75.3 mm) and February (27.4 mm), respectively. Climate data obtained from the General Directorate of Meteorology were from the climatic station that is located in a close proximity to the study area (41° 22′ 15” N, 33° 46′ 32” E) at elevation of 800 m. The topography ranges from nearly flat to gently sloping. The soil is primarily loamy clay and mostly moderately deep, ranging from 40 to 80 cm, while the humus layers were mull. The parent rock of the study site is neritic limestone and shale covered with sandy loam and clay (FAO-Unesco 1981). The altitude of the study site varies from 700 to 800 m above sea level.

A forest stand dominated by black pine was selected for the study. Scots pine (*Pinus sylvestris* L.) is the other main tree species of the study site. The stand had an area of approximately five ha and represents an even-aged stand structure. Dominant ages of trees range from 30 to 50, while the average height of the trees was 10.2 m. The stand was thinned from

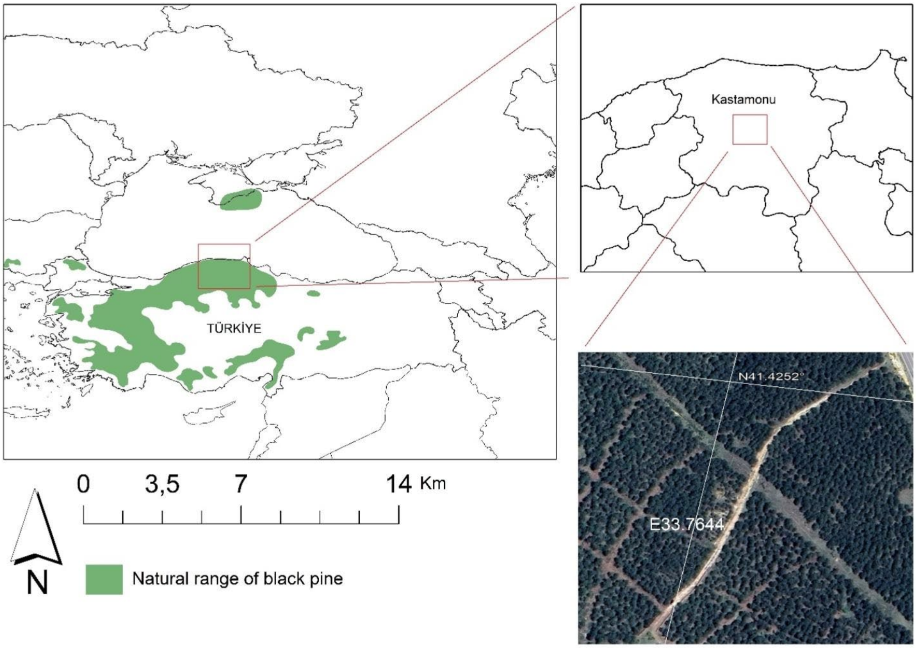

Fig. 1 Natural distribution of black pine and the location of Kastamonu city and study stand in northern Türkiye

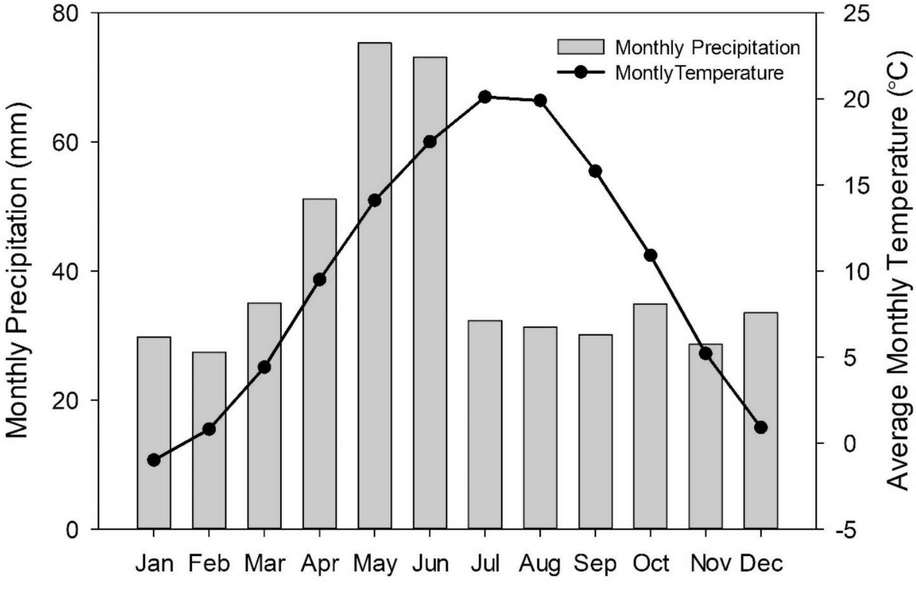

Fig. 2 Climograph of monthly mean temperature (°C) and mean monthly precipitation (mm) of the study area

below in late 2019 and exhibited a partial canopy following the thinning. The average basal area of the stand was around 23 m^2 ha^{-1} before thinning, and approximately 25% of it was removed during the operation, while the mean canopy was reduced from 90 to 75%. Juniper sporadically exists within the study stand. It is a thermophile shrub that grows on a variety of sites across the Mediterranean regions and around Black Sea from sea level up to 1600 m elevation (Orhan et al. 2011; Vilar et al. 2016), in black pine forests in particular. No other understory vegetation was dominant across the study site.

Study design and seedling measurements

In the study stand, thirty well-developed understory junipers were randomly selected in the understory of the study stand. The selected junipers were more than 2 m away from overstory black pine trees. The average root collar diameter (RCD) of the junipers was 25 mm ranging from 11 to 43 mm across the stand. In addition, the height of the junipers ranged from 33 to 90 cm, with an average of 60 cm. To examine the competing effects of junipers on seedlings, three black pine seedlings were planted near each selected juniper (i.e., a total of 90 seedlings) within a 20 cm distance, as suggested by Lhotka and Lowenstein (2015). The planted seedlings were acquired from Daday Nursery Directorate, which is in close proximity to the study stand. The planted black pine seedlings were 1-year-old and bare-root. The initial mean RCD of the planted seedlings was 4.43 mm ranging from 2.22 to 6.84, while the average height of them was 26.9 cm ranging between 16.5 and 42.8 cm. For control purposes, the same number of seedlings (i.e., a total of 90 seedlings) were planted at least two meters away from the selected junipers to minimize their interspecific competition with the junipers (Kara et al. 2017). On the day they were transported from the nursery in March 2020, all black pine seedlings were hand-planted. Planting was conducted following a rainy period; thus, the seedlings were not watered afterward.

Soon after the planting, the initial RCD and height of planted seedlings were recorded to the nearest millimeter and centimeter, respectively. RCD measurements were taken using a digital caliper, while seedling height was measured with a ruler. At the end of the first and second growing seasons (i.e., October 2020 and 2021, respectively), RCD and height measurements were repeated to obtain RCD and height growth of the seedlings after two years and to monitor juniper effects on seedling growth. Moreover, seedling survival was also recorded during each measurement period to examine the effects of junipers on black pine seedling mortality.

Decomposition experiment

The nylon-net litter bag technique was followed to examine the influence of junipers on needle litter decomposition (Chen et al. 2012). In early October 2019, recently fallen fresh needle samples were collected beneath mature black pine trees by laying down nets on the forest floor to provide representative samples. In this location, the primary time of litter fall usually peaks in the autumn. When the litter material was gathered, the temperature was around 10 °C, and the litters at this point exhibited no clear mycelial growth or noticeable symptoms of discoloration. The needle samples were air-dried in the laboratory before being oven-dried for 48 h at 40 °C until they were slightly crushed by hand (Sariyildiz and Küçük 2009). To attain a correction factor for calculating the initial oven-dry mass of the litter, samples were also taken and oven-dried at 65 °C (Rietl and Jackson 2012; Chen et al. 2019).

The 20×20 cm litterbags with a mesh size of 0.1 mm were used to monitor needle decomposition, as suggested by Savaci and Sariyildiz (2020). This mesh size allows for the inclusion of mesofaunal decomposers but not macrofaunal decomposers (Yang et al. 2018). A 5 g of air-dried black pine litter was placed in each litter bag, as suggested in previous studies (Li et al. 2021). At the end of October 2019, nine litterbags were fixed to the bare ground beneath each selected juniper to ensure the contact of the litterbags with mineral soil, as outlined by Yang et al. (2018). Moreover, at each location, nine litterbags were also placed away from the junipers under the canopy of the black pine stand as control. In order to track the continuum of litter decomposition rates over the course of 18 months, three litterbags were retrieved from each corresponding location every six months (i.e., six months, 12 months, and 18 months after litterbag placement). The retrieved litter samples were carefully cleaned from soil particles and other debris, oven-dried for 72 h at 85 °C, and then weighed to determine the amount of litter mass loss (LML) (Chen et al. 2019). The percentage of mass loss in the needle litter was used to calculate the rate of decomposition using the formula below.

$$\mathrm{LML}\,(\%) = \frac{5.0 - \text{litter weight of the period}}{5.0}\text{x}100$$

where 5.0 is the initial weight of the sample in each litter bag. Using the exponential decay model below, the rate of litter decomposition (k) was determined from the percentage of dry mass remaining (Olson 1963).

$$\frac{W_t}{W_0} = e^{-kt}$$

where W_t/W_0 is the friction of initial mass remaining at time t. The years needed for 50% (T_{50}) and 95% (T_{95}) mass losses were calculated as $1/k$ and $3/k$, respectively, as outlined by Olson (1963).

The stored needle litters were oven-dried at 65 °C, ground in a laboratory mill to a mesh fraction less than 1 mm, and analyzed for organic C and total N contents. The dry combustion technique was used to measure the organic C and N contents using a CHN-S elementary analyzer (EA 3000 v.3.0 single, Eurovector, Milan, Italy).

Light measurements

To determine the influence of LT (%) on black pine seedlings' growth and survival, and on litter decomposition, first, photosynthetically active radiation (PAR) was measured above each planted seedling and above where the litter bags were located (i.e., in understory). A total of five PAR readings were taken, and averaged where PAR measurements were conducted. PAR measurements were taken using a CI-110 Plant Canopy Imager (CID Bio-Science Inc., Washington, USA), on a nearly cloudless day, possibly between 11:00 and 13:00 as suggested (Kara and Topaçoğlu 2018). During the PAR measurements, the device was leveled, and extra care was taken to prevent the operator's shadow from blocking the sensors. In an open area, another PAR measurement was made concurrently. Then, PAR for each measurement spot, LT (%) was attained using the formula below.

$$\mathrm{LT}\,(\%) = \frac{\mathrm{PAR\,understory}}{\mathrm{PAR\,in\,open}}\mathrm{x}100$$

Analyses

The effects of junipers and LT on the RCD and height growth of black pine seedlings and on litter decomposition were examined using a mixed-effect multiple regression model. The presence of junipers (i.e., competition versus no-competition with junipers) and LT were utilized as fixed-effects variables (i.e., independent variables), while height and RCD growth, and litter decomposition (%) were used as the response variables (i.e., dependent variables). Junipers were treated as random effects in the models. It should be noted that an individual juniper was considered as the experimental unit (i.e., replication). The models were defined by the equation below.

$$\mathrm{Rv} = \beta_{\mathrm{o}} + \mathrm{Re} + \mathrm{X}^{\mathrm{T}} + \varepsilon$$

where Rv is the dependent variable, β_0 is the intercept, Re is the random effect, X^T is the transposed matrix of the independent variables, and ε is the error term. The impacts of junipers and LT on seedling survival were tested using logistic regression. In these analyses, the presence of junipers (i.e., competition verses no-competition) and LT were used as independent variables, while survival (i.e., survived or dead) was the dependent variable. Logistic regression is usually utilized when conducting mortality analysis because survival is not normally distributed (binomial), and survival data are not continuous. This analysis is a statistical method that aids in classification. It should be noted that initial RCD and height of the planted seedlings were also used as independent variables in the analyses since they likely affect seedling survival and growth. With the use of residual analysis, the data's normality and homogeneity of variance were examined, and no deviations from these model assumptions were discovered. During statistical analyses, the "lme" and "glm" functions of R-Statistical software (R Development Core Team 2021) were used.

Results

Seedling survival and growth

The LT (%) measured above the seedlings and above litter bags ranged from 5.2 to 100%, indicating that the measurement locations were dispersed under a wide range of light transmittance (Table 1). The mortality of the seedlings planted near junipers (hereafter, NJ_P) was significantly greater than the mortality of seedlings planted away from the junipers (hereafter, AJ_P) ($p = 0.001$). Moreover, RCD growth of AJ_P seedlings was significantly higher than that is for NJ_P seedlings ($p = 0.001$), while the difference of their height growth was statistically insignificant ($p < 0.05$) (Fig. 3).

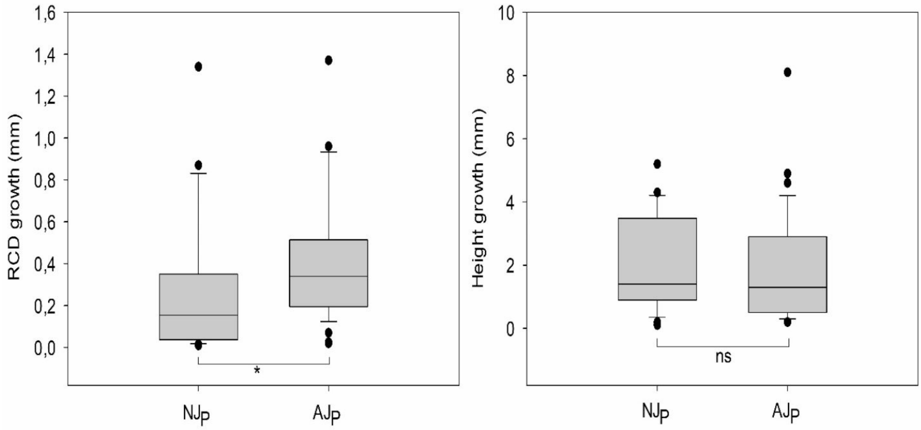

Fig. 3 The differences of RCD and height growth of black pine seedlings planted near (NJ_P) and away (AJ_P) junipers. Bars represent the standard errors, while the dots indicate potential outliers. ns, *, and ** are not significant, $p>0.05$, $p<0.05$, and $p<0.01$, respectively

Table 1 Influences of light transmittance (LT) (%) and junipers on survival, root-collar diameter growth, and height growth of black pine seedlings planted near (NJ_P) and away junipers (AJ_P).

Variables	Survival	RCD growth	Height growth
Intercept	0.7992 (1.31)*	-0.3118 (0.31)*	0.1164 (0.51)*
LT	-0.0145 (0.01)*	0.007 (0.11)***	-0.3784 (0.40) ns
Juniper: AJ_P (vs. NJ_P)	0.5924 (0.42) *	0.3549 (0.01) **	0.0094 (0.01) ns
Initial RCD	0.3607 (0.29) ns	-0.016 (0.06) ns	0.2146 (0.87) ns
Initial Height	-0.0647 (0.05) ns	-0.012 (0.01) ns	0.0280 (0.54) ns

ns, *,**,*** are not significant, $p>0.05$, $p<0.05$, $p<0.01$, and $p<0.001$, respectively

The linear mixed effect models indicated that seedling survival, after two years of planting, was significantly affected by LT (%) and junipers ($p<0.05$) (Table 1). Seedling survival increased with decreasing LT (%) across all planted seedlings, and the presence of junipers negatively affected seedling survival. In addition, there were statistically significant effects of LT ($p=0.001$) and junipers ($p=0.014$) on RCD growth of the seedlings following two growing seasons (Table 1). RCD growth of the seedlings increased with increasing LT, and the presence of junipers negatively affected the RCD growth. Moreover, there were no significant effects of LT (%), junipers, initial RCD, and initial height of the seedlings on height growth ($p>0.05$) (Table 1).

Litter decomposition

Average mass losses across the study stand were 23.3%, 34.4%, and 41.4% after six, twelve, and eighteen months, respectively (Fig. 4). The linear mixed effect models indicated that litter mass loss after six months of litterbags' placement was not significantly affected by LT

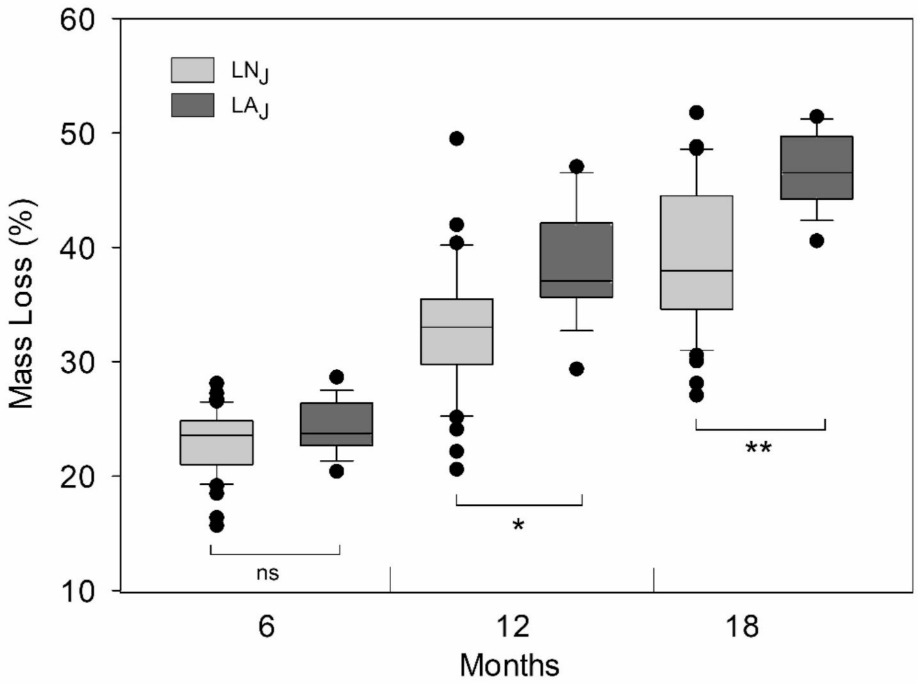

Fig. 4 The difference of the mean mass loss of black pine litters between LN_J and LA_J after 6th, 12th and 18th months. ns, *, and ** are not significant, $p>0.05$, $p<0.05$, and $p<0.01$, respectively

Table 2 Influences of light transmittance (LT) (%) and junipers on litter mass placed near junipers (i.e., LN_J) and away from junipers (i.e., LA_J)

Variables	6 months	12 months	18 months
Intercept	24.041 (1.24)***	36.589 (2.10)***	44.565 (2.31)***
LT	-0.023 (0.02)ns	-0.078 (0.04)*	-0.1064 (0.04)*
Juniper: LA_J (vs. LN_J)	1.031 (1.28) ns	4.829 (2.17)*	6.082 (2.38)*

ns, *,**,*** are not significant, $p>0.05$, $p<0.05$, $p<0.01$, and $p<0.001$, respectively

(%) or junipers ($p>0.05$) (Table 2). However, the influences of the parameters (i.e., LT and junipers) on litter mass loss were statistically significant after twelve and eighteen months following the litterbags' arrangement in the field ($p<0.05$). Needle litter mass loss at the 12th and 18th months decreased with increasing LT, as well as with the presence of junipers (Table 2).

Table 3 provides the decay rate (k) and time needed for 50% (T50) and 95% (T95) mass loss for LN_J and LA_J conditions. The decay rate was significantly higher at LA_J locations in comparison to LN_J locations ($p<0.001$). For 50% and 95% mass losses, a longer time period is required for needle litters placed near junipers (i.e., LN_J) compared to litters placed away from junipers (i.e., LA_J) (Table 3).

Table 3 Annual decomposition rate (k) and the time (year) required for 50% (T_{50}) and 95% (T_{95}) mass loss at LN_J and LA_J conditions

Parameters	LN_J	LA_J
k (yr^{-1})	0.28	0.35
P-value	$p<0.001$	$p<0.001$
T_{50} (yr)	3.71	2.85
T_{95} (yr)	11.11	8.56

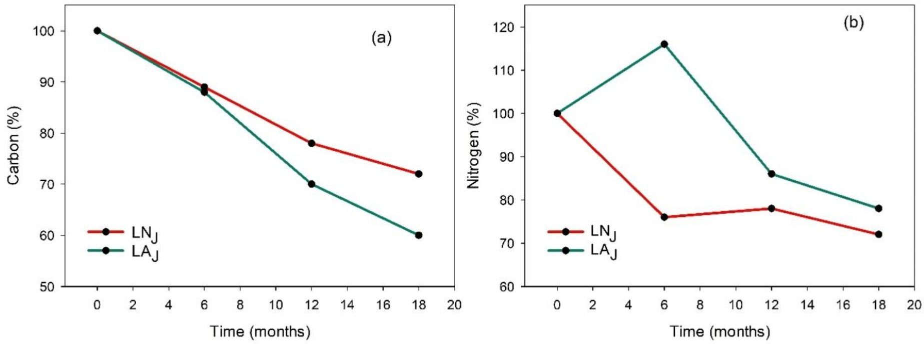

Fig. 5 Variation in total carbon (**a**) and nitrogen (**b**) concentrations in litters after 6th, 12th and 18th months during the decomposition period under two conditions (i.e., LN_J and LA_J).

Table 4 Goodness fit for linear regression of mass losses at 6, 12, and 18-months against the litter quality variables for black pine litters

Chemical Properties	6-month	12-month	18-month	Correlation
	r^2	r^2	r^2	
C	0.001	0.711***	0.069	+
N	0.397	0.025*	0.046	+
C/N	0.408	0.015*	0.061	-

The initial litter carbon concentrations all decreased over time. A reduction occurred by 89% and 88% in the 6th month in LN_J and LA_J, respectively. In the following periods (i.e., 12th and 18th months), carbon concentrations decreased by 78% and 70%, and 72% and 60% in LN_J and LA_J, respectively (Fig. 5a). Initial N concentrations of needles placed near junipers decreased over time, but those placed away from junipers had a peak at the 6-month (%116) interval and then decreased by 86% at 12-months and 78% at 18-months (Fig. 5b).

The goodness of fit statistics for the regression of mass losses on litter quality variables are shown in Table 4. Mass losses from black pine after 12 months showed the highest positive correlation with initial carbon ($r^2=0.711$). Nitrogen concentration and C/N ratio explained less variance at 12th month ($r^2=0.025$ and $r^2=0.015$, respectively). N concentration positively correlated with mass losses, but the C/N ratio showed a negative correlation (Table 4).

Discussion

Seedling survival and growth

Light is crucial for the survival and growth of seedlings and is thought to be one of the most important variables that prompt or impede their growth (Daryaei et al. 2019). It stands to reason that reduced stand density and subsequent rise in light entering the stand will favorably affect seedling survival for semi-tolerant tree species such as black pine (Noémie et al. 2011). However, it has been noted that young black pines may survive better beneath parent trees (Odabaşı et al. 2004; Tiscar and Linares, 2014), and the protection of overstory trees increases the number of seedlings in black pine stands (Deligöz et al. 2019; Kara 2022), as observed in the present study. This situation is especially anticipated in areas where soil moisture content may be restricted, such as the study area representing typical characteristics of a continental climate (Köseoğlu and Kara 2019) This is usually associated with a greater amount of soil surface moisture in the event of lower light conditions under the canopy since high irradiance may cause water availability to decrease and evaporative demand to rise, which would hinder seedling establishment (Valladares et al. 2005; Topaçoğlu et al. 2016).

One of the most significant drivers of the development and growth of black pine seedlings is understory light availability (Mercurio et al. 2009), which is mainly provided through silvicultural treatments, including thinning. Instead of affecting their survival, the lack of light in the understory may have a detrimental impact on the further growth of black pine seedlings (Tiscar and Linares 2014). Our findings reporting the influence of LT on the RCD growth of planted seedlings substantiate these statements. The reason why LT did not affect seedling height growth is likely because black pine seedlings mostly use most of their initial energy to develop their stem and root system rather than height (Köseoğlu and Kara 2019). In addition, previous studies pointed out that the height increment of seedlings in regard to light may be time-dependent (Sevillano et al. 2016; Sangsupan et al. 2021). Relevantly, previous research stated that light usually plays a more crucial role in the height growth of black pine seedlings after the age of three (Eler et al. 1989; Genç 2020). Therefore, further monitoring is usually required to see the long-term effects of LT on the height growth of seedlings (Tripathi et al. 2020). Moreover, the fact that the seedlings were grown in full sunlight for one growing season under nursery conditions may have delayed their height growth after they were planted under the canopy (Welander and Ottosson 1998), suggesting that the earlier light conditions may have a greater impact on height growth than present light conditions (Sevillano et al. 2016).

The competition of understory seedlings with understory vegetation for resources may be as much of a limiting factor as understory light availability for seedling development (Kuusipalo 1983). Though some studies found that understory vegetation has a positive or no effect on pine seedlings' survival and growth (Hyppönen et al. 2013), the general consensus is that understory vegetation has a negative impact on seedling growth and survival by competing for soil moisture and other resources (Smidt and Puettmann 1998; Yılmaz et al. 2018). Black pine requires partial canopy due to its moderate shade tolerance in early stages, and this canopy structure allows the establishment of other understory vegetation, including junipers (Odabaşı et al. 2004; Genç 2020). A study that examined black pine recruitment in central-eastern Spain came to the conclusion that control of competing vegetation improved seedling emergence in pure stands (Lucas-Borja et al. 2016). In a similar research, Tardós et al. (2019) monitored the impacts of understory removal on black pine seedling establishment and found that the removal enhanced seedling recruitment. The linkages between understory vegetation and seedling growth are usually associated with climatic conditions; that is, the impact of competing understory vegetation is mostly greater under harsh climate conditions (Juntunen and Neuvonen 2006). Atalay and Efe (2012) reported that black pine establishes better where the mean annual precipitation was above 1000 mm, and the competitive ability of black pine with understory vegetation reduced where a continental climate is prevailing, which appears consistent with our findings. Moreover, the allelopathic potential of junipers on the survival and growth of neighboring plants (Young and Bush 2009; Semerdjieva et al. 2022) can also be associated with the negative impacts of junipers on black pine seedlings examined in the present study.

Litter decomposition

The general trend in litter decomposition processes was rapid at first, then slowed. Previous studies revealed a similar pattern in the decomposition of pine litter (De Marco et al. 2012; Chae et al. 2019). Higher substrate availability in the first year compared to later years might explain why litter decomposition slows down with time (Margesin et al. 2016). Conversely, later, slower litter decomposition rates are probably caused by challenges with microbial degradation and mineralization of chemically recalcitrant complex compounds, such as polyphenols and lignin (Savaci and Sariyildiz, 2020). Moreover, the decay rates of black pine needles in our study were also in line with previous studies (Enez et al. 2022). However, it should be noted that we observed the short-term effect of thinning in soils that influence the decomposition, given the time of thinning and litterbag placements.

Forest thinning involves partial tree removal to allocate more growing space for remaining individuals. A decrease in tree density in forests can change the microclimate or ground conditions where the litter decomposes. It is generally accepted that light passing through the forest canopy and reaching the forest floor following thinning operations may facilitate the decomposition of litter (Chen et al. 2014; Savaci and Sariyildiz 2020; Li et al. 2021). An enhanced photodegradation due to increased solar radiation following thinning may potentially speed up the decomposition of litter (Almagro et al. 2017). However, some researchers asserted that rates of decomposition decreased with increased light transmittance (Blanco et al. 2011; Bravo-Oviedo et al. 2017), as we observed in the present study. It should be noted that moisture and temperature are other factors that influence the decomposition process in forests (Yang et al. 2014). Previous studies stated that when moisture is limited in the understory, increasing light availability usually reduces the decomposition rate (Lado-Monserrat et al. 2015). In other words, more light availability may result in higher soil temperature, lower soil moisture, and decreased litter decomposition. Relevantly, Bravo-Oviedo et al. (2017) monitored the relationships between light availability and litter decompositions and found that increasing light created an aridification effect on litter decomposition. Moreover, in a similar study, Blanco et al. (2011) observed litter decomposition following a thinning in a Scots pine *(Pinus sylvestris* L.) stand exposed to a continental climate, and found a reduction effect of overstory thinning on the decomposition. Given the restricted amount of annual rainfall in the study site as well as the wide range of LT in the study, our findings regarding light-decomposition relationships seem to be consistent with previous studies.

In the present study, the *k* values attained for both conditions (LN_J and LA_J) were comparable with the previous studies conducted on needle litter decomposition (Yang et al. 2014; Li et al. 2021). High levels of organic acids are frequently found in the leaves and wood of many evergreen plants, including junipers (Duan et al. 2020). This organic acidity, in turn, makes the forest floor and soil more acidic (Sariyildiz and Küçük 2009). Consequently, the increased soil and forest floor acidity may have slowed down the mineralization process, lignin breakdown, and total microbial biomass—all of which are important regulators of litter decomposition rates (Pritchett and Fisher 1987). In addition, under continental climate conditions, it is likely that soil moisture decreased at spots where junipers and pine seedlings were in competition (Sariyildiz and Küçük 2009). Species-species competition in the understory might result in a greater amount of soil moisture consumption than the competing species, and consequently, the reduced soil moisture may negatively influence the rate of decomposition (Lado-Monserrat et al. 2015; Chen et al. 2019). Moreover, junipers are known to produce allelopathic compounds (Young and Bush 2009; Semerdjieva et al. 2022), which can negatively impact litter decomposition (Sariyildiz and Küçük 2009). Therefore, the abundance, composition, and activity of the decomposing community may have been likely negatively impacted by junipers' recognized ability to create allelopathic chemicals. Yet, further monitoring is needed in future studies to better understand the main reasons for reduced litter decomposition by junipers. The amount of carbon in the litter decomposition process usually decreases in parallel with the mass loss (Berg and Laskowski 2005; Baldantoni et al. 2013; Tunç 2019; Enez et al. 2022), as we observed in this study. Moreover, higher nitrogen content in LA_J conditions than LN_J can also be associated with a relatively higher rate of decomposition in LA_J (Savaci and Sariyildiz 2020).

Conclusions

The current study found that light through the canopy and the presence of understory junipers play crucial roles in black pine seedling growth and survival, as well as pine needle decomposition. This study demonstrates the importance of residual stand density during silvicultural implications since they evidently influence the understory light conditions and consequently seedling development and decomposition. Moreover, the study also points out the significance of juniper control in the understory of black pine stands since they can negatively affect seedling growth and survival, and decomposition. Initial findings regarding the relationships among junipers, black pine seedlings, and the understory light regime would enable forest managers to use silvicultural practices that modify the understory light availability and response of seedlings, as well as regulate understory competing species. When natural regeneration is aimed in black pine stands, understory vegetation including junipers is commonly removed to expose mineral soil, and to control competition of seedlings with this shrub. Although this study found negative effects of junipers on black pine seedlings and litter decomposition, the current study does not intent to encourage the eradication of junipers from black pine stands, because their other benefits to ecosystem are likely. Given the inconsistencies in previous research regarding understory vegetation-seedling relationships as well as species-decomposition relationships, our knowledge about how juniper effects on seedling development and decomposition vary over time seems to be still limited. Therefore, long-term monitoring of the study area may be recommended.

Author contribution FK conceived the idea, conceptualized the project, and acquired funding. FK, GS and AÇ collected data and compiled the literature. FK conducted analyses. FK conducted writing and editing. All authors reviewed manuscript drafts and gave final approval for publication.

Declarations

Competing interests The authors declare no competing interests.

Conflict of interest The authors declare there are no competing interests.

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