FOLIA OECOLOGICA – vol. 45, no. 1 (2018), doi: 10.2478/foecol-2018-0001

Deer game, a key factor affecting population of European yew in beech forests of the Veľká Fatra Mts, Slovakia

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Abstract

Sedmáková, D., Kýpeťová, M., Saniga, M., Pittner, J., Vencurik, J., Kucbel, S., Jaloviar, P., 2018. Deer game, a key factor affecting population of European yew in beech forests of the Veľká Fatra Mts, Slovakia. *Folia Oecologica*, 45: 1–7.

Browsing and bark peeling by ungulates is known to affect biodiversity and may constitute the main driving factor of single tree population dynamics. In Slovakia, European yew (*Taxus baccata* L.) is a threatened species protected by law and present in many protected areas. In the study, we emphasize that protecting land and individual plants may not be sufficient for maintaining of yew populations, unless controlling over damage by deer game is also undertaken. Our results show that in beech forests of the Veľká Fatra Mts, browsing and bark peeling constitute the main negative factor affecting yew seedling-sapling ingrowth transition, and the mortality and vitality loss of adult yew trees. We argue that ungulates may have a larger effect on biodiversity conservation than currently realized.

Keywords

biodiversity conservation, forest management, plant-animal interactions, protected tree species

Introduction

Ensuring the persistence of long-lived and slow-growing tree species such as *Taxus baccata* (L.) that maintains the unique biodiversity of beech forests requires the establishment of efficient conservation management system that enhances the forest biological diversity in general and increases growth rates of yew isolated populations. Practically, the time frame of 100 years is used in conservation decisions and strategies (Wood and Gross, 2008). In this time period populations of long-lived tree species, even lacking regeneration often do not undergo substantial declines and thus receive little attention in conservation plans (Kwit et al., 2004). Strategies as protecting land and individual plants along with the less frequently applied reintroduction of ecological processes important to regeneration may not be sufficient for maintaining and increasing growth rates of populations in decline (Kwit et al., 2004). Regarding yew, targeting other life stage transitions along with actions such as racing of public awareness seems to be important to increase the probability of its survival (Vacik et al., 2001). Particularly in yew, illegal cuttings, deer browsing and bark peeling along with high competition pressure are most often reported risks in the recruitment of yew to later life stages (Dhar et al., 2008). Reduction of deer game and application of shelterwood cuttings to release yew from competition and herbivory pressure have been shown as successful conservation actions (Saniga, 2000).

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Nevertheless, widespread lack of regeneration, high seedling mortality and the inability of recruitment to develop beyond a sapling stage seem to affect European yew negatively and its long-term performance (no trees to build up future populations) across its wide geographic range. Among factors limiting recruitment success, particularly lack of light and low temperature along with herbivory (browsing by deer and seed predation by rodents) seem to be important in the northern and eastern parts of yew distribution area (Korpeľ, 1995; Hulme, 1996; Svenning and Magård, 1999; Saniga, 2000; Saniga and Jaloviar, 2005; Iszkuło and Boratyński, 2005; Dhar et al., 2007; Iszkuło, 2011). In natural conditions, yew regenerates less frequently and mainly under the canopy of different tree species (Iszkuło and Boratyński, 2004).

This study focuses on the structure of yew population and its conservation management. The main objectives of the study are: (1) to characterize ecological conditions and structure of yew population in the selected locality of the Veľká Fatra, (2) to analyse vitality of yew trees in relation to damage by ungulates (3) to address conservation management recommendations based on the results of the study.

Material and methods

Study area

For the purpose of this study, we selected the locality representing limestone beech forests, a rare habitat with species-rich plant associations covered in EU Habitat Directive and Natura 2000 and characteristic for the presence of long-lived rare tree species – yew. We surveyed forest stand structures with adult yews. Within the selected locality 'Veľká Skalná' in the Veľká Fatra Mts (48°52′N; 18°57′E), sampled yew adults have grown within a vertical range from 948 to 1,036 m asl, on the rather steep slopes 23–40° with prevailing northeast-northwest aspect. Mean annual air temperature and precipitation sums range from 2 to 4 °C and from 900 to 1,000 mm respectively. We placed sampling plots in forest stands with close to natural tree species composition, established by natural regeneration and providing mainly regulating and provisioning services. Selected, mostly multi-layered stands with yew present in the understorey have closed canopy. Mean estimated canopy cover was 0.83. Except European yew (*Taxus baccata* L.), stands have consisted mainly of European beech (*Fagus sylvatica* L.), sycamore maple (*Acer pseudoplatanus* L.), and Norway spruce (*Picea abies* [L.] Karst.).

Sampling and data analysis

Data on stand density, stand basal area and volume were derived from 500 m^2 circular sampling plots (n = 34) established with a central yew tree placed in the middle of the plot according to design already described in Sedmáková et al. (2017). Sampling plots were established in the surrounding of adult yew trees with a minimum diameter of 15 cm at 1.3 m above ground (dbh). On each plot, coordinates of all living and dead standing trees and stumps with dbh > 8 cm were mapped by FieldMap device. Each individual was assigned by the attributes of tree species, dbh, height (h), and height of the crown base. Central yews were recorded for crown dimensions, sex, growth form as well as degree and type of damage.

The crown vitality of central yew was assessed as a combination of the crown length (relative percentage of the living crown), the degree of defoliation (relative percentage of needle loss) and crown formation (different types of crowns), similarly to (Dhar et al., 2007; Table 1). Damage to stems by herbivory was assessed qualitatively according to four classes. Class one corresponds with healthy undamaged stem, two with the weakly damaged stem up to 25% of stem circumference, three with damaged stem from 25% to 50% of stem circumference, and four with the heavily damaged stem when more than 50% of stem circumference is bark peeled.

In between sampling plots following the isohypse if regeneration of yew was present, we established a sampling plot for regeneration. The yew regeneration was less often observed. Fifteen square plots (4 m^2) were established to analyze the species composition and height structure of natural regeneration. A number of regenerated individuals were calculated per hectare and in percentage. Based on their height measurement, all individuals were assigned into two categories: seedlings with height 0–20 cm or saplings with height > 20 cm. In case of yew, we also recorded its age and health condition, and especially damage by herbivory. The age of seedling/saplings was determined as number of bud whorls along the main axis of

Table 1. Description of crown vitality parameters' classes

Defoliation	Crown formation
1 – undamaged crown < 10%	1 – well developed, strong crown
2 – weakly damaged to 25%	2 – weakly developed, constricted crown
3 – damaged from 25% to 50%	3 – undeveloped, mostly unilaterally clamped crown
4 – heavily damaged > 50%	4 – dying crown

the saplings. Additional method of age determination was the number of annual rings at the radial cut of dead yew individuals. To determine the growth vitality, the recent height increment of each yew was measured at the end of 2017 growing season (if the measurement was possible).

Statistical significance of arithmetic differences in mean heights and diameters among tree species were tested by one-way ANOVA, effective hypothesis decomposition. Statistical differences in height and diameter distributions were tested by Kolmogorov-Smirnov test. Relationships among crown vitality parameters and degree of stem damage were tested by nonparametric rank correlations (Spearman's R correlation coefficient). The significance of all reported proportions in classes (degrees) of damage or undamaged trees was tested by *t*-test.

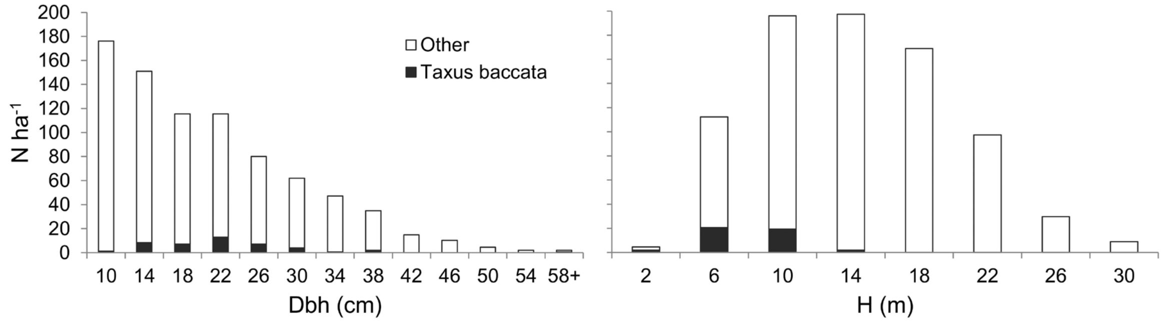

Fig. 1. Distribution of diameter and height classes of European yew and all tree species in selected forest stands in the locality 'Veľká Skalná'.

Table 2. Basic characteristics of the selected forests in the locality 'Veľká Skalná'

Tree species	Tree density (N ha^{-1})	Basal area (m^2 ha^{-1})	Growing stock (m^3 ha^{-1})	Dbh ± SD (cm)	H ± SD (m)
Taxus baccata	44	2.0	6.7	22.4 ± 8.4 ^{a}	7.8 ± 2.2 ^{a}
Fagus sylvatica	425	21.8	187.8	23.2 ± 9.9 ^{a}	15.8 ± 5.5 ^{b}
Acer pseudoplatanus	122	2.6	18.6	15.7 ± 5.3 ^{b}	14.1 ± 3.7 ^{c}
Picea abies	183	6.2	46.0	18.6 ± 9.0 ^{c}	13.3 ± 6.2 ^{c}
Others	42	1.3	7.3	18.7 ± 5.9 ^{c}	11.8 ± 3.5 ^{d}
Total	815	33.8	266.4	20.8 ± 9.8	14.4 ± 5.6

Dbh and H represent mean measured dimensions (diameter at 1.3 m above ground and height) of trees listed with range of standard deviation values (SD). The identic letter defines the group of tree species, which arithmetic means are not significantly different at $p > 0.05$. Others include tree species: *Sorbus aria* and *aucuparia*, *Fraxinus excelsior*, and *Abies alba*.

Results

Status of adult yew population

In the selected locality yew trees reach small growth dimensions. Unlike other tree species, yew is mostly present in the lower diameter and height classes, which corresponds with its prevailing understorey stand position (Fig. 1). On the average, yew basal area represents 5.9% of the total stand basal area (Table 2). The frequency of yew trees in the 8–12 cm (2.3%) and 12–16 cm (18.2%) diameter classes was low. Average height of yew trees is 7.8 m; above half of yew trees (52%) are present in the height class 4–8 m. Shapes of yew dimensional (diameter and height) distributions are unimodal and significantly differ from shapes of other tree species according to Kolmogorov-Smirnov test, $p < 0.01$.

In contrary to other tree species, yew regeneration shows the absence of individuals in the lowest diameter classes. Concerning the parameters describing crown vitality, mean crown length represents on average 71% from the total stem height (range between 52 and 88%). 41% of yew trees show damaged or heavily damaged crowns. One-third of yew trees have well developed strong crowns. Majority have weakly developed (59%) or undeveloped crowns (12%). There is a moderate relationship among degree of defoliation, the degree of crown formation and percentage of living crown. Percentage of living crown decreases with increasing degree (class) of crown formation (Spearman's $R = -0.34$, $p < 0.05$) and defoliation (Spearman's $R = -0.48$, $p < 0.01$). No relationships between stem damage and crown vitality parameters has been detected, possibly due to

Fig. 2. Heavily damaged European yew trees by herbivory (more than 50% of stem circumference), showing crown vitality loss. a) yew crown with lower needle density; b) dieback of the crown, actually a whole stem out of a two-stem yew tree has died; c) recently died tree because of acute stem herbivory; d) dead standing adult yew tree. Photo by D. Sedmáková.

acute damage of yew trees with well-developed and less damaged crowns (Fig. 2).

The majority of yew trees show signs of stem herbivory. Together, 65% of yews are assigned by 3rd or 4th degree of damage. 26% of stems have been damaged in the current year. 44% of yews have damaged roots and root collars (either by bark peeling or mechanically). 38% of stems are rotten.

The majority of species consists of European beech, which also noticeably dominates in higher classes of natural regeneration (Table 3, Fig. 3). The results show the abundant number of yew in the category of seedlings, which represents the second most frequent tree species in natural regeneration. However, there is a considerable reduction of yew in the number of saplings. The maximum height of yew saplings is approx. 30 cm.

Table 3. Basic characteristics of natural regeneration in the locality 'Veľká Skalná'

Variable	Seedlings			Saplings		
Tree species	Density ($N\ ha^{-1}$)	(%)	Height h ± SD (cm)	Density ($N\ ha^{-1}$)	(%)	Height h ± SD (cm)
Taxus baccata	18,000	29.9	8.0 ± 2.9	500	2.7	24.5 ± 5.6
Fagus sylvatica	23,833	39.6	13.7 ± 3.5	16,167	88.2	31.0 ± 10.1
Acer sp.	11,667	19.4	10.9 ± 3.5	833	4.6	25.2 ± 5.0
Picea abies	6,000	10.0	4.6 ± 2.4	333	1.8	44.0 ± 9.9
Others	667	1.1	15.2 ± 1.3	500	2.7	36.2 ± 19.0
Total	60,167	100.0		18,333	100.0	

SD represents standard deviation values. Others include tree species: *Sorbus aria, Sorbus aucuparia* and *Fraxinus excelsior*.

Status of natural regeneration

In general, the density of natural regeneration reaches 7.8 individuals per m^2, while *T. baccata* represents the proportion 23.6% (Table 3). Seedlings of yew represent nearby one-third, while saplings only 1.8% of all naturally regenerated saplings. In the whole yew population, 98% are seedlings and 2% are saplings. The most abundant height class of young yews is 0–10 cm, whereas the majority of broadleaved natural regeneration belongs to the height class of 10–20 cm (Fig. 3).

In the studied locality, browsing pressure caused damage in 42% of yew seedlings and 100% of yew saplings. Herbivory impacts the height growth of yew. The mean height of damaged yews is significantly different from healthy ones as well as the height increment. While damaged yews reach on average 6% of the current height, the healthy yews reach 18% (*t*-test, $p < 0.001$). The height position of yew seedlings significantly differs from other tree species, but there is no significant difference in height of saplings among tree species (Table 3).

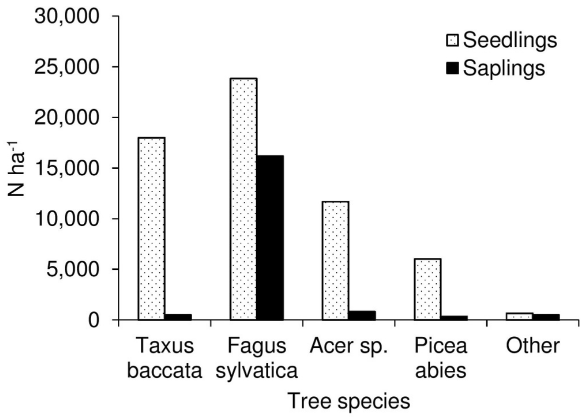

Fig. 3. Numbers of naturally regenerated individuals according to height categories (seedlings and saplings).

The relationships between age and height are significant ($p < 0.001$) in both categories of yew seedlings (damaged and healthy, Fig. 4). The proportion of explained variance (62%) is lower in damaged yews, respectively the influence of age on height growth is weaker compared with healthy yew juveniles. Damaged yews are lower than undamaged in comparable age category. The difference in height growth increases with increasing the age.

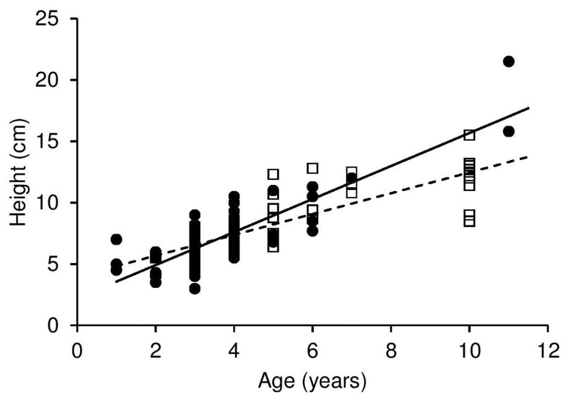

Fig. 4. The relationship between height and age of damaged and healthy yew juveniles. □ white squares represent damaged yews and ● black points healthy yews; - - dashed line means linear trend (damaged) of regression with coefficient $R^2 = 0.62$ and — full black line means linear trend (healthy) of regression with coefficient $R^2 = 0.71$.

Discussion and conclusion

Our results demonstrated that enormous browsing pressure has led to yew recruitment failure. The effect of browsing resulted in the sharp decrease in the density of saplings, and their almost complete extinction. The lack of regeneration has lasted several decades. In the studied locality, yew trees reach the height of 16–20 cm at the age of 10 years. Based on the absence of yew individuals in the height interval of 30–130 cm, the minimum estimated gap corresponding with the lack of recruitment would be 65–80 years. In addition, the majority of yew regeneration above 20 cm showed browsing damage. Therefore, we assume that all individuals, which become visible to deer game, are grazed (Brändli, 2017; Saniga et al., 2017). Relevant records exist in Slovakia that since the World War II (when deer populations were reduced) deer numbers continue to increase beyond historical numbers, despite increasing number of predators. In the study area, a recent 10-year interval (2006–2016) represents 58% increase of red deer and 30% of roe deer populations (*PŠR SR*, 2006, 2016). By preferentially feeding on the selected plant species – yew – ungulates have changed the structure and composition of yew population and overall the diversity of beech forests.

Except for saplings, adults do not show sufficient numbers of individuals in the lowest diameter classes that would declare continuous species regeneration and assure the future presence of the yew in the locality. Lack of relationship between stem damage and crown vitality possibly points out to acute, lethal damage caused by herbivory. Adult yew trees maintained (to a certain degree depending on the competition with neighboring trees) in the past to develop well shaped strong crowns comprising more than a half of the total stem length. However, due to a high degree of herbivory, their crowns suffer from needle loss and are dying (drying) out, lacking tissues for transportation of water and nutrients to needles. Even yews on the steepest slopes (inclination of 37–39°) with parent rocks and reefs present on sampling plots are bark-peeled.

Natural regeneration of yew is relatively abundant in the locality, but the mortality of seedlings older than 10 years is very high. This pattern was also reported by García and Obeso (2003), Farris and Filigheddu (2008), or Iszkuło (2011) in different parts of Europe. Therefore, the establishment of new yew generation is in danger. Due to the shade tolerance of yew, we do not expect that lack of yews in higher height classes is the result of auto reduction or slow growth (Thomas and Polwart, 2003). The main reason is herbivory pressure, which is evident in height increments. Browsed yews have lower height increments regardless the time of herbivory damage, i.e. previous/past damage will significantly reduce the growth rate of yew in further years. Generally, stagnation of height growth because of herbivory damage is a very common sign in young forests (Ammer et al., 2010).

Damage and reduction of height growth could express the apparent competition of other tree species in relation to yew (Ammer, 1996). The deterioration of height growth causes that young yews remain in the lowest height categories, while it is not the same with broadleaved trees (especially the beech). Consequently, the additional lack of light and decrease in competitive ability leads to the degradation of the species diversity of natural regeneration, including the yew.

There are arguments that among others, a) climate change because of patchy distribution of suitable habitat conditions (restriction to calcareous soils) and poor dispersal ability (Thomas and Garcia-Martí, 2015), b) distinctive habitat fragmentation and its shrinking as a consequence of human impact (Thomas and Polwart, 2003; Piovesan et al., 2009), and c) competition with shade tolerant late successional tree species due to lack of light and competitive reduction because of slow growth (Saniga, 2000; Dhar et al., 2008; Ruprecht et al., 2010; Sedmáková et al., 2017) are main drivers responsible for yew decline in many parts of its natural distribution area. Except the above-mentioned factors driving the development of yew populations, we argue that in the selected area, deer browsing and bark peeling has a superior impact on the condition of yew, thus constitutes one of the main negative factors in yew decline. Overall, numerous and dynamically regenerating populations of European yew showing no damage by ungulates are exceptional in Carpathians (Iszkuło et al., 2005; Bodziarczyk and Chachuła, 2008).

The damage by ungulates is often slow and remains overlooked. Currently, populations of yews have received little attention in management and conservation plans. While the impact of climate change and other drivers is uncertain, the negative impact of high deer pressure is unequivocal. Thus reducing the impact of deer herbivory should become the main forest management and conservation strategy. Protecting single trees by mesh guards or protecting parts of forest areas by building fences is desirable, but may not be sufficient in long-term. Therefore, changes in policies to reduce deer populations are necessary. Moreover, even if deer densities would be reduced dramatically, the damage to the adult yew population by deer is enormous and with long-lasting effects (rotten stems and roots). The suggestion that population of ungulates be reduced might generate resistance from both the public and the hunters. However, forest conservationists and managers are not specially trained to communicate such issues to the wide public and government representatives. Without carefully aimed public relations effort and engagement of society and public representatives, the persistence of yew and unique biodiversity of beech forests remain at risk.

In conclusion, despite the presence of large carnivores, the damage of yew trees by bark peeling and browsing is enormous, lethal not only to yew natural regeneration but also to adult yew trees. This points out to the urgent need of conservation action, such as protecting stems by mesh tree guards, building fences to protect natural regeneration and intense game hunting to reduce the population of ungulates.

Acknowledgment

This publication is the result of the project implementation: APVV–14–0014. Authors are thankful to Janka Povaľačová and Ján Hronec for their help in the field.

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Received December 21, 2017
Accepted April 17, 2018