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Stand structure and natural regeneration of *Taxus baccata* at "Stiwollgraben" in Austria

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Abstract: English yew (*Taxus baccata* L.) is a rare tree species in Austria and gene conservation forests reserves are used to maintain English yew populations by silvicultural treatments. This paper describes the current situation of an English yew population at "Stiwollgraben" in Austria with regard to stand structure, vitality and natural regeneration. The area is one of the most important sites in Austria as it consists of 2236 yews. The vitality condition of the yew is very good, and more than 79% of the yews have been assessed as very vital to vital. The potentiality for natural regeneration (13019 one-year seedlings ha^{-1}) is very high, but not all height classes are represented. This indicates a high survival ability of English yew at this site. Three different treatment strategies are described to maintain the yew population. The future effects of these treatments are discussed in the light of the environmental requirements of English yew.

Keywords: Forest management, gene conservation forest, population structure, vitality, yew decline.

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Introduction

The English yew (*Taxus baccata* L.) is one of the most ancient European tree species, with origins reaching beyond 2 million years ago into the late Tertiary period (Dovciak, 2002). Although the yew rarely forms pure forest stands, only a few centuries ago it was an integral part of forests throughout much of Europe, ranging from as far north as Scandinavia all the way to the Mediterranean, and from as far west as North Africa all the way to Turkey and the Caucasus mountains. The yew is also one of Europe's slowest growing and longest living tree species, sometimes reaching over 3000 years (Pridnya 2002) in age but declining sharply over most of its range (Tittensor 1980; Hulme 1996). During the last 5000 years human land-use has reduced the area of temperate forest in Europe and changed the structure and species composition of the remaining fragments (Svenning and Magard 1999). English yew is negatively affected by this ongoing processes and the species is in danger of extinction in Europe as well as all over the world. Natural regeneration of the yew in temperate regions appears limited by both seed predation pressure and the scarcity of microsites for recruitment (Hulme 1996; Wilson et al. 1996). Moreover, this tree species is frequently damaged by herbivores (Tittensor 1980).

The yew is a rare tree species in Austria as well (Niklfeld 1999; Schadauer et al. 2003; Russ 2005). The reasons for the decrease of the yew population refer to the over use in the past centuries. The yew was exported to England as much desired wood for cross bows and was heavily reduced in the last century by man because of the risk domestic animals being poisoned by eating parts of the yew (specially horses).

Other reasons are related to an unsuccessful natural regeneration of yew due to browsing by deer (Scheeder 1994; Meinhardt 1996) or shading by beech (Meinhardt 1996). The information on the stand history is scarce, the majority of the stands originated from natural regeneration. The gene conservation forest network in Austria is used to maintain the biodiversity of tree populations (Müller and Schultze 1998). English yew (*Taxus baccata* L.) populations are described for 13-gene conservation forests in Austria with a total area of 232.4 ha (Herz et al. 2005). The primary focus of this conservation category is the *in-situ* conservation of rare tree species by silvicultural treatments (Frank and Müller, 2003). There are a limited number of studies on the management of yew populations in gene conservation forests until now (e.g. Vacik et al. 2001). We want to compare the environmental situation for different yew populations in Austria in order to adapt the management activities in these gene conservation forests. The aim of the present study was to characterize the site conditions, stand structure and regeneration in the most recently identified site at "Stillwollgraben" in Austria before and after the implementation of conservation activities, in order to provide basic data for further genetic studies. In this contribution we want to present first results of this study.

Materials and methods

Location and site characteristics

The gene conservation forest of "Stiwollgraben" is located in the southern part of the Austrian Federal State Styria. The site is almost 20 kilometres north-west from the city of Graz (Fig. 1) and has a size of 4.55 ha. The area is privately owned and belongs to the community of Gschnaidt. The longitude and latitude of this place are 15°11'48? and 47°07'50?, respectively. The area belongs to the ecoregion "Eastern and central hilly region of Styria" at the submontane vegetation belt (Kilian et al. 1994). The slope of the site is 53% to 75%, the exposition is west and the elevation is 580 to 700 m a.s.l. The site is dominated by an irregular micro relief with cambisols covered with a mull/moder humus layer and an inhomogenic soil depth (30–120 cm). The water balance is moderate fresh. The annual average rainfall and temperature are 1060 mm and 7.7°C, respectively (Station: Pleschkogel, 910 m, Ref: Hyrographischer Dienst 2000–2004).

The pole stand is characterized by a mixture of *Fagus sylvatica* L., *Picea abies* L. Karsten, *Pinus sylvestris* L., *Taxus baccata* L., *Larix decidua* Miller as well as some *Abies alba* Miller, *Acer pseudoplatanus* L., *Ulmus glabra* Hudson, *Fraxinus excelsior* L. and *Sorbus aria (*L.) Crantz. The regeneration is dominated by *Picea abies* L. Karsten, *Taxus baccata* L., *Fagus sylvatica* L., *Acer pseudoplatanus* L. and *Fraxinus excelsior* L.

The area is under the supervision of the district forest authority of Graz. The local foresters have carried out several experiments in order to maintain the yew population at this site. For examining the effects of different treatments, the foresters performed three different thinning operations in March and April 2005. There were intensive thinning (T I) with a removal of 55% of the stocking volume, a moderate thinning (T II) with a removal of 27% of the stocking volume and a third variant with no thinning (T III).

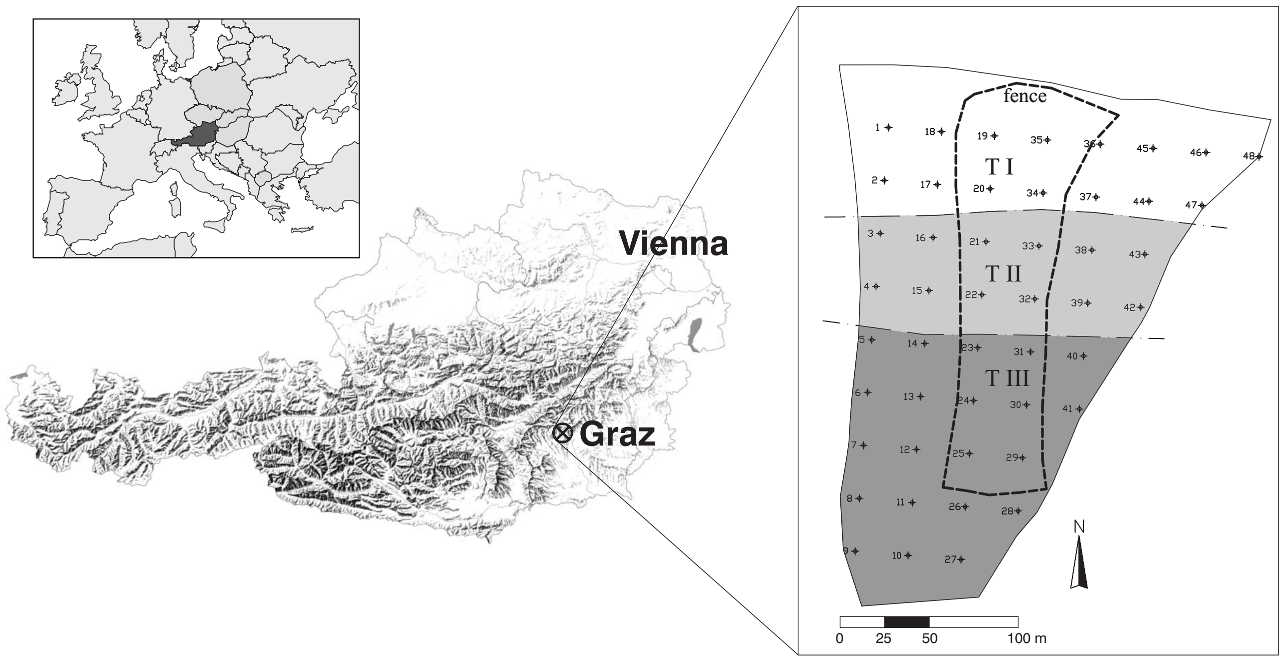

Fig. 1. The location of the *Taxus baccata* L. population at "Stillwollgraben" in Styria, Austria

Table 1. Stand characteristics according to different treatments

Treatment	Area [ha]	Total tree [n ha^{-1}]	Tree basal area [m^2 ha^{-1}]	Tree volume before cutting [m^3 ha^{-1}]	Tree volume after cutting [m^3 ha^{-1}]	Standing dead wood [m^3 ha^{-1}]
T I	1.63	648	17.77	403	173	9
T II	1.16	1398	34.13	530	354	32
T III	1.76	882	30.99	321	321	0
In total	4.55	959	27.54	418	282	13

T I – intensive thinning, T II – moderate thinning, T III – no thinning

Some of European beach trees have been treated as "Ringelbaum" (stop growth by cutting the phloem fibre with a chainsaw) and have not been removed from the site. To identify the negative effects of selective browsing a fence was established on a part of the experimental area. The fenced area is almost 1.31 ha and includes all three treatments (T I: 0.49 ha, T II: 0.37 ha and T III: 0.45 ha) out of 4.55 ha in total (compare Fig. 1 and Table 1).

Experimental design and data collection

A regular grid of permanent sample plots (marked with an iron stick) was set up for the monitoring of the yew population (30 × 30 m). On every sample plot an angular count method was performed to investigate stand data (e.g. growing stock, basal area, stand structure). Site characteristics (e.g. soil, relief, water balance) were described for each plot. All living individuals of English yew (DBH ≥ 5 cm) were marked with a small aluminium tag. From each yew the tree height, Diameter at breast height (DBH), crown length, crown foliage, vitality class, height class, growth form (e.g. straight, curved, forked, complex stem), stem damages and the origin were estimated. Four different types of damages were identified according to the age of damage (old, new) and the impact (moderate: 1/4 of the perimeter, until 25 cm long; strong: more than moderate).

In total 48 plots were sampled in the area of the gene conservation forest (14 plots inside the fence and 34 outside the fence). For calculating the natural regeneration every sample plot was split into four satellite plots according to each cardinal point (north, east, south and west).

The natural regeneration was investigated according to three different height classes (< 30 cm, 30–50 cm and 51–150 cm) by means of three circular plots with various sizes (1st circle with a radius of 0.5 m; 2nd circle with 1.6 m; 3rd circle with 3.2 m). All seedlings, juveniles at two and more years and up to 30 cm height were sampled at the 1st circle, all individuals from 30–50 cm and 51–150 cm height at the 2nd circle and all individuals from 150 cm height up to 4.9 cm DBH at the 3rd circle.

To examine the relationship between yew regeneration and stand structure, canopy closure and vegetation cover were estimated for each subplot.

Classification and calculation of English yew's vitality

In order to assess the vitality of each individual yew the parameters percentage of the living crown, the foliage density and the crowns formation have been determined instead of a qualitative judgement of the vitality through subjective impression (compare Table 2).

Results

Stand structure

The present pole stand (after thinning) is composed of *Fagus sylvatica* (34%), *Picea abies* (23%), *Pinus sylvestris* (15%), *Taxus baccata* (12%), *Larix decidua* (11%) and *Abies alba, Acer pseudoplatanus*, *Ulmus glabra*, *Fraxinus excelsior* and *Sorbus aria* (5%) with respect to basal area.

Total 2236 individual trees of English yew with DBH ≥ 5 cm were found in the gene conservation for-

Table 2. Classification scheme for the vitality of *Taxus baccata* L.

Vitality class	Attributes		
	percentage of living crown	foliage density	crowns formation*
A (very vital)	> 70 %	> 90 %	1 or 2
B (vital)	50–70 %	75–90 %	1 or 2
C (less vital)	30–50 %	< 75 %	1, 2 or 3
D (the least vital)	< 30 %	< 75 %	1, 2, 3 or 4

*1 = universally, strong crown, 2 = weakly developed, constricted crown, 3 = undeveloped, most unilaterally, clamped crown, 4 = almost dying crown

Table 3. Characteristics of the *Taxus baccata* L. population according to treatments

Treatment	Tree ≥ 5 cm DBH [n ha^{-1}]	Basal area [m^2 ha^{-1}]	Tree volume [m^3 ha^{-1}]	Ave. tree height [m]	Ave. DBH [cm]	Ave. canopy closure [%]	Ave. leaf density [%]	Ave. crown [%]
T I	423	2.77	15.4	5.9	8.8	74	82	62
T II	662	4.13	24.8	6.5	8.6	76	80	62
T III	443	2.99	17.9	6.6	8.9	94	79	63
In total	492	3.20	18.8	6.3	8.8	84	81	62

T I – intensive thinning, T II – moderate thinning, T III – no thinning

Table 4. Vitality classes of *Taxus baccata* L. according to treatments

Treatment	Vitality classes			
	A very vital [%]	B vital [%]	C less vital [%]	D the least vital [%]
T I	31.2	46.2	19.3	3.1
T II	29.7	49.8	17.4	3.1
T III	36.1	44.1	15.7	4.1
In total	32.4	46.8	17.4	3.4

T I – intensive thinning, T II – moderate thinning, T III – no thinning

est. Among them 689 trees belong to the area of the 1st treatment (T I), 768 to the 2nd treatment (T II) and 779 to the 3rd treatment (T III). The maximum tree height and DBH were 14.4 m and 24.8 cm respectively. Tree height ranged from 1.55 m to 14.4 m. similarly counted DBH from ≥ 5 cm to 24.8 cm. In relation to the yews the top height of the dominating tree species is on the average 28.1 m. The highest density of yews (662 trees ha^{-1}) was found in the T II (compare Table 3).

With regard to the stand structure most of the yews (97.81%) belong to the third tree layer and only very few (2.19%) to the second tree layer (classified according to the individual crown length in relation to the top height). Nine percent (9%) of all individuals have been assigned as complex stems and 19% have been assigned as forked trees. Seventy-five percentages (75%) of all yews are originated from seed and 25% from sprouting.

Regarding the damage, 42.41% of the yew population was assigned as damaged. Among these 133 (14%) yews were damaged during the recent thinning operation. The highest number of damaged trees was observed in T I (47%), and T II (46%), whereas the lowest number of damaged trees was found in T III (34%) where no thinning was done. No biotic damages could be identified in the gene conservation forest. The highest canopy closure was found in T III (94%), which indicates more or less the canopy closure before the implementation of the thinning operation.

It was observed that 32.4% of all trees belong to the vitality class A, 46.8% to the vitality class "B" and the rest was classified as less or the least vital (20.8%) (Table 4). The vitality classes according to the diameter distribution are shown in Fig. 2. At lower diameter classes all vitality categories were represented and only a minority of trees were estimated as very vital (A). With higher diameter classes almost no tree was classified as less or very less vital.

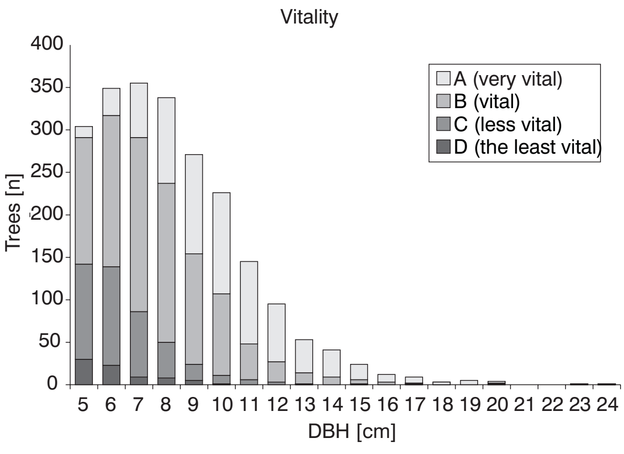

Fig. 2. Vitality classes of *Taxus baccata* L. according to diameter distribution

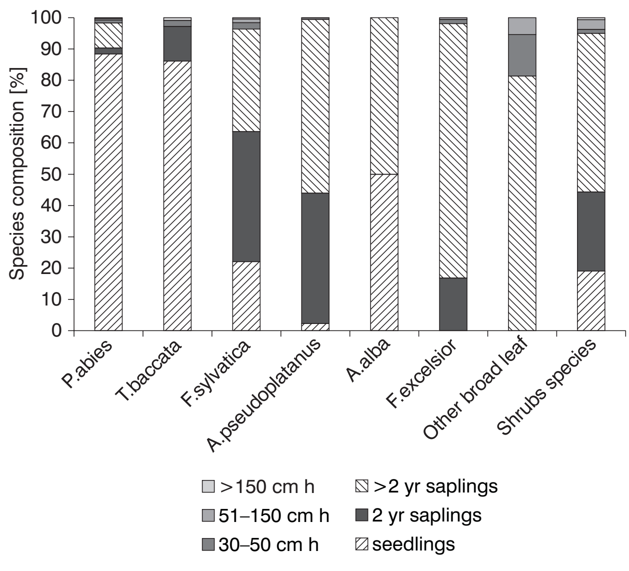

Fig. 3. Percentage of tree species in natural regeneration of the gene conservation forest

Natural regeneration

The total amount of natural regeneration at the gene conservation forest was 51541 n ha^{-1}. The natural regeneration was dominated by *Picea abies* (35%), *Taxus baccata* (29%), *Fagus sylvatica* (22%), *Acer pseudoplatanus* (6%), *Fraxinus excelsior* (5%) and some individuals of *Abies alba*, other broad leaf species and shrubs (3%). The natural regeneration can be classified according to the categories; seedlings (62.1%), 2 year old juveniles (18.5%), > 2 years (17.5%), 30–50 cm height (0.9%), 51–150 cm height (0.5%), > 150 cm height and up to 4.9 cm DBH (0.5%) (compare Fig. 3).

The differences regarding the tree mixture and number of individuals' ha^{-1} among the three treatments were small (Fig. 4). The estimated density of English yew natural regeneration is about 13019 n ha^{-1}. An enormous number of seedlings can be found in all three treatments (8338, 10523 and 17614 seedlings ha^{-1} in the treatment no I, II, and III respectively). However, the average number of survived saplings decreases and turns to zero within the height classes 30–150 cm (Fig. 5). It is also mentionable that we did not observe any yew sapling > 2 years in treatment I. The taller yew poles of the category "individual > 150cm height" can be estimated with a density of 227 n ha^{-1}. In this category the tree species *Taxus baccata* (60%), *Fagus sylvatica* (19%), *Picea abies* (17%), *Sorbus aria* (3%) and *Acer pseudoplatanus* (1%) were identified.

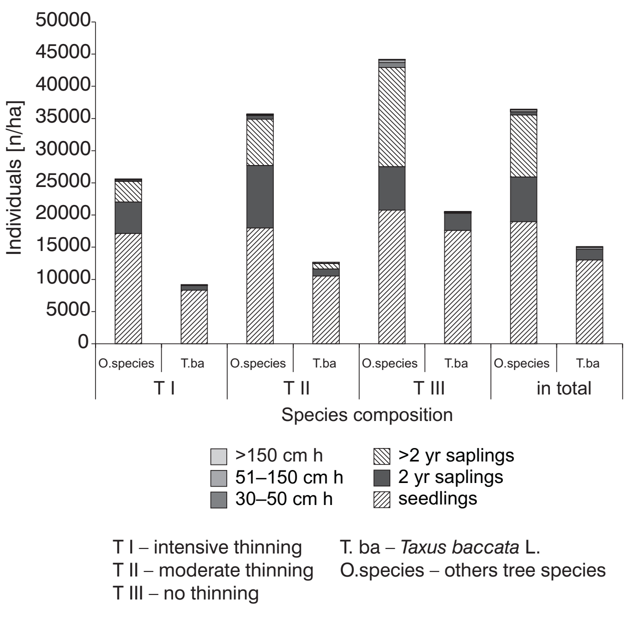

Fig. 4. Number of individuals of all tree species in the natural regeneration according to height classes and treatments

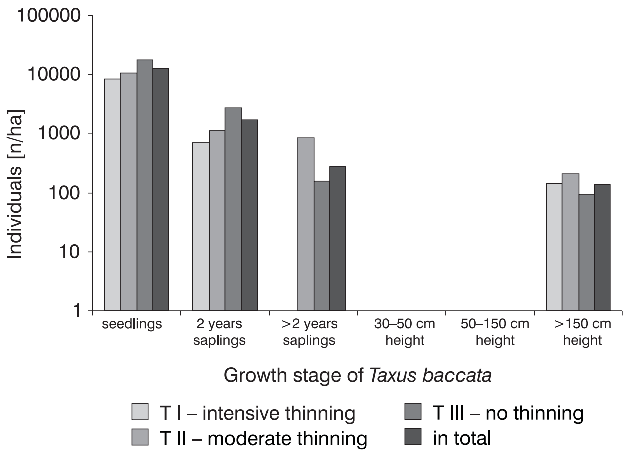

Fig. 5. Number of individuals of *Taxus baccata* L. in the natural regeneration according to height classes and treatments (logarithmic scale)

Discussion

The large number of yews (492 ha^{-1} at DHB $\geq$ 5 cm) and natural regeneration (13019 ha^{-1}) in the gene conservation forest indicate good conditions for reproduction and growth at "Stiwollgraben" in relation to other populations in Austria (Oitzinger 2000; Tod 2004; Herz et al. 2005) The present site (West exposition, sub mountainous region, cambisols, fresh water balance) and climatic conditions (temperate climate) allow high growth and reproduction rates of English Yew. Cambell (1993) reported that water availability increases the total number of trees per hectare. Also the shade tolerance of yews allows growth under strong shade conditions (Lilpop 1931; Krol 1978; Brzeziecki and Kienast 1994). However, the reproductive activity and recruitment of yew can be enhanced by better light availability (Svenning and Magard 1999; Saniga 2000) which is related to the over story density, basal area and species composition (Pacala et al. 1993). We had found 14 different tree species mixed with *Taxus baccata*. The present tree species have different specific environmental requirements depending on light conditions, early growth rates or seed production. Therefore the competition between these species is an importance factor for the viability of the yew population. Saniga (2000) observed that a removal of 18–20% of the standing volume (especially *Fagus sylvatica* and *Picea abies*) reduces the competition between the species, which allowed an increase of the average height of the yew population. On the other hand, Iszkulo (2001) reported that a rapid change in light conditions or a sudden increase of light intensity and temperature are causes of yew death. In this context the long term observations of the effects of the different thinning operations in this gene conservation forest should help to identify an optimal strategy to increase the growth and reproduction rates of yew.

Vitality is an important attribute to assess the condition of the trees regarding the viability of the total population. The vitality condition of the yew population at "Stiwollgraben" is good. More than 79% of the yews have been assessed as very vital to vital. Thus vitality level is better compared to other studies on *T. baccata* populations in Austria. For instance Vacik et al. (2001) reported that more than 50% of trees belong to the less vital to the least vital class. However, the vitality condition is increasing with an increase of the diameter class. This indicates that the younger parts of the population are less vital than the older individuals. So need of thinning operations to reduce the competition among yew and the main tree species in the gene conservation forest is evident in that perspective. A large number (42.41%) of yews had visible injuries. Among these 14% (5.9% of the total population) of the trees were damaged during the recent thinning operations. Until now, almost no interaction can be found between vitality condition and damages of the yew population. However, it might be important to communicate guidelines of good practice for harvesting operations in gene conservation forests for the future.

It is interesting to note that saplings higher than 30 cm were not found at the gene conservation forest even though 13019 one-year-old seedlings ha^{-1} were estimated. A similar pattern regarding the occurrence of natural regeneration of yew can be found in another gene conservation forest in Austria described by Oitzinger (2000). There are several causes related to that aspect. The quantity of relative solar radiation at the forest is important for the reproduction and growth of yew. As the canopy closure for the observed regeneration plots was very high before the implementation of the silvicultural treatments it might be concluded that the level of solar radiation for seedling survival was too low (compare Table 3). For some tree species a low level of solar radiation (2–3% solar radiation of open areas) is sufficient for seed germination to next 2–3 years but not sufficient for seedling survival over the next few years (Evstivgneev et al. 1992; Svenning and Magard 1999; Pridnya 2002). Iszkulo and Boratynski (2006) observed seedlings can survive below 2% photosynthetic photon flux density (PPFD) for 2-3 years but the light demand is increase with the age. Therefore light deficiency can be considered as a main reason for seedling mortality (Boratyński et al. 1997; Krol 1975; Thomas and Polwart 2003; Iszkulo and Boratynski 2006 and Iszkulo et al. 2001). The different amount of standing volume removed with the two thinning methods will help us to identify the importance of the different amounts of solar radiation for the survival of the yew regeneration. The monitoring of the survival rate of the yew individuals will allow sound recommendations for future conservation activities.

However, it can be assumed that selective browsing is the main reason for the loss of yew saplings even though yew might be considered as cutting tolerant in general. Kelly (1975) describes that *Taxus baccata* is one of the most browsing sensitive trees in the Irish Killarney woodlands. Browsing of seedlings by rabbit and deer and seed predation by rodents is recognized to be a main causes for the lack of seedling establishment (Watt 1926; Williamson 1978; Kelly 1981; Mitchell 1988; Haeggström 1990; Hulme 1996; Hulme and Borelli 1999; Saniga 2000). The long term monitoring of the growth of yew regeneration within and without the fences and the different thinning experiments will help to increase our knowledge about the impact of selective browsing.

A strong negative influence by the adults of *T. baccata* on seedlings establishment was not observed at this site (Thomas and Polwart 2003; Krol 1975; Williamson 1978; Tittensor 1980). The high number of yews at a DBH ≥ 5 cm has no negative influence on the establishment of seedlings.

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