Biodiversity of English yew (*Taxus baccata* L.) Populations in Austria

a PhD thesis

by

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Dedicated

To

My Beloved Parents

Preface

The core part of this thesis consists of five-pre-reviewed papers published in scientific journals (or submitted), which are added in the appendix of this work. A table regarding the possible timeline and status of the manuscript in the scientific publication process are given in section 8.6 (Appendix). The initial text describes the research concept and the major findings of the work. A detailed description of the research methodology and findings can be found in the respective papers.

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The author

Abstract:

English yew (*Taxus baccata* L.) is a native evergreen non-resinous gymnosperm long living dioecious, conifer tree species. It is one of the ancient European tree species and only a few centuries ago it was an integral part of forests throughout Europe. Human interventions and changes of the land-use system by modern technologies changed the structure and species composition of the temperate forests in Europe. The English yew populations are negatively affected by this process and decreased in most of their ranges though out Europe. Although yew is getting priority for conservation activities as an endangered tree species in Austria the knowledge about conservation management is scarce. The aim of this research was to characterize selected yew populations from different geographic locations in Austria in order to study their biodiversity with respect to stand and genetic structure as well as to develop a conservation and management action plan. The stand structure of yew forests was illustrated with regards to different tree attributes (tree height, DBH, crown length, damage, vitality) and stand characteristics (mingling, vertical and horizontal structure). The genetic variation was described according to genetic traits by using isozyme gene marker. All these characteristics were used to describe the viability of yew populations. The Population Viability Risk Management (PVRM) framework was used to develop proper conservation and management actions by analyzing the current ecological and environmental condition. The Analytical Hierarchy Process (AHP) as part of the PVRM framework was used to evaluate different conservation strategies for selecting an appropriate management strategy with regards to the viability of yew. It was found that Austrian yew populations have shortcomings in certain regeneration classes although most of the forests showed abundant number of one-year seedlings. Considering the tree vitality of the adult yews the results indicate that the vitality is influenced by the inter-specific competition of the neighbouring tree species. The yews with the lowest vitality are indicating the smallest mean distance and highest tree height differentiation to its neighbours. For the analysis of the genetic structure 9 isozyme gene loci were investigated. English yew showed a high level of genetic variation (*He* = 0.274 and *Ho*=0.238) with a medium level of inbreeding (0.130). The overall most significant risk factors for the viability of the population are browsing, tree competition, light availability, illegal cutting, and less people awareness. The PVRM framework allowed to evaluate six conservation strategies through a qualitative assessment of the probability for a decrease of the yew population along with four different environmental scenarios. In this context a management strategy combining selective thinning, protective measures, wild life management and public relation activities seems to be the most appropriate conservation activity for yew populations in Austria.

Key words: Stand structure; regeneration; structural diversity; Genetic variation; Isozyme; conservation management; population viability; Analytic Hierarchy Process

Kurzfassung

Eibe (*Taxus baccata* L.) ist eine einheimische immergrüne zweihäusige Nadelbaumart. Die sehr langlebige Art war vor wenige Jahrhunderten ein wesentlicher Bestandteil der europäischen Wälder. Der menschliche Einfluss und Änderungen in der Landnutzungsform durch moderne Technologien haben die Struktur und Baumartenzusammensetzung der gemäßigten Wäldern in Europa verändert. Eiben Populationen wurden durch diesen Prozess negativ beeinflusst und ihr Vorkommen ist meist stark eingeschränkt worden. Obwohl die Eibe in Österreich als gefährdete Baumart behandelt wird, sind Kenntnisse über notwendige Erhaltungsmaßnahmen gering. Das Ziel dieser Forschungsarbeit war, 7 Eibenpopulationen aus verschiedenen Regionen Österreichs hinsichtlich ihrer biologischen Vielfalt und genetischen Struktur zu charakterisieren und Maßnahmen zur Erhaltung zu entwickeln. Die Bestandesstruktur der Eibenwälder wurde anhand ausgewählter Baummerkmale (Höhe, BHD, Kronenlänge, Schäden, Vitalität) und Bestandesmerkmale (strukturelle Vierergruppe) erfasst. Die genetische Variation der Eiben wurde anhand von genetischen Markern durch eine Isoenzym-Analyse beschrieben. Die erhobenen Merkmale wurden verwendet, um die Überlebensfähigkeit der Eibenpopulationen zu beschreiben. Das Population Viability Risk Management (PVRM) Konzept wurde eingesetzt, um auf Basis der aktuellen ökologischen und umweltrelevanten Bedingungen geeignete Strategien zur Erhaltung der Populationen zu identifizieren. Der Analytic Hierachy Process (AHP) wurde im Rahmen des PVRM Konzepts benutzt, um verschiedene Erhaltungsstrategien zur Steigerung der Überlebensfähigkeit der Eibe zu analysieren.

Es zeigte sich, dass bei den untersuchten Eiben Populationen nicht alle Höhenklassen der natürlichen Verjüngung vertreten sind, obwohl ausreichend Keimlinge vorhanden sind. Die Vitalität der adulten Eiben wird durch die interspezifische Konkurrenz, den mittleren Abstand zu den unmittelbaren Nachbarn und deren Höhendifferenzierung beeinflusst. Für die Analyse der genetischen Struktur wurden 9 Isozym Genorte untersucht. Die Eibe zeigte eine hohe genetische Variabilität (*He* = 0,274 und *Ho*=0.238) mit einer mittelmäßigen Tendenz zur Inzucht (0.130). Die bedeutsamsten Risikofaktoren für die Überlebensfähigkeit der Population sind Verbiss der Naturverjüngung, interspezifische Konkurrenz, Lichtökologie und der Faktor Mensch in Form von illegalen Nutzungen und geringem Bewusstsein. Das PVRM Konzept erlaubte die Evaluierung von sechs Erhaltungsstrategien durch die Beurteilung der Wahrscheinlichkeit für die Abnahme der Population im Zusammenhang mit vier Umweltszenarien. Dabei hat sich eine Erhaltungsstrategie, welche unterschiedliche Maßnahmen (Auslesedurchforstung, Schutzmaßnahmen, Habitatmanagement und Öffentlichkeitsarbeit) kombiniert, am geeignetsten zur Sicherung der Überlebensfähigkeit von Eibenpopulation erwiesen.

Schlagwörter: Bestandesstruktur; Naturverjüngung; Strukturvielfalt; genetische Vielfalt; Isoenzyme; Naturschutz; Überlebensfähigkeit von Populationen; Analytic Hierarchy Process

Table of contents

List of tables

List of figures

1. Introduction

The English Yew (*Taxus baccata* L. Taxaceae) is one of the most primeval tree species in Europe. Spjut (2000) mentioned that *Taxaceae* was radiated from the southwest China and evolved into several species in Europe by the Tertiary period. He concluded that *T. baccata* arose from hybridisation between an extinct Russian species (*T. contorta*) and Tertiary relics spreading north from North Africa. From the Pollen records it was observed that *Taxus* was present in Europe during previous interglacial periods, starting with the Cromerian (450 000–700 000 yr BP) (Srodon 1978) but was in maximum abundance in the warm, oceanic climate of the Hoxnian, 367 000– 400 000 yr BP (West 1962). In the past centuries yew was over exploited for different purposes in Austria. The huge amount of yew was exported from Austria to England for preparing crossbows in the middle age to late 18th century. It was heavily removed in the last century by man due to the risk of domestic animals especially horses being poisoned by eating parts of the yew.

There are many archaeological records of the use of yew from Neolithic to Roman as, for example, spears, axe shafts and bows. Yew pegs were also used as fastenings for the Neolithic track ways in the Somerset levels, and more esoterically, yew wood was used to sew together the timbers in the 'sewn boats' (Wright and Churchill 1965). Its tough and long lasting timber was used for buildings and the high aesthetic appeal made yew a popular decorative material (Dovciak 2002). Its bark and needles have been using as a anti cancer medicine containing the chemical Taxol which is the best natural sources for cancer treatment (Witherup *et al.* 1990) however, English yew has been also using as medicine in the Unani system of medicine science since hundreds of years in the India (Anon. 1976).

The geographic distribution of English yew is in the north up to 61° N latitude in Scandinavia and in the south to Iberian Peninsula, vertically up to 2300 m elevation in the Caucasus (Vidakovic 1991) and about 1400 m in the Alps (Schweingruber 1993). It is scattered throughout Europe (Bolsinger and Llody 1993), northern Africa (Sauvage 1941) and the Caspian region of southwest Asia (Mossadegh 1971).

English yew is often found mixed with deciduous and conifer forests in Europe. This species is restricted to the mountain areas following the climatic regression after the Ice Age. As a result of the climatic change and human interventions the area of temperate forest in Europe were reduced and structure and species composition of the remaining fragments changed (Svenning and Magard 1999). This ongoing process has negatively affected English yew and causes the extinction from most of its ranges. The main reasons for the decline of yew are widespread deforestation, light competition, selective felling and browsing by herbivore (Bugala 1978; Tittensor 1980; Haeggström 1990; Jahn 1991). It is very vulnerable to browsing and barks stripping by rabbits, deer and domestic animals such as sheep and cattle (Kelly 1975; Haeggström 1990) in spite of its poisonous properties. In fact, it is one of the most grazing sensitive trees (Kelly 1975) and a densely deer populated area has a strong negative effect on its recruitment and adult endurance (Kelly 1981, Mitchell 1988). Another most important factor is light, although yew is shade tolerant (Kórl 1978, Brzeziecki and Kienast 1994). Seedlings and saplings often die or show poor growth when yew grows underneath the shelter of beech (Czatoryski, 1978, Pridnya 1984). Other factors influencing the viability of yew are (1) adverse soil condition, (2) loss of genetic variation (Bugala 1978), (3) illegal cutting and lack of people awareness, (4) unfavourable site conditions (Thomas and Polwart 2003) (5) damages caused by fungi (Strouts 1993) and insect pests which restrict the yew recruitment. At present yew is a rare and endangered tree species in Austria as well (Niklfeld 1999; Schadauer *et al.* 2003; Russ 2005) with restricted occurrence due to human activities, over uses in the past, browsing pressure, unsuccessful regenerations (Scheeder 1994; Meinhardt 1996).

Genetic diversity is the basis of the overall biological diversity because it provides raw materials for adaptation, evolution and survival of species and individuals in the changing environmental condition. From different studies (e.g., Bergmann *et al.* 1990; Raddi et al 1994) it was suggested that a reduction of genetic diversity could predispose forests species, which are therefore more vulnerable.

Studies on the genetic variation of yew are important to compare the actual condition of yew in Austria with other studies in Europe as well as for the development of proper management strategies. An amazing development has been taken place on the studies of genetic variation in last two decide owing to the application of electrophoretic techniques in population genetics. Studies on the genetics of forest trees have been performed using different categories of simply inherited traits: morphological markers, monoterpene variants and isozyme gene markers as well as molecular markers. Isozymes are cost efficient tools, relatively easy to handle and particularly recommended for genetic diversity studies (Glaubitz and Moran 2000) although it has some limitation in loci detection systems. However, isozymes are still important markers (Müller-Starck *et al.* 2005) and competitive to molecular markers like AFLPs or RFLPs (Nybom 2004). There are numerous publications reporting on genetic variation of forest tree species, but papers addressing yew are very rare. It is also mentionable that studies regarding the genetic variation of English yew using isozyme gene marker in Austria are not yet done. Some studies from Northern Germany (Hertel 1996, Cao *et al.* 2004; Leinemann and Hattemer 2006), Switzerland (Hilfiker *et al.* 2004) or Poland (Lewandowski *et al.* 1992) provide some basic information on this rare dioecious conifer species in Europe. Those first studies reported on a surprising high level of genetic variation even for small relict populations.

Populations of slow growing long living plants like English yew typically received little attention in the past. Due to less awareness, this species is now catalogued as a rare and endangered species prone to extinction from all over Europe (Thomas and Polwart 2003). There are two general conservation strategies for slow growing long living species, which are rare and endemic in small geographic areas. On the one hand most plans for management of such species have focused on protection measures with the goal of protecting established individuals (Cardel *et al.* 1997). Secondly, the conservation efforts have focused on the reinstitution of ecological processes, which are important for recruitment of new individuals. These efforts promote successful regeneration and increase the genetic diversity on the long run (Barrett and Kohn 1991). However, these two conservation strategies may not be sufficient if a population of slow growing, long living plants are predicted to be in long term decline (Kwit *et al.* 2004).

Though English yew is one of the priority species for nature conservation in Austria, there is lack of research interest for developing proper management strategies for this species. So, there is a need to conduct research activities in order to develop conservation management strategies. In conservation sciences Population Viability Analysis (PVA) is one of the powerful and pervasive tools and has become a commonly used method in the management of endangered species. In general PVA includes any systematic attempt to understand the process that makes a population vulnerable to extinction (Malcom and Hunter, 2002). On the other hand Population Viability Risk Management (PVRM) provides a framework for explicitly including uncertainty about the possible outcomes of a management decision with regard to the viability of a population (Marcot and Murphy, 1996). At the primary stage the PVRM concept was used for the management of endangered wild life populations but it has been applied for the conservation of endangered plant species from the early nineties decade (Menges, 1990; Vacik *et al.* 2001, Abiyu *et al.*, 2006). Decision making about how to manage the endangered species is often difficult for forest managers. So, decision analysis methods, which have been originally developed for guiding business decisions under uncertainty can be applied for the management of endangered species (Maguire 1986). Multi Criteria Decision Making (MCDM) is a decision-making technique that allows the rigorous selection of the most preferred choice in a context where several criteria apply simultaneously. The Analytical Hierarchy Process (AHP) is a MCDM technique, which enables the pair wise comparison of different management alternatives with respect of single decision criteria based on a ratio scale. Now a day AHP is extensively applied in many fields, including multi-objective forest management (see Mendoza and Prabhu 2000, Kangas and Kangas 2002) and conservation management aspects (Kangas and Kuusipalo, 1993; Abiyu *et al.*, 2006). It is of interest to find out how the AHP can be used to select the best management alternative within a PVRM framework.

The gene conservation forest network in Austria maintains different endangered tree species in various gene conservation forests (Müller and Schultze 1998). There are 13 English yew gene conservation forests in Austria with a total area of 232.4 ha (Herz *et al.* 2005). The primary focus of this conservation network is the *in-situ* conservation of this rare tree species by silvicultural treatments (Frank and Müller, 2003). Considering the yew populations in Austria, the majority of the stands originated from natural regeneration. The information regarding the stand history of English yew populations, the environmental conditions and the appropriate conservation measures to maintain the species at risk are scarce; previously only one study has been carried out (compare Vacik *et al.* 2001). Therefore a study is needed to increase our knowledge related to the conservation management of English yew populations in Austria.

2. Research Objectives

The overall aim of this study was to investigate the biodiversity of English yew populations in Austria. The assessment was based on the analysis of the current ecological condition, the environmental requirement as well as stand and genetic structure, which lead to develop and select appropriate conservation management strategies for this endangered species.

The main objectives of this study are given below-

1. To characterize the current ecological condition, population structure and regeneration of English yew in Austria.
2. To compare the structural diversity of English yew populations for assessing the effects of inter-specific and intra-specific competition in relation to the viability of yew.
3. To estimate the level of genetic variation and diversity of Austrian yew populations at different geographic locations.
4. To propose possible conservation and management strategies by using the Population Viability Risk Management (PVRM) framework.

A major focus of this study (Paper 1 and 2) was to characterize the site conditions, stands structure and regeneration status of *Taxus baccata* populations for understanding the specific environmental requirements in relation to the vitality of a yew population. Therefore a detailed investigation concerning the different tree attributes (e.g. tree height, DBH, growth form, crown formation, crown length) had to be carried out. The initial results regarding the study site "Stiwollgraben" were presented in paper-1 (see Appendix -1) and a comparative study on two gene conservation forests (Stiwollgraben and Bad Bleiberg) was published in paper – 2 (see Appendix - 2).

The study regarding the quantification of the structural diversity (paper-3) identifies the effects of inter-specific and intra-specific competition on the viability of English yew. It is important to consider competition and structural parameters in conservation planning for improving the management of gene conservation forests especially for endangered tree species like English yew. The main objectives of the contributions in paper (3) were to compare the ecological condition of three English yew populations and to link the vitality of English yew with selected components of structural diversity (see Appendix-3).

It is important to understand the genetic structure of yew for the development of a proper conservation management strategy in relation to modern conservation sciences, but genetic information considering the Austrian yew populations are missing till now. So paper (4) is dealing with the genetic structure of 7 yew populations from different geographic locations, which describes the pattern of genetic structure and geographic differentiation of this tree species. (see Appendix-4).

The last paper (5) is based on the conservation and management of an English yew population. In this contribution the Analytical Hierarchy Process (AHP) was used as part of a population viability risk management (PVRM) framework for the selection of a management strategy. It has the flexibility to evaluate different conservation plans in order to maintain the viability of species and allows to identify appropriate courses of action. The viability for the English yew population was assessed based on the results of previous studies (see papers 1, 2, 3 and 4) for selecting a compromise solution for *in-situ* conservation. Based on this PVRM framework the operational plan has been designed for Stiwollgraben (see Appendix-5).

3. Materials and Methods

3.1 Characterisation of the study areas

In this study 7 populations have been selected from different geographic locations in order to study the Biodiversity of English yew populations in Austria (see Table-1 and Fig-1). Among them three populations (Stiwollgraben, Bad Bleiberg and Mondsee) were used for a detailed ecological analysis of the stand characteristics, the natural regeneration and the current ecological conditions as well as for the data investigation for the genetic analysis. Other 4 populations (Almtal, Hirschwang, Losenstein, Piesting) were included in this study for the analysis of the genetic variation of yew populations in Austria. Within these studies two students Oitzinger (2000) at Bad Bleiberg and Aigner (2007) at Mondsee worked on the population structure of this two populations during their master thesis. The data of these two studies were used in this study as well. At Stiwollgraben management activities have been implemented in order to study the long-term effects of the conservation activities.

Detailed geographic and climatic information regarding the 3 locations Stiwollgraben, Bad Bleiberg and Mondsee are given in paper 3. Although detailed descriptions about the other 4 locations are not completed but some basic information are given in Table 1.

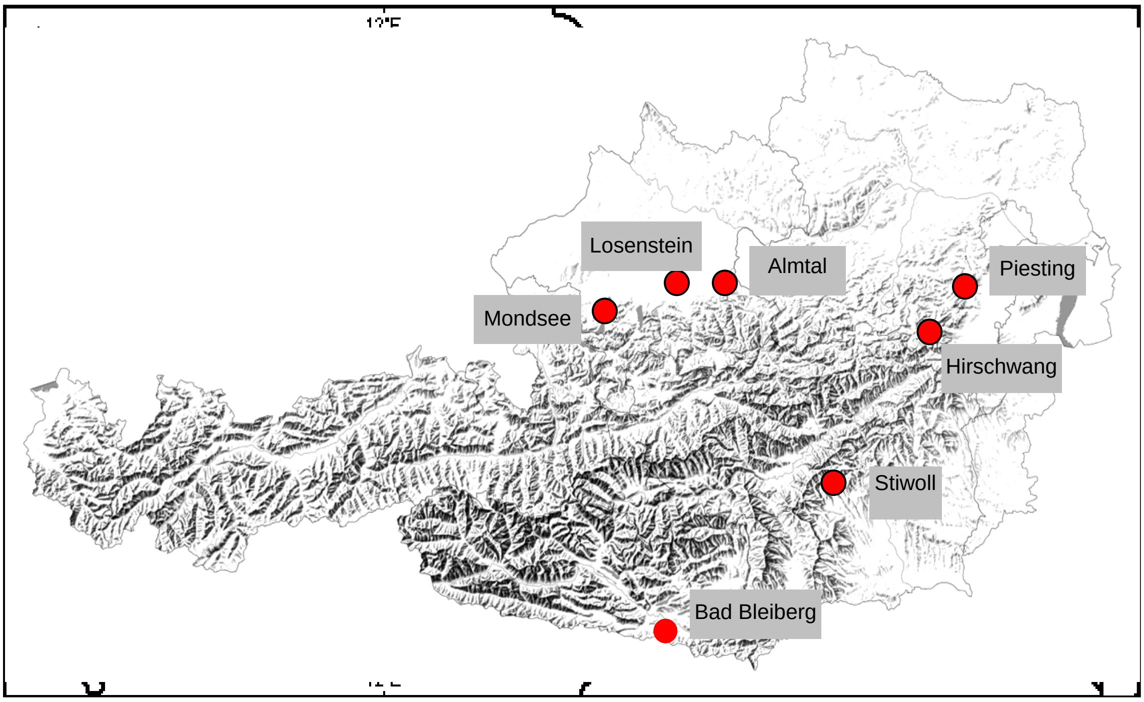


Figure 1. Locations of the study populations in Austria

Table 1. Characteristics of the different study populations

Name of the site	Province Eco-region	Total area [ha]	Population size	Altitude [m]	Major tree species	Types of Investigation
Bad Bleiberg*	Kärnten WG 6.1	18.3	828	900-1300	*F. sylvatica, P. abies, P. sylvestris, L. deciduas, A. alba, T. baccata*	Ecological and Genetic
Stiwollgraben	Steiermark WG 5.3	4.5	2236	580 – 700	*F. sylvatica, P. abies, P. sylvestris, L. deciduas, A. alba, T. baccata, A. pseudoplatanus* L., *U. glabra, F. excelsior*	Ecological, Genetic and Management
Hirschwang	Niederösterreich WG 5.3	scattered	approximately 80	700 - 900	*P. abies, P. sylvestris,*	Genetic
Piesting	Niederösterreich WG 5.1	scattered	>100	400 - 650	*F. sylvatica, P. abies, P.nigra*	Genetic
Losenstein	Oberösterreich WG 4.1	39.6	1815	540 – 680	*F. sylvatica, A. alba, T. baccata, A. pseudoplatanus* L., *U. glabra, F. excelsior*	Genetic
Almtal	Oberösterreich WG 4.1	3.2	> 2000	460 – 490	*F. sylvatica, A. alba, T. baccata, A. pseudoplatanus* L., *U. glabra, F. excelsior*	Genetic
Mondsee*	Oberösterreich WG 4.1	2.6	253	480 – 530	*F. sylvatica, P. abies, A. alba, T. baccata, A. pseudoplatanus, F. excelsior, S. aria, Quercus* sp.	Ecological and Genetic

[* Metric data from Oitzinger and Aigner]

3.2 Sampling design

A regular grid of permanent sample plots were set up for the monitoring of the three gene conservation forests with a detailed ecological assessment (n= 48, 72 and 22 in Stiwollgraben, Bad Bleiberg and Mondsee respectively). The size of the sample plots was 30 × 30 m for Stiwollgraben and Mondsee and 50 × 50 m for Bad Bleiberg. All individuals of yew (DBH ≥ 5 cm) in the studies areas have been marked and different tree attributes such as tree height, diameter at breast height (DBH at 1.30 m), crown length, foliage percentages, height class, stem damage and vitality indices were measured.

3.3 Measurement of regeneration

For counting the natural regeneration every sample plot was spilt into four satellite plots in four sky directions (north, east, south and west) and the natural regeneration was investigated in respect of four different height classes by means of three circular plots with different radius (1st, 2nd and 3rd circle with a radius of 0.5 m, 1.6 m and 3.2 m respectively). All seedlings, juveniles at two and more years and up to 30 cm height were sampled at the 1st circle, all individuals from

31-50 cm and 51-150 cm height at the 2nd circle and all individuals from 151 cm height up to 4.9 cm DBH at the 3rd circle.

3.4 Quantifying vitality

The vitality is an important parameter for assessing the health condition of tree species and it is described according to four different classes (1 = very vital, 2 = vital, 3 = less vital and 4= least vital). The vitality class of each individual English yew was assessed on a combination of the parameters crown length (relative percentage of the living crown), foliage density (relative percentage of living green needles) and crown formation (different types of crowns) qualitatively (see table 2).

Table 2. The vitality classification outline for English yew

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

3.5 Quantifying structural diversity

Forest structure has three major characteristics—species diversity and mingling, spatial distribution of tree positions, and variation in tree dimensions like tree diameter or tree height (Pommerening 2002, Aguirre *et al.* 2003, Kint *et al.* 2003). For quantifying the forest structure, three neighbouring trees of each individual of male and female yew at each sample plot (n= 96, 140 and 35 in Stiwollgraben, Bad Bleiberg and Mondsee respectively) have been used to calculate the different structural indices like mingling ((DM_i)), DBH (TD_i) and height (HD_i) differentiation as well as distance to nearest neighbours (D_i) according to Füldner (1995). For details please refer to paper 3 (Appendix-3).

3.6 Analysis of genetic variation

In total 624 bud samples from 7 populations were taken for isozyme analysis and the sample size ranged from 40 to 122. Horizontal starch gel electrophoresis was applied for separating the isozymes and six enzyme systems were chosen for this study, which are known to exhibit polymorphism in at least one of the encoding gene loci (Hertel 1996). Electrophoretic procedures and staining protocols followed the methods described by Hertel (1996) and Konnert (2004). The following genetic parameters were calculated by using the GSED-1.1 program (Gillet 1998) to assess the genetic diversity for each populations: percentages of polymorphic loci (0.95 criterion: a locus is considered polymorphic if the frequency of the most common allele does not exceed 0.95, $P_{>95}$ *%*), average number of alleles per locus (*A/L*), average expected (*He*) and observed (*Ho*) heterozygosities per locus and gene pool distance among the populations. Total genetic diversity (H_T) and its distribution within (H_S) and between (D_{ST}) the populations, the proportion of inter-population differentiation (G_{ST}) and the Wright fixation index (*F*) for each locus were calculated by using the FSTAT computer programme (Goudet 2001). For details regarding the methodology for assessing the genetic variation please refer to paper-4 (Appendix-4).

3.7 Development of conservation and management strategies

The Population viability risk management (PVRM) was used as a basic framework for designing the guidelines as well as implement and ensure the long-term conservation and management of endangered species. The Stiwollgraben population was used as a model population for developing an appropriate conservation strategy by using the PVRM framework.

3.7.1 Guideline for PVRM

There is no general guideline for conducting PVRM although Marcot and Murphy (1996) proposed a nine-step approach to guide conservation managers' for selecting conservation strategies but in this study a general procedure was adapted according to the research prospective which are briefly given below (For details please refer to paper 5)-

1. Identifying the species at risk and relevant regulations
2. Description of the ecological conditions of the target species and their environment
3. Development of conservation management alternatives
4. Evaluation of viability effects of alternative management
5. Array and select an alternative
6. Implementation and monitoring

3.7.2 Development of management alternatives

Population viability risk management (PVRM) allows to evaluate the potential effects on the viability of populations from alternative courses of action. According to the analysis of the current environmental condition the major threats for the yew population at the gene conservation forest in Stiwollgraben were slow growth (related to competition), susceptibility to browsing and grazing, low people awareness, and the special consideration of the dioecious sexual system (for detail please refer to paper – 5). The combination of personal field experiences, opinions from local foresters, forest expertises as well as different research activities (Czatoryski 1978; Mitchell 1988; Elizabeth and Alison 1995; Svenning and Magárd 1999; Thomas and Polwart 2003; Iszkulo and Boratyński 2006) which have been done on this tree species through out the world were considered as basis for the development of management strategies for this site. The idea was to develop different strategies by altering the main characteristics driving the viability of the population. In this study six different combinations of management strategies (see Table 3) were selected, which will cover most of the major threats on yew population. It also includes activities according to hunting, rising people awareness, wildlife management in general and economic aspects, which might help to enhance the acceptability of the local people.

Table 3. Strategies for conservation management of English yew population

Characteristics	Management Strategies					
	0 (do nothing)	I (wild life strategy)	II (minimum strategy)	III (single tree selection system)	IV (conservation strategy)	V (timber production strategy)
Wild Life Management	no	Fence + game control	no	Fence	Fence + game control	no
Thinning intensity	no	0 %	10 %	no	30 %	50 %
Selective thinning	no	no	no	yes	yes	no
Careful harvesting	no	no	yes	yes	yes	no
Site preparation	no	no	no	yes	no	no
Regeneration	Natural	Natural	Natural	Natural	Natural + Artificial	Natural + Artificial
Public awareness	no	yes	no	no	yes	no

3.7.3 Evaluation process of management strategies

The PVRM approach requires the identification of key conservation management decision sequences that affect environment and population as well as an estimation of various responses of species to each management decision. In this approach the AHP is used to evaluate the conservation strategies with regard to viability of the yew population. The criteria used to evaluate the viability of the population are “genetic sustainability”, “vitality of pole stand”, “viability of seedlings” and “socio economic factors” which are based on the description of the environmental condition and reasons for the population decline. The management strategies are at the lowest level of the hierarchy and they are evaluated against all criteria and sub criteria, which influence the viability of the population. According to Saaty (1995) pair wise comparisons were made on a scale of relative importance where the conservation manager expressed the preferences between two elements on a ratio scale from equal important to absolute priority of one element over another.

4. Results

4.1 Population structure of Stiwollgraben, Bad Bleiberg and Mondsee

4.1.1 Status of natural regeneration

The density of natural regeneration in different age classes' distinctly varied (Fig. 2) between the different sites. The highest number of seedlings (14978 n ha^{-1}) was observed in Stiwollgraben whereas in Bad Bleiberg and Mondsee it was 2392 and 5209 n ha^{-1}. In spite of a large number of seedlings there were no saplings in the height class 51 to 150 cm in all three sites and no saplings in the height class 30 to 50 cm in Stiwollgraben and Mondsee.

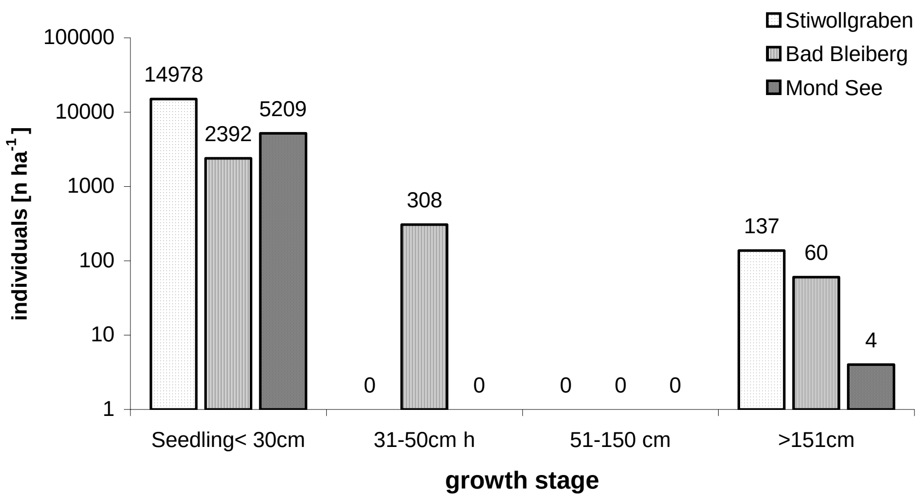


Figure 2. Regeneration status of English yew population in three different gene conservation forests

4.1.2 Pole stand distribution

The different trees attributes regarding the yew populations are given in Table-4. The density of the population (individual trees with a DBH ≥5 cm) for Stiwollgraben was 492 n $ha^{-1,}$ which is followed by Mondsee 97 n ha^{-1} and Bad Bleiberg 45 n ha^{-1}. Considering the DBH distribution the population of Bad Bleiberg and Mondsee represent a wide range of distribution compared to Stiwollgraben (Fig 3). The maximum DBH was found in Bad Bleiberg 40.9 cm whereas in Stiwollgraben it was 24.8 cm.Considering the health condition the population of Stiwollgraben showed a very good condition, more than 79 % of the total yew individuals belong to the very vital to vital class whereas in Mondsee 63.3 % and in Bad Bleiberg 47.4 % of the yew individuals are very vital to vital (see Fig-4).

Table 4.Comparison of English yew population's characteristics in three Austrian gene conservation forests

Populations	trees ≥ 5 cm DBH [n ha^{-1}]	ave. tree height [m]	ave. DBH [cm]	max. DBH [cm]	ave. canopy closure for Adult [%]	ave. crown [%]	basal area [m^2 ha^{-1}]	tree volume [m^3 ha^{-1}]	Ave. seed weight [g]
Stiwollgraben	492	6.3	8.8	24.8	84	62	3.20	17.3	63.97
Bad Bleiberg	45	7.6	16.3	40.9	68	65	1.04	5.05	62.98
Mondsee	97	7.5	17.0	34.8	89	70	4.0	16.7	Not avail.

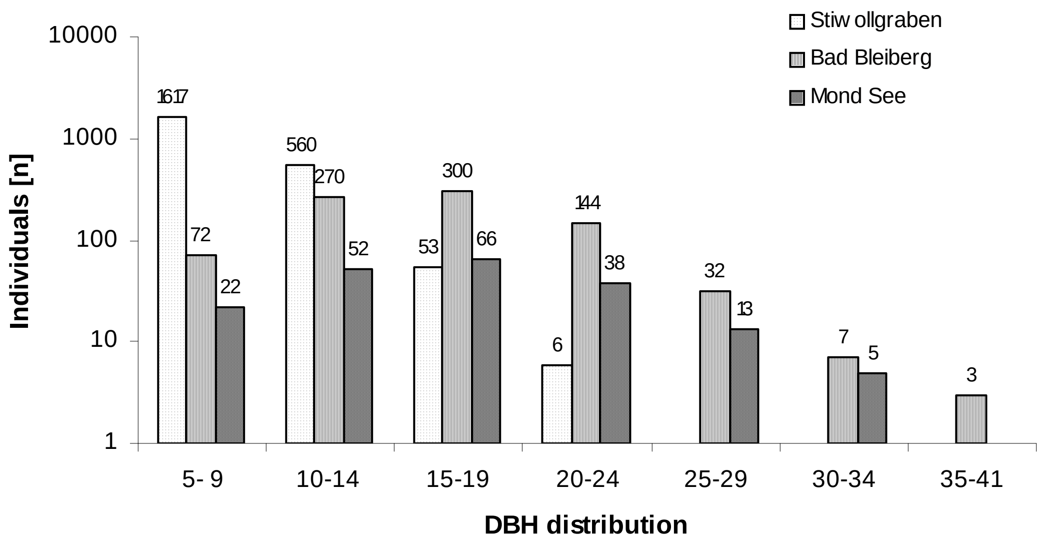


Figure 3. Diameter distribution of English yew population in three Austrian gene conservation forests

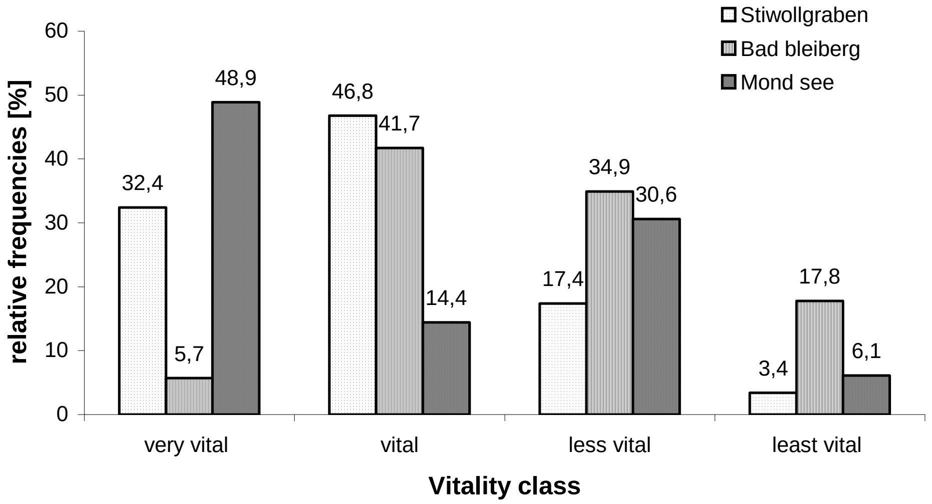


Figure 4. Vitality of English yew population in three-gene conservation forests

4.1.3 Structural diversity of English yew

The tree-tree-interval (*Di*) describes the spatial arrangement of trees in the forest stand and allows interpreting the spatial relationship between yew and its neighbours (Pommerening 1997). Fig-5 indicates that the population at Bad Bleiberg is less densely whereas Stiwollgraben and Mondsee are more densely populated. The mingling value provides the information about the diversity of species as well as inter-specific and intra-specific competition within the cluster. The site Bad Bleiberg shows highest species diversity, highest inter-specific competition within the group and in more than 72 % of all cases all of its neighbours are from different species. In Mondsee and Stiwollgraben 45.7 % and 27.1 % of all its neighbours are from different species which indicates a higher intra-specific competition. The vitality of each individual yew is directly influenced by the inter-specific competition of the neighbouring tree species. The yews with a low vitality index (class 4) indicate a small mean distance to their neighbours (less than 2.5 meters) and high negative tree height differentiation (up to -0.8) (Fig 6). With the decrease of the height differentiation and an increase of the distance from the target tree to nearest neighbouring trees the yews are indicating a better vitality. In that context it can be concluded that the intra-specific competition is less important than the inter-specific competition. It is mentionable, that the findings for this relationship between vitality, height differentiation and distance to neighbours are statistically not significant. There is a trend among the three parameters observed only.

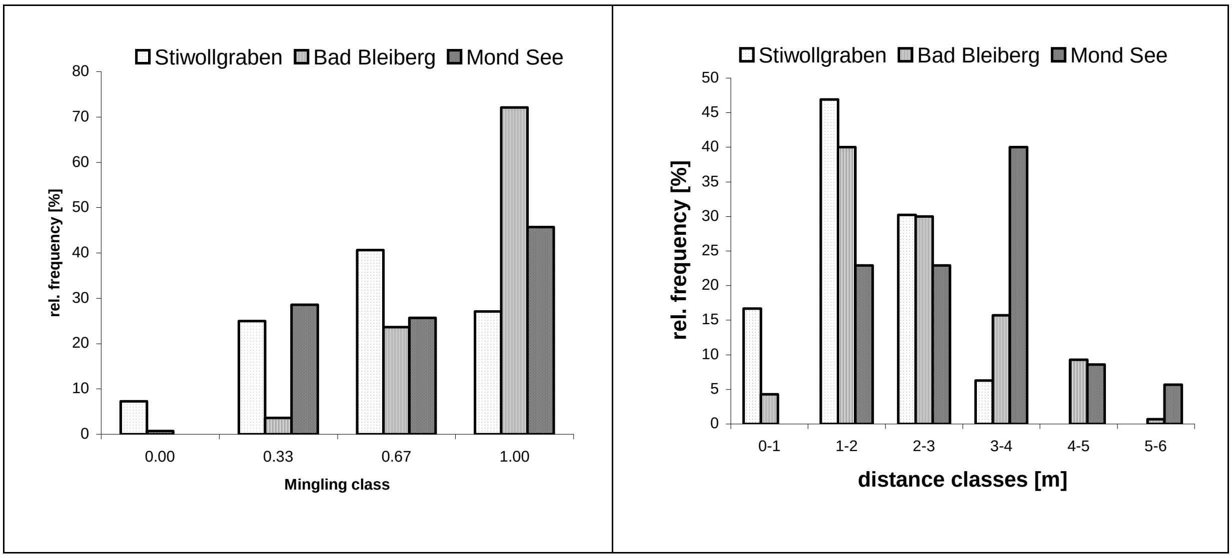


Figure 5. Mingling (DM_i) and distance to neighbours (D_i) for English yew in the three gene conservation forests

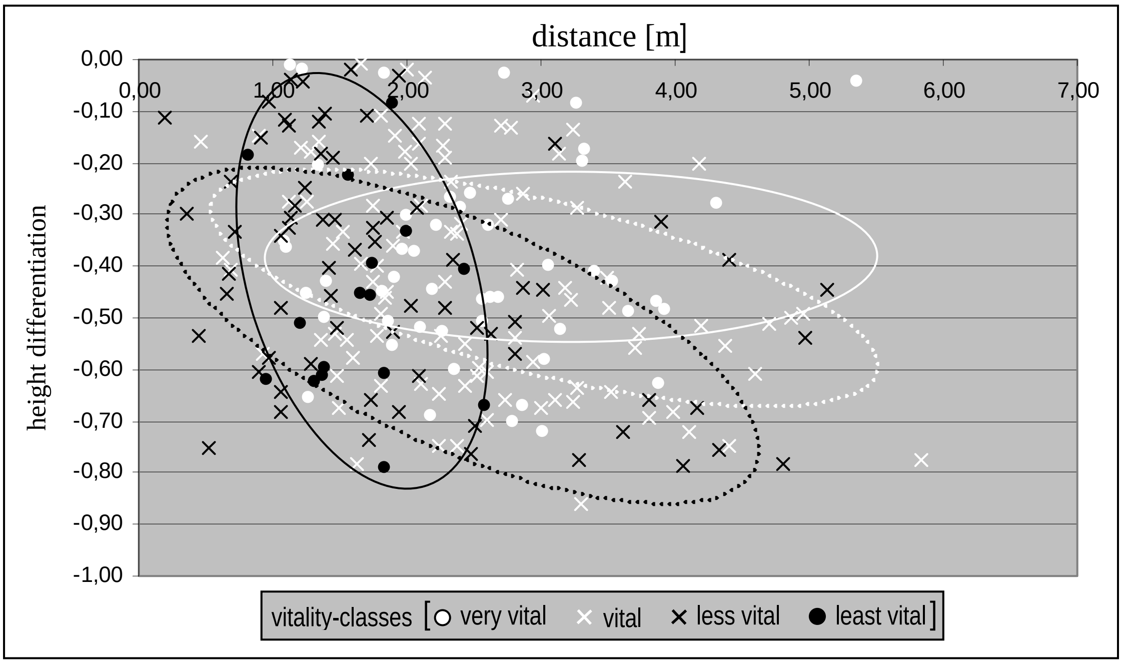


Figure 6. Relation between the vitality class, tree-tree distance, and negative height differentiation for each English yew from the structural group of four

4.2 Genetic variation and differentiation

For evaluating the genetic structure of the investigated yew populations 6-enzyme systems were used to identify 9 isozyme gene loci and 32 alleles. Among these 9 loci only two loci AAT-A and LAP-A were monomorphic in 6 populations whereas in Stiwollgraben all loci are polymorphic. The average number of allele per locus varied from population to population. The highest number of allele per locus (2.8) was found in Bad Bleiberg, Stiwollgraben and Almtal whereas Mondsee represented the lowest value (2.4) and 76.43 % of the gene loci were polymorphic in all populations (Table-5). The average effective number of allele per locus was 1.37 and the average hypothetical gamete diversity was 24.98. Considering the heterozygosity Austrian yew populations showed a wide range of difference. The range of expected (*He*) and observed (*Ho*) heterozygosity was 0.230-0.304 and 0.178-0.272 respectively and the average expected and observed heterozygosity for the seven populations was estimated to be (*Ho*) 0.238 and (*He*) 0.274 respectively (Table 5). The analysis of the Wright's fixation index showed an overall considerable deficiency of heterozygotes relative to Hardy-Weinberg expectation. The range of *F* values was 0.066 to 0.228 with an average of 0.131.

Table 5. Estimates of genetic diversity for 7 English yew populations in the eastern Alps

Population	Parameters						
	Poly. Loci 95 %	*A/L*	*Ne*	Hypo. Gamete. Diversity	*Ho*	*He*	Wright's Index *F*
Bad Bleiberg	67	2.8	1.296	12.57	0.178	0.230	0.228
Stiwollgraben	100	2.8	1.362	17.26	0.232	0.267	0.124
Hirschwang	78	2.7	1.363	21.24	0.242	0.270	0.105
Piesting	67	2.6	1.382	27.72	0.260	0.279	0.066
Losenstein	78	2.7	1.423	31.98	0.272	0.299	0.089
Almtal	67	2.8	1.363	21.50	0.228	0.267	0.149
Mondsee	78	2.4	1.433	42.60	0.257	0.304	0.155
Average	76.43	2.7	1.370	24.98	0.238	0.274	0.131

[*P* = percent of polymorphic loci; *A/L* = mean number of alleles per locus; *Ne* = effective number of allele per locus; *Ho* = observed heterozygosity; *He* = Hardy-Weinberg expected heterozygosity or genetic diversity; *F* = Wright's Fixation index]

Table 6. Sex ratio of English yew in three Austrian gene conservation forests

Study site	Total no of Individuals	Female	Male	Undefined	Ratio
Stiwollgraben	2236	835	535	866	1.56*
Bad Bleiberg	828	392	432	4	0.91
Mondsee	252	88	80	84	1.05

[* significantly difference]

The sex ratio of mature fertile individual is an important parameter for further generation development. The population of Stiwollgraben were significantly female biased whereas Bad Bleiberg and Mondsee showed insignificant result considering sex biasness which means these two populations were represent the balanced sex ratio (Table-6).

4.3 Application and selection of a management strategy

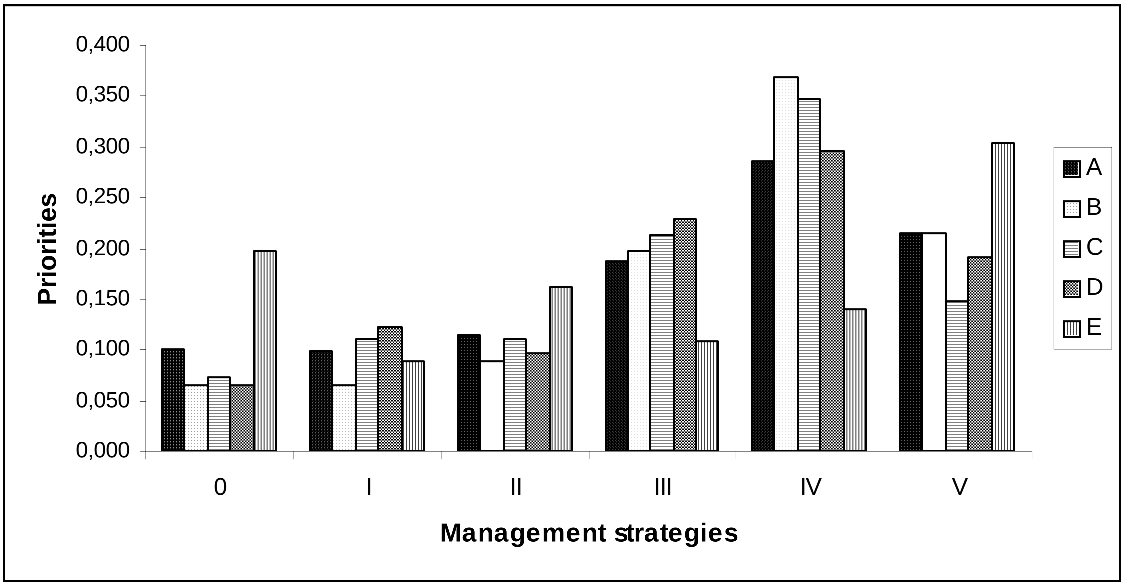
A population viability risk management (PVRM) framework was used for the design and evaluation of in-situ conservation strategies of a yew population in an Austrian Gene conservation forest at Stiwollgraben. To select an appropriate management strategy for maintaining the viability of English yew different environmental scenarios was evaluated. The scenarios were characterized in respect of different combination of priorities for the evaluation criteria vitality of pole stand, genetic sustainability, survival rate of seedlings and socio economic conditions. Scenarios A corresponds to the actual situation of the criteria influencing the viability of the population where all criteria were equally prioritised and scenarios B, C, D, E have different priorities according to different criteria where each of those criteria is set to a maximum in one of the scenarios (see Table-7). Applying the priorities for each criterion in five different scenarios (see Table-3) allowed to evaluate the viability of the yew population for each management strategy.

Table 7. Priorities for criteria of scenarios A to E as well as overall priorities, rank and average for Management Strategies 0 to V

scenario	priorities of criteria for scenarios				overall priorities and rank for management strategies					
	genetic sustain-ability	vitality of pole stand	survival rate of seedlings	socio economic condition	0	I	II	III	IV	V
A	0.25	0.25	0.25	0.25	(0.100)*5	(0.098) 6	(0.114) 4	(0.187) 3	(0.286) 1	(0.214) 2
B	0.70	0.10	0.10	0.10	(0.066) 5	(0.065) 6	(0.088) 4	(0.198) 3	(0.369) 1	(0.215) 2
C	0.10	0.70	0.10	0.10	(0.072) 6	(0.111) 4	(0.111) 5	(0.212) 2	(0.346) 1	(0.148) 3
D	0.10	0.10	0.70	0.10	(0.065) 6	(0.122) 4	(0.097) 5	(0.228) 2	(0.296) 1	(0.191) 3
E	0.10	0.10	0.10	0.70	(0.198) 2	(0.089) 6	(0.161) 3	(0.108) 5	(0.140) 4	(0.303) 1
average rank					4.8	5.2	4.2	3.0	1.6	2.2

A= overall result, equally prioritized, B=priority on genetic sustainability,
C= priority on pole stand, D=priority on survival rate of seedlings,
E= priority on socio economic condition.
* numbers in parentheses indicating the overall priorities for the management strategies according to each scenario

Management strategy IV achieved almost the highest preference in all scenarios except scenario E (Table 6 and Fig. 8). Strategy V is the second best alternative management approach in respect of scenarios A, B, and E, which is followed by strategy III where scenarios C and D showed the best options. Strategy I has the lowest priority among the management strategies with respect of scenario A, B and E. Considering the result of the sensitivity analysis it is evident that strategy IV dominates all other strategies independently.



management strategies
0- do nothing
I- wild life strategy
II- minimum strategies
III- single tree selection system
IV- conservation strategy
V- timber production strategy

scenarios
A- over all priority
B- priority on genetic sustainability
C- priority on vitality of pole stand
D- priority on establishment and viability of seedlings
E- priority on socio economic factors

Figure 7. Overall priorities of management strategies for different environmental scenarios

5 Discussion

5.1 Population structure of English yew in Austria

Despite an adequate number of yew seedlings in all three sites (Stiwollgraben, Bad Bleiberg and Mondsee) the sapling stage showed shortcomings in the height class of 51 to 150 cm and from 30 to 50 cm at Stiwollgraben and Mondsee (Fig. 2). These might be caused by several impacts simultaneously such as less availability of light, inter-specific or intra-specific competition and herbivore browsing. It is also mentionable that almost 78 % of all saplings from Stiwollgraben and 81 % of all saplings from Mondsee are under dense canopy (≥ 90 %) while in Bad Bleiberg only 43 % of all saplings. Hulam (1996) and Król (1978) stated that seedlings only survive and grow where the canopy is relatively dense and successful sapling recruitment has been associated with an opening of canopy. Similarly Iszkulo and Boratynski (2006) reported that yew seedlings can survive on deeply shaded sites for several years, but the light demand increases with an increase of age. Although the optimum light requirement was not measured in this study different silvicultural thinning operations were initiated in the Stiwollgraben to increase the solar radiation on the forest floor. However further research initiates about the light requirement of yew is recommended. Besides this, browsing could be one of the major contributory factors for the loss of yew seedlings. Haeggström (1990) and Kelly (1981) mentioned that English yew is very susceptible to browsing. In that context a fence was established in Stiwollgraben for the long term monitoring the browsing pressure on yew seedlings.

The size class structure of English yew varied between the different geographic locations. Density of pole stems (DBH ≥5 cm) was higher in Stiwollgraben, which was followed by Mondsee, and Bad Bleiberg (Table-4), which might indicate that the site condition of Stiwollgraben is more favourable compared to the other sites. Site characteristics like west exposition, sub montane region, cambisols, and fresh water balance might have a positive impact on the growing conditions for the population. Cambell (1993) mentioned that water availability increases the total number of tree per hectare although there is not enough information regarding the soil water relations on this site. Considering the different tree attributes Bad Bleiberg represent the highest average tree height (7.6 m) and maximum DBH (40.9 cm) whereas Stiwollgraben showed the lowest value (Table-4). Iszkulo *et al.* (2005) reported that average height and DBH was lower in shadiest place compared to those of growing in better light conditions. These finding are comparable with Stiwollgraben because the average canopy closer of this site is 84 %. Considering the analysis of the vitality of single trees it revealed the fact that there are significant differences among the populations although they have almost the same percentages of crown closure (see Table 4). These results allow to prove the shade tolerance of English yew (Brzeziecki and Kienast 1994; Kròl 1978) which does not influence the vitality of yew. However, the reproductive activity and recruitment of yew can be enhanced by better light availability (Svenning and Magard 1999; Saniga 2000)

Structural diversity generally describes the species composition, horizontal and vertical variation within the forests stands, which is an important parameter to initiate appropriate forest management actions. Among the different structural indices species mingling (*DMi*) is one of the key indices, which describe the species mixture with respect to the target tree. Considering the species mingling the population of Stiwollgraben belongs to the smaller mingling class, which means less inter-specific and high intra-specific competition while Bad Bleiberg population located in the higher mingling class and it showed high inter-specific and less intra-specific competition (see Fig-5). Another important index is tree-tree interval (*Dj*), which helps to interpret the spatial relationship between yew and its neighbours, which describes the species aggregation with respect of the target tree. From the result it can be shown that 93.7 % neighbouring trees are situated within 3 m distance in Stiwollgraben, whereas in Mondsee 45.8 % are as close, which means that cumulative stand density is the lowest in Mondsee compared to the other 2 sites (see also Table-4). There is a non-significant relation considering the relationship between distance and negative height differentiation with respect to vitality. Vitality is increasing with the increasing of tree-tree distance and decreasing of negative tree height differentiation. A small mean distance and high mean negative tree height differentiation with yew and their neighbours is indicating a low vitality class. From this observation it can be predicted that the vitality of yew is more related to inter-specific competition as yew itself does not affect the vitality of its neighbouring yews (see Fig-6).

5.2 Genetic variability of English yew

Knowledge regarding the distribution patterns of genetic variation in plants and between the populations is an important key factor for developing conservation strategies. It is mentionable that English yew has a widespread geographic distribution throughout the Europe and occurs rather sporadically in most of its range. So this study presents the first results of the genetic variability and geographic variation of yew populations throughout the eastern Alpine mountain regions in Austria. The analysed yew populations in Austria showed a high level of genetic variation with some differences compare to others studies in eastern and central Europe in respect of observed (*Ho* = 0.238) and expected (*He* 0 0.274) heterozygosity (compare Cao et al 2004; Lewandowski *et al.* 1995) and showed a similar trend like Asian (Chung et al 1999) and American species (El-Kassaby and Yanchuk 1994). From the different studies it assumed that the needle or apical meristeme based analyses showed the lower values of *Ho* in comparer to *He* (see El-Kassaby and Yanchuk 1994; Chung et al 1999) and balanced the value in respect of microgametophyte based study (Senneville et al. 2000).. Besides these, some other factors such as breeding system, slow growing long living species (Ledig 1986), mechanisms of seed dispersal (Hamrick *et al.*1992), geographic distribution (Hamrick *et al.*1992), and ecological amplitude could influence the heterozygosity.

The level of inbreeding is described by Wright's fixation index (*F*). The average *F* value for the Austrian yew populations of 0.131 indicates the moderate excess of homozygotes. This moderate level of inbreeding can result from a variety of causes such as positive assortative mating (mating among the similar genotype) (Crow and Felsenstein 1968); selection for homozygotes; family structure within a restricted neighbourhood causing mating among relatives (Levin and Kerster 1974) and finally Wahlund effect caused by the artificial grouping of individuals from different breeding populations (Wahlund 1928) or due to the sampling procedure and size. So further studies on the genetic variation comparing the different components of the population will help to increase the level of understanding about the genetic consequence of English yew population in the eastern Alpine mountain regions. However considering the genetic consequences of English yew it can be concluded that Austrian English yew populations have a high level of genetic variation with a medium level of inbreeding effect.

It is mentionable that only a balanced ratio of sexually mature colonies could provide a good reproduction ability, which influences the seed production as well as future progeny production. This would permit the preservation of the natural population dynamics and long-term evolution at the landscape level. Austrian yew populations showed balanced sex ratio for Bad Bleibeg and Mondsee whereas Stiwollgraben was female-biased sex ratio (Table-6). Svenning and Magárd (1999) reported that the population of Munkebjerg was female biased whereas Willamson (1978) mentioned that Kingely valley in England was male biased. On the other hand Hilfiker et al (2004) noted that small population showed female biased sex in Switzerland, which is not proved by our study because small population Mondsee (252 individuals) represent the balanced sex ratio (see Table-6). So, sex biasness is not a general consequence for English yew and it is important to mention that more than 1/3 population of Stiwollgraben and Mondsee were unidentified. The result could be changed after identification of all individual’s sex. It is mentionable that identification of the individual sex for English yew is very difficult due to its dioecious sexual system.

The main goal of this study was to maintain the viability of English yew populations in Austria by developing the conservation action plan. So, this genetic information was used as a major component of the PVRM framework for draw a proper management strategy for this endangered English yew populations.

5.3 Population viability risk management

The effect of environmental and natural changes in certain parts of a population life cycle is a key question both in population management and life history evolution. Therefore it is essential to identify the appropriate instance of a population life cycle where most management efforts should be taken in order to ensure and maintain the maximum viability of the population. The PVRM approach could be helpful to identify that instance by evaluating different conservation management strategies in order to identify courses of action for improving the viability of the population. The AHP is a multi-criteria decision method where both qualitative and quantitative information is used for comparing the importance of different criteria in respect of different alternatives. The qualitative information’s like people acceptance, level knowledge and quantitative information’s such as productivity and income of different management strategies can easily be determinate in this process. During the qualitative assessments of population viability a multi professional judgment and pragmatic evidence was used to proposed management actions.

According to the analysis of the different management actions an active management strategy maintains the viability of the yew population as its best because, it enhances the light availability, reduces the browsing pressure by building a fence and maintain the genetic variation. The thinning operation will lead to a better light availability, environmental condition, balanced structure and seed production of the mature yews. A balanced structure according to vertical, spatial and DBH-distribution provides a good vigour for the pole stand and increases the light availability on the forest floor additionally. On the other hand this management strategy raises people awareness about illegal cuttings and increases the knowledge about the management of this tree species. Many authors reported that appropriate silvicultural practices decrease inter-specific competition and activities for increasing public awareness are the most effective way for conservation of yew populations (e.g. Elizabeth and Alison, 1995; Vacik *et al.*, 2001).

6. Recommendations for Research and Conservation Management

This work exemplifies how different tree attributes effect the viability of yew populations. For developing conservation management strategies for English yew the ecological characteristics such as conditions of natural regeneration, the stand structure, structural diversity and genetic variation should be considered simultaneously. This research provided an initial framework for developing comprehensive conservation guidelines based on a detailed study of the species at risk. Future investigations and proposed management strategies are likely to be changed as new biological information become available. From the results of this study the following additional points should be taken into consideration with regard to conservation and management of English yew populations in Austria:

For planning activities

- A multi level approach (e.g. game management, silvicultural treatments, rising people awareness) is required to meet the demands of sustainable conservation strategies for yew populations in Austria. To utilize the PVRM approach generally could be helpful in order to identify courses of action for improving the viability of endangered populations .
- During conservation planning an active participation of several institutions (e.g. research institutions, local foresters) is needed to support the implementation of conservation activities. The active support of scientists for the planning process (including problem identification, problem modelling, problem solving and monitoring activities) and the collection of the available information about this endangered tree species seems valuable.
- Public awareness programmes will help to enhance the knowledge about the ecological importance of yew for the local people. Regular information and publications might help to increase the level of awareness and improve the overall knowledge about this species and have an effect on the reduction of illegal logging. Beside this, the presence of research activities will have positive effects on the public awareness too.

During monitoring activities

- The establishment of a fence in the studied gene conservation forests will help to observe the impacts of browsing on the regeneration. This will help to reduce the pressure on the natural regeneration and will help to identify the level of browsing in gene conservation forests in Austria. However, even without a clear quantification of the severity of these impacts it seems not rationale to plan for conservation activities ignoring the browsing effect.
- It is very important to monitor the reproduction rate and sex ratio of the mature yew individuals. Only a balanced number of sexually mature colonies allow a good reproduction, which influences the seed production as well as future progeny production. This would help to understand natural population dynamics and support the long-term evalution at the landscape level.
- The methods of seed dispersal are an important parameter for dioeciously plants. So, more attention is needed for a better documentation of the role of birds and mammals that are responsible for seed dispersal. Within a multi-level planning approach such research activities could be included.
- The regeneration status needs to be evaluated in 5-10 years cycles. The analysis of the survival rate of the young yew individuals will allow sound recommendations for conservation activities in the future.

Operational guidelines for management activities

- Continuous selective thinning will enhance the light availability on the forest floor and in the tree layer. This improves the overall health condition for both the pole stand and the seedlings of yew. It also helps to minimise the intra-specific and inter-specific competition as well as improve the horizontal and vertical structure of the forest. The thinning will increase pollen disperse within the forest and reduces the risks of inbreeding.
- Although English yew is a damage tolerant species stem damages will increase the susceptibility for other biotic infections. In that context sound and professional harvesting operations can reduce stem damages during tree felling. These techniques will allow to avoid other prevention measures to control diseases.

Further research activities

- Further investigations are needed in other gene conservation forests in order to find the appropriate ecological requirements for the viability of yew populations in Austria. Investigations need to be extended in other gene conservation forests for assessing the regeneration status of yew as well. This will help to find out the actual causes about the shortcomings of certain height classes of seedlings. As in this study only a limited set of populations could be studied it is needed to further prolong the research activities in order to develop sound conservation activities.
- It is necessary to investigate the optimum requirements of solar radiation for the seedling establishment and survival of the seedlings. The knowledge about the minimum requirements will help to adapt the thinning activities accordingly. In that context not only the survival of seedlings but the seed production should be analysed as well.
- The soil water relation is another important factor for reducing the survival rate of seedlings. Therefore it is important to find the minimum requirements for the water balance for a maximum rate of seedling survival.
- From this study a high number of alleles have been found. These results are indicating the relatively high multiplicity as well as confirm the high value of Eastern Alpine yew. Beside this English yew populations showed a high level of genetic variation in Austria but no geographic differentiation. It will be of interest to find out the genetic structure of other populations and try to reconstruct the pathways of yew after the last ice-age. It was found that there are some problems with inbreeding also. So, further investigations regarding the genetic structure are needed and more attention should be put on the number of samples as well as the sampling design additionally.
- Further investigations related to the possible impacts of climate change on different yew populations in Austria can help to enhance our understanding about the adaptation mechanism of yew and the proper management activities for conserving this species.

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8. Appendix

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

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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 northwest 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).

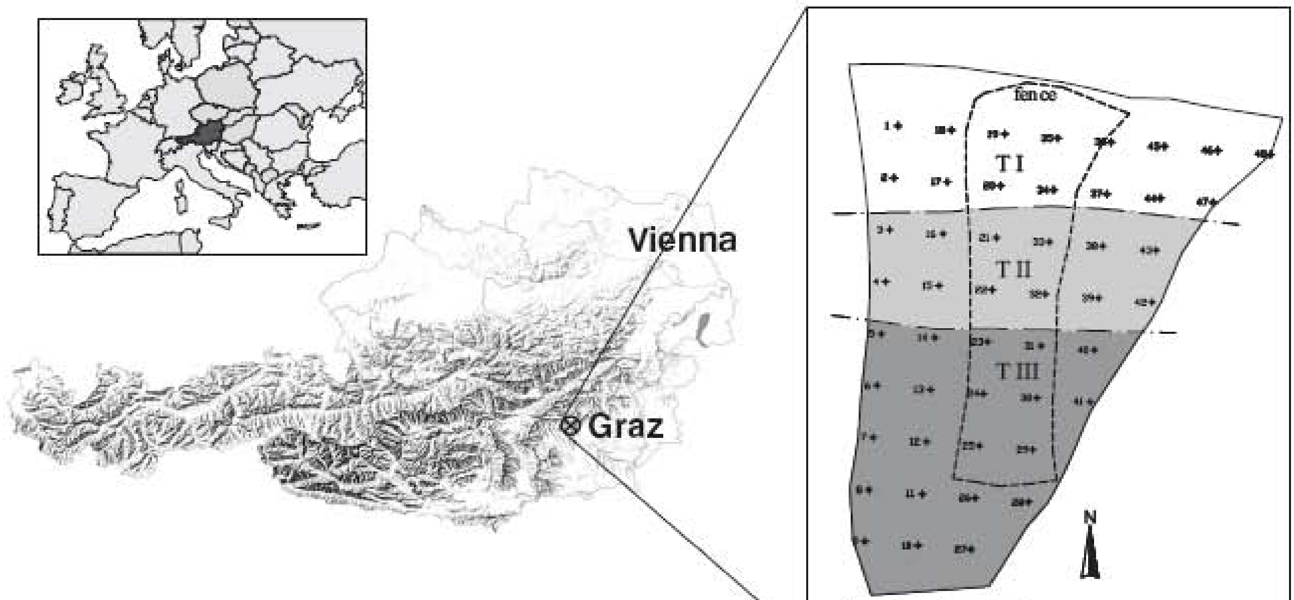

Fig. 1. The location of the *Taxus baccata* L. population at "Stillwollgraben" in Styria, Austria

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.

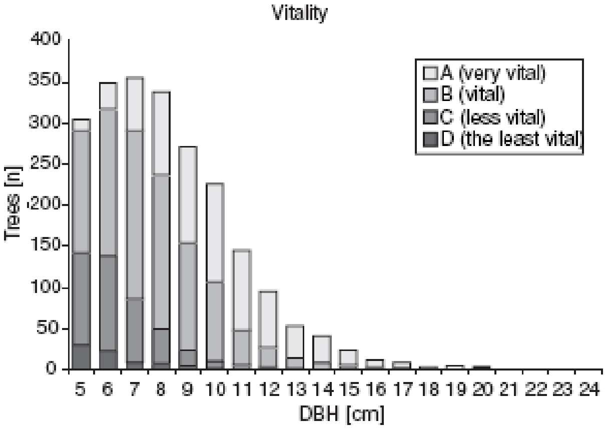

Fig. 2. Vitality classes of *Taxus baccata* L. according to diameter distribution

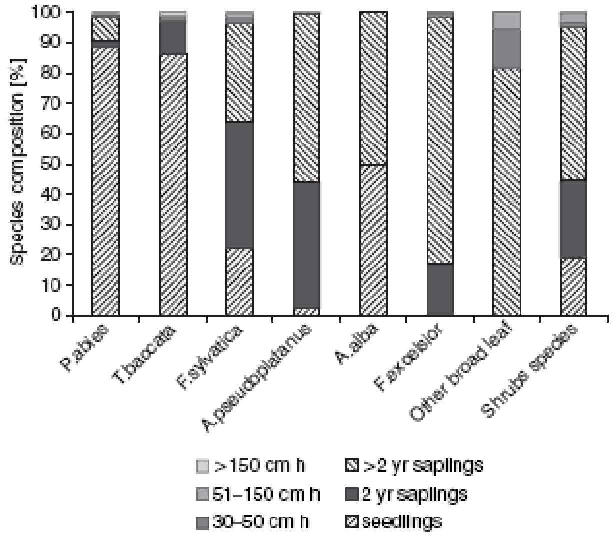

Fig. 3. Percentage of tree species in natural regeneration of the gene conservation forest

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.

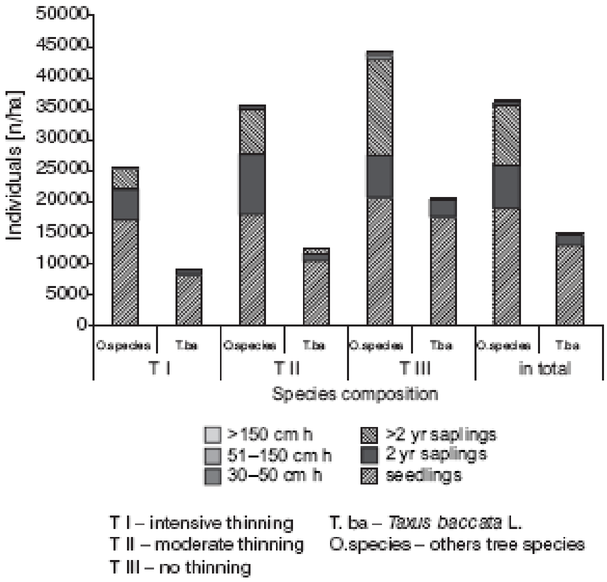

Fig. 4. Number of individuals of all tree species in the natural regeneration according to height classes and treatments

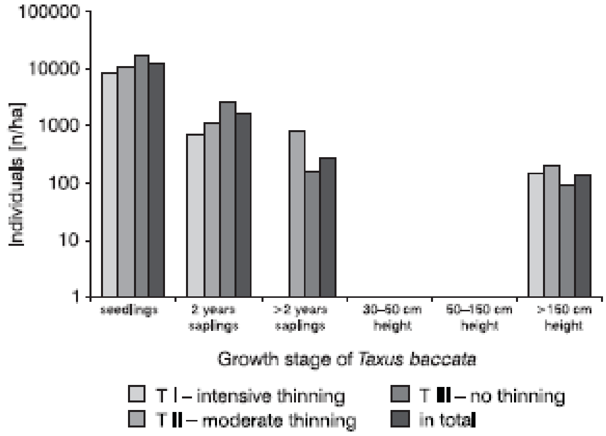

Fig. 5. Number of individuals of *Taxus baccata* L. in the natural regeneration according to height classes and treatments (logarithmic scale)

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 $\geq$ 5 cm has no negative influence on the establishment of seedlings.

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8.2 Comparison of ecological condition and conservation status of English yew population in two Austrian gene conservation forests

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Comparison of ecological condition and conservation status of English yew population in two Austrian gene conservation forests

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Abstract: English yew *Taxus baccata* L. has been catalogued as endangered tree species and prone to extinction in Austria as well as many other parts of Europe. The present work is based on the comparison of the natural population of two gene conservation forests from different geographic locations in Austria where the spatial structure, regeneration status and possible conservation measures are examined. The pole stand distribution varied distinctly in each sites. The total no of individuals per ha (DBH $\geq$5 cm), average DBH and average height were 492 n·hm^{-2}, 8.8 cm and 6.3 m in Stiwollgraben whereas in Leininger Riese 45 n·hm^{-2}, 16.3 cm and 7.6 m respectively. Over 79% of the Stiwollgraben population were represented the good health condition, while in Leininger Riese it was less then 49 % which means population of Stiwollgraben is in better condition compared to Leininger Riese. The sites differed considerably in the pattern of regeneration but pattern were consistent with the dynamics depicted by the age distribution. Considering the one-year-old seedlings Stiwollgraben contains 13 019 individuals·hm^{-2} whereas Leininger Riese only 1 368. Surprisingly there were no any saplings in respect of 51 to 150 cm height classes in both sites and 30 to 50 cm in Stiwollgraben. In that context the conservation of English yew on the forest level may require well-managed reserves and long-term rotations between harvest events, protection from the herbivore and reduction of competition, which will enhance the long-term viability of the species.

Keywords: Endangered species; *Taxus baccata*; Population structure; Forest management; Conifers

Introduction

The English yew (*Taxus baccata* L) is a slow-growing, long-lived, shade loving evergreen conifer tree species in temperate forests. It is scattered throughout Europe (Bolsinger and Llody 1993), northern Africa (Sauvage 1941) and the Caspian region of southwest Asia (Mossadegh 1971). It has gained considerable importance as a source of anti-cancer drug and high aesthetic value of timber. The main reasons for the decline of yew are widespread deforestation, light competition, selective felling of yew and browsing by herbivore (Bugala 1978; Tittensor 1980; Haeggström 1990; Jahn 1991).

Despite of its poisonous properties yew is very vulnerable to browsing and bark stripping by rabbits, hares, deer and domestic animals such as sheep and some other cattle (Kelly 1975; Haeggström 1990; Dhar *et al.* 2006b). Indeed *T. baccata* is one of the grazing sensitive trees (Kelly 1975) and there is a strong negative effect on recruitment and adult survival if the area is densely deer populated (Kelly 1981; Mitchell 1988). Similarly, *T. Canadensis* Marsh. is declining in abundance in the Great Lakes region due to heavy deer browsing (Gill *et al.* 1995).

Another most important factor is light, although yew is shade tolerant (Korl 1975, Brzeziecki and Kienast 1994). However, seedlings are hindered and saplings often die or show poor growth when yew grows beneath the shade of Beech (Czatoryski, 1978, Pridnya 1984). Moreover it is mandatory for natural regeneration of yew. Some other contributory factors are (1) adverse soil condition, (2) loss of genetic variation, (3) illegal cutting and lack of people awareness, (4) unfavourable site conditions (Thomas and Polwart 2003) like damaged caused by fungi (Strouts 1993), insect pests which restrict the yew recruitment and so on.

Population of slow growing long-lived plants like English yew typically received little attention in the past. Due to less awareness, this species is now catalogued as a rare and endangered species prone to extinction from all over the Europe (Thomas and Polwart 2003). There are two general conservation strategies for slow growing long living species, which are rare and endemic to small geographic areas. On the one hand most plans for management of such species have focused on land protection with the goal of protecting established individuals (Cardel *et al.* 1997). Secondly, the conservation efforts have focused on the reinstitution of ecological processes, which are important for recruitment of new individuals. These efforts promote successful regeneration and increase the genetic diversity on the long run (Barrett and Kohn 1991). However, these two conservation strategies may not be sufficient if population of slow growing, long lived plants are predicted to be in long term declines (Kwit *et al.* 2004).

At present yew is a rare and endangered tree species in Austria (Niklfeld 1999; Schadauer *et al.* 2003; Russ 2005) with restricted

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occurrence due to human activities, over uses in the past, browsing pressure, unsuccessful regenerations (Scheeder 1994; Meinhardt 1996; Dhar *et al.* 2006b). The gene conservation forest network in Austria has developed a programme to maintain the biodiversity of endangered species in Austria (Müller and Schultze 1998). The primary focus of these conservation strategies is the *in-situ* conservation of rare tree species by silvicultural treatments (Herz *et al.* 2005). 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; Dhar *et al.* 2006a).

In this contribution, we compared the ecological condition of two Austrian gene conservation forests and developed conservation management recommendations for these endangered populations.

Materials and methods

Characterisation of the study areas

The study site Stiwollgraben is situated in the eastern Alpine mountains (Fig. 1) with estimated 4.6 hm^2 of land. The slope of the site is 53 % to 75 %, west exposition and 580 to 700 m a.s.l. elevation. The soil type is dominating substrate dolomite and sandy rock. The area mainly dominated by an irregular micro relief with a mull/moder humus layer. The annual average rainfall and temperature is 1 060 mm and 7.7°C, respectively.

Fig. 1 Map showing the Location of two study sites Stiwollgraben (•) and Leininger Riese (o)

The pole stand of Stiwollgraben is 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. In case of regenerative stage *Picea abies*, *Taxus baccata*, *Fagus sylvatica*., *Acer pseudoplatanus*. and *Fraxinus excelsior* are the dominating species.

According to Dhar *et al.* (2006a) the local foresters performed three different forest operations: intensive thinning (T I) with a removal of 56 % and moderate thinning (T II) with a removal of 27 % of the stocking volume and third activity with no thinning (T III). A fence was established on a part of the experimental area to examine the effects of browsing. The fenced area is almost 1.31 hm^2 and covers all three treatments (T I: 0.49 hm^2, T II: 0.37 ha and T III: 0.45 hm^2) out of 4.6 hm^2.

The second site is in the northern part of the Villacher Alps at Bad Bleiberg (Fig. 1) in the area of that so-called "Leininger Riese" where it can be found at Northern exposition with an elevation of between 940–1160 m a.s.l. The total forest is covered by 18.4 hm^2 of land. The soil contains reddish and light weathered dolomite with a mull/moder humus layer. The annual average rainfall and temperature are 1420 mm and 5.9°C, respectively.

The pole stand consists of *Fagus sylvatica*, *Picea abies*. *Pinus sylvestris*, *Taxus baccata*, *Larix decidua* and *Abies alba*. There was also some moderate selective thinning done due to increase the favourable environmental condition for the yew population and singletree protection for the yew regeneration was applied to reduce the browsing pressure.

Sampling

The study sites were permanently marked with 30m × 30 m for Stiwollgraben (in total 48 plots) and 50m × 50 m for Leininger Riese (in total 72 plots). All individuals of yew in the study areas have been marked and tree height, diameter at breast -height (DBH at 1.30 m), health condition, crown length, foliage percentages, height class, and stem damage with DBH ≥5 cm were recorded. The natural regeneration was investigated according to three different height classes by means of three circular plots with different sizes (1st, 2nd and 3rd circle with a radius of 0.5 m, 1.6 m and 3.2 m respectively). 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 151 cm height up to 4.9 cm DBH at the 3rd circle.

The health condition of each individual English yew was assessed on the basis of percentage of the living crown, the foliage density and the crowns formation (compare Dhar *et al.* 2006b).

Results and discussion

Ecological condition of yew populations

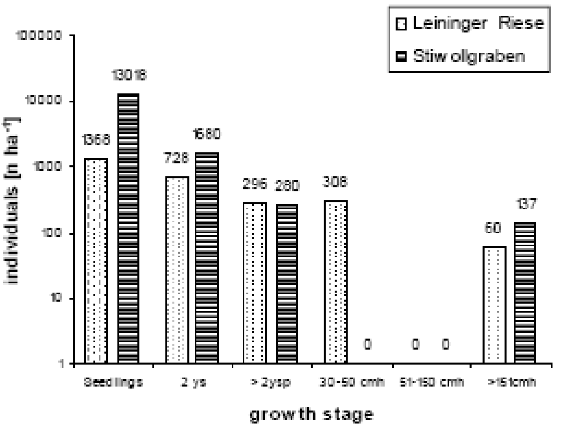
The density of seedlings at different age classes varied distinctly (Fig. 2) from each other's. In Stiwollgraben it was observed that the number of 1-year-old seedlings (13 018 $n \cdot hm^{-2}$), and two years seedlings (1 680 $n \cdot hm^{-2}$) whereas in Leininger Riese, the number of 1-year-old seedlings (1 368 $n \cdot hm^{-2}$) and 2 years seedlings (728 $n \cdot hm^{-2}$). In regards to sapling stage (>2 years) Leininger Riese (296 $n \cdot hm^{-2}$) consists of a higher number than Stiwollgraben (280 $n \cdot hm^{-2}$). It is mentionable that there are no any saplings with respect to 51 to 150 cm height classes in both sites and 30 to 50 cm height class in Stiwollgraben.

The populations' structures of both sites are given in Table 1. The estimated population size (individual trees with a DBH ≥5 cm) is 2 236 individuals in Stiwollgraben and 828 in Leininger Riese. The average DBH and height as well as the average crown percentages are quite similar at both sites which were 8.8 cm, 6.3

m and 62 % in Stiwollgraben whereas 16.3 cm 7.6 m and 65 % in Leininger Riese respectively. In that context Leininger Riese shows a wider range of DBH distribution compared to Stiwoll graben (Fig. 3). In respect of health condition Stiwollgraben shows a very good condition, more than 79 % of the total yew population are very vital to vital whereas in Leininger Riese only 49 % are vital to very vital condition (Fig. 4). Regarding the analysis of the vitality of single trees it revealed the fact that there are considerable differences between the populations of Stiwollgraben and the Leininger Riese. According to Lilipop (1931), Krol (1975) and Brzezieck and Kienast (1994) yew is highly shade tolerant and can easily grow under shade condition. Also the adult trees of the yew population at both two sites indicate a quite remarkable condition in relation to the competition with other tree species in the overstory. Although yew reproductive activity can be enhanced by better light availability (Svenning and Magard 1999).

Table 1. Population structure of English yew in two Austrian gene conservation forest

Treatment	trees ≥ 5 cm DBH ($n \cdot hm^{-2}$)	Average. tree height (m)	Average. DBH (cm)	max. DBH (cm)	ave. canopy closure for Adult (%)	ave. crown (%)	basal area ($m^2 \cdot hm^{-2}$)	tree volume [$m^3 \cdot hm^{-2}$]	Ave. seed weight (g)
Stiwollgraben	492	6.3	8.8	24.8	84	62	3.20	17.3	63.97
Leininger Riese	45	7.6	16.3	40.9	68	65	1.04	5.05	62.98



2ys= 2 years seedlings, > 2ysp= > 2 years saplings, 30-50 cm h = 30-50 cm height, >151cmh = 151 cm height and up to < 4.9 cm DBH

Fig 2. Regeneration status of *Taxus baccata* population in Leininger Riese and Stiwollgraben

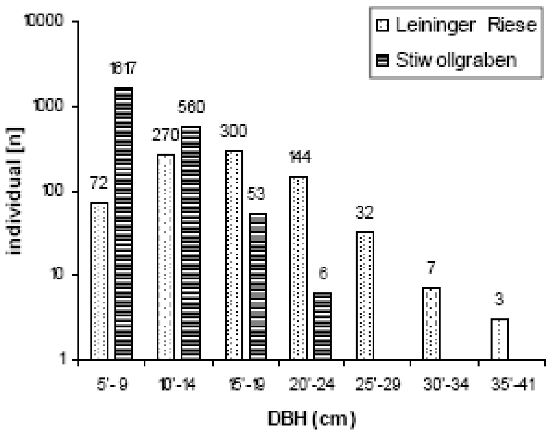


Fig. 3 Histograms showings the diameter distribution of English yew population in two Austrian gene conservation forest

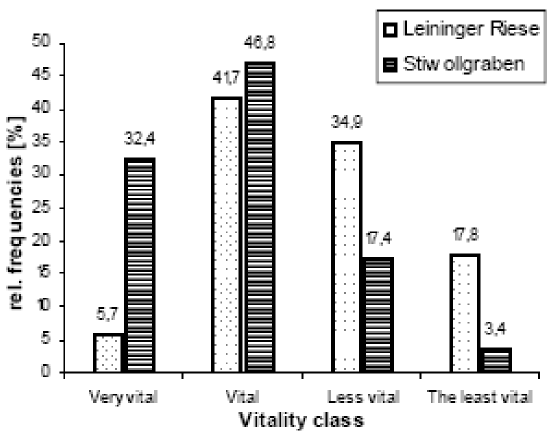


Fig 4. Vitality of yew population in Leininger Riese and Stiwollgraben

The sex ratio of the fertile individuals of both sites showed differences (Table 2). The yew population of Stiwollgraben was female-biased (1.56) up to now whereas Leininger Riese was male baised (0.91). So, sex-biasness is obviously a general phenomenon in yew. Williamson (1978) reported that a large yew population in Kingley Valley in England was male-biased whereas Svenning and Magard (1999) mentioned that population of Munkebjerg was female-biased. However, it is important to consider, that 36 % of the total Stiwollgraben population is unidentified. Sex identification is very difficult for yews due to its dioecious sexual system. A full identification of each individual is still in progress, which could have some effects on the sex ration.

The status of yew seedlings, saplings and adults represented considerable differences in both sites (see Table 3). In case of Stiwollgraben it showed that the number of seedlings was 14 699 $n \cdot hm^{-2}$, saplings 417 $n \cdot hm^{-2}$ whereas at Leininger Riese were 2 096 $n \cdot hm^{-2}$ and 664 n ha^{-1} respectively. It is also mentionable that almost 78 % of total saplings from Stiwollgraben were under dense canopy (≥ 90 %) while in Leininger Riese it was only 43 % of total saplings. A dense canopy has negative effects on growth and survival of yew saplings (Svenning and Magard 1999; Iszkulo *et al.* 2005; Boratysski *et al.* 2001). According to Iszkulo and Boratyński (2006) yew seedlings could germinate and grow in very shady conditions but their light demand increase with the increase of age. As there is no significant relationship between the canopy closure and the total no ha^{-1} of seedlings and saplings, it can be assumed, that some additional factors might influence the population structure as well.

Table 2. Sex ratios of *T. baccata* population in Leininger Riese and Stiwollgraben

Site	Total no of individuals	Female	Male	undefined	Ratio
Leininger Riese	828	392	432	3	0.91
Stiwollgraben	2236	835	535	866	1.56

Table 3. Status of English yew population in Leininger Riese and Stiwollgraben in respect of different age class

Site	Area [ha]	Density				Ave. canopy closure for saplings < 5 cm DBH with SD (%)
		Total (No·hm^{-2})	Seedlings ≤ 2 years (No·hm^{-2})	Saplings > 2 years (No·hm^{-2})	Adults ≥ 5 cm DBH (No·hm^{-2})	
Stiwollgraben	4.6	15608	14699	417	492	95 (+/-18)
Leininger Riese	18.4	2805	2096	664	45	80 (+/-17)

According to our investigations it was observed that both sites contained an adequate number of yew individuals especially at Stiwollgraben (15 608 individuals·hm^{-2}). With regards to the sapling stage both sites showed shortcomings in the height class of 51 to 150 cm at both sites and from 30 to 50 cm at Stiwollgraben (Fig. 1). These might be caused by several impacts simultanously. Herbivore browsing, less availability of light or interspecific tree competition are reported to be major drivers for the loss of saplings. Haeggström (1990) and Kelly (1981) mentioned that English yew is very susceptible to browsing. On the contrary Hulam (1996) and Krol (1975) stated that seedlings only survive and grow where the canopy is relatively dense and successful sapling recruitment has been associated with an opening of canopy. Similarly Iszkulo and Boratynski (2006) reported that seedlings can survive on deeply shaded sites for 2–3 years, but the light demand increases with an increase in age. In our case no evidence was found for seedlings predation and seedlings did not show any preference for especially protected microsites. However, it can be assumed that the browsing impact is quite severe in both cases, as control measures with fenced areas indicate some differences in the vegetation mixture and seedlings growth potential. Likewise, no autotoxicity was found and recruitment was common even close to large individuals (Dhar *et al.* 2006b). In that context some other factors could be mentioned as causes for a loss of yew seedlings such as cold wind and freezing during the winter. Thick layers of litter are preventing the growth as well as cause the heating of seedlings (Izdebski 1956; Kościelny and Król 1965).

Illegal cutting is another important factor for English yew decline in Austria. Its tough and long-lasting timber was extensively used for building and its high aesthetic appeal made it a popular decorative material from the Ancient time. People are not aware about the importance of yew. So low public awareness are creating another detrimental effect on declining of yew population.

Soil water relation is an important limiting factor. Soil moisture can be an extremely restrictive factor for seedling survival (Małgorzata 2004). Although in our study we had found the moderate fresh water balance in both sides.

Genetic variation is one of the major important factors for the survival of populations in adverse condition. In our study population of Stiwollgraben showed high level of genetic variation and the population of Leininger Riese under investigation and we don't have the result yet.

Although English yew is a damage tolerant species, stem damages increase the susceptibility of other biotic infections. Yew is notably susceptible to *Phytopthera* sp. root diseases (Strouts 1993) and ramorum dieback (*P. ramorum*) (Lane *et al.* 2004). We have observed Gall mite at Leininger Riese whereas in Stiwollgraben was absent.

From the above discussion we have drown Table-4, which is representing the major factors related to yew decline in two Austrian gene conservation forests.

Table 4. Problems related to yew population in two Austrian gene conservation forests

Major problem related to yew declination	Gene conservation forest	
	Stiwollgraben	Leininger Riese
Browsing by herbivore	high	high
Predation by rodent	not measured	not measured
Competition for light	high	high
Genetic variation	high	under investigation
Illegal cutting	present	present
Abiotic damage	present	present
Fungal diseases	not found	not found
Biotic damage (gall mite)	not found	present
Low Public awareness	present	present

Conservation of yew Population

A number of causes regarding the yew declination have been point out in different parts of the paper. From the results of the recent studies the following recommendations can be formulated for management and conservation of English yew populations in Austria:

Yew populations with a minimum size of 500 individuals should be dispersed or connected in the landscape to maintain the viability.

For controlling the browsing pressure, herbivory should be excluded from the forest by establishing fences (Dhar *et al.* 2006b) or reduced in number (if the population size is small).

Fences and single protection measures with shelters were established at both sites to reduce the browsing pressure.

Predation by rodent should be checked scientifically.

Appropriate light and micro climatic conditions (moderate crown closer of the upper story) are needed to maintain the yew population. To maintain the light availability a continuous selective thinning reducing the competition with other tree species is advocated to improve the status of yew population (Czatoryski 1978; Svenning and Magard 1999; Dhar *et al.* 2006a). In our study different types of thinning operation were performed in both sites to find appropriate light requirements to maintain the yew population.

Genetic variation is one of the major important factors for the survival of populations in adverse condition. If the population size is small or the genetic variation is low artificial regeneration could be an important way to increase the genetic variation. Although the population of Stiwollgraben showed high level of genetic variation and population of Leininger Riese under investigation.

Although English yew is a damage tolerant species, stem damages increase the susceptibility of other biotic infections. Careful harvesting operations can reduce the damage during tree felling. However, it is very difficult to take protective measures for fungal or biotic damage. So prevention measures can be the easiest way to control such diseases. It is mentionable that "ringelbaum" (stop growth by cutting the phloem fibres with chainsaw) was done which will remove later on.

Public awareness will help to enhance the knowledge and ecological importance about yew (Vacik *et al.* 2001). Regular information and publications might help to increase the level of awareness and improve the overall knowledge about this species in the general public. Local foresters have been initiating public awareness programme by public media at both sites. Also the presence of research activities at the site has positive effects on the public awareness.

If yew trees need to be cut, it should be done 25 cm above from the ground as yew can produce more sprouting buds from that origin.

The success of yew regeneration should be evaluated by a regeneration survey in 5–10 year cycles. The ongoing monitoring programm at our study sites will help to investigate the regeneration status in future.

Conclusions

For the yew population in Stiwollgraben proper management strategies are applied to maintain its present health condition. On the other hand well-defined management strategies are needed to increase the health condition in Leininger Riese. However, the recommendations which are given are likely to change as new biological information become available they provide an initial framework for developing more comprehensive conservation guidelines for the future investigation.

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8.3 Structural diversity of English yew (*Taxus baccata* L.) populations

Structural diversity of English yew (*Taxus baccata* L.) populations

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Abstract:

In Europe English yew (*Taxus baccata L.*) is an endangered tree species. Intensive human land-use and the effects of forest management caused a decrease of the yew populations all over Europe. In Austria gene conservation forests are used for the *in-situ* conservation of populations of this rare tree species by silvicultural treatments. For improving the conservation management in these gene conservation forests this study analyses the use of structural diversity indices in assessing the relation between competition and viability of yew populations.

The structural indices mingling, tree-tree distance, diameter and tree height differentiation were determined for a structural group of four trees including the neighbouring trees of the male and female yews at the monitoring plots of a regular grid in three gene conservation forests. Although the three study sites show quite different environmental conditions for English yew it was found that the vitality of each individual yew is influenced by the inter-specific competition of the neighbouring tree species. Yews with a low vitality indicate the smallest mean distance to their neighbours and a high tree height differentiation. It is discussed that a combination of different structural indicators supports an integrative assessment of the gene conservation forests, which leads to a better evaluation of management practices with respect to the viability of the yew population.

Key words: English yew; tree-tree distance; diameter differentiation; height differentiation; neighbourhood analysis; vitality

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1. Introduction

Diversity has become an important issue within the discussion of sustainability in the last decade and the resilience and stability of a forest ecosystem is often linked to the diversity level (Swindel et al. 1984; Schuler 1998¸ Pommerening 2002). The structural, functional, and compositional attributes of a stand are often interdependent, so that attributes from one group may also be surrogates from another group (Noss 1990; Ferris and Humphrey 1999; Franklin et al. 2002;). Vertical and horizontal differentiation resulting from positioning, mixture and competition determines the spatial variation in microclimatic conditions, nutrient supply and structural complexity, thus directly and indirectly affecting the presence and abundance of species (Grime, 1973). In this context structural diversity generally considers species composition, horizontal and vertical variation within forests and on the other hand, spatial diversity considers these characteristics in space or arrangement of these dimensions in relation to each-others. The growth of trees is a reaction to their spatial context and conversely the growth processes influence the spatial forest structure (Dobbertin, 2005). For quantifying the spatial forest structure an impressive number of structural indices have been developed (Gadow et al. 1998; Pommerening 2002). These indices help to identify the effects of inter-specific and intra-specific competition on the viability of tree species and provide valuable information on stand evolution and its underlying processes (Wagner and Radosevich 1998; Pommerening 2006).

A good understanding of the dependencies between biotic, abiotic and human induced impacts on spatial forest structure is important for the adaptation of forest management activities and conservation measures especially for endangered tree species (Dhar et al. 2008). English yew (Taxus baccata L.) is a rare and endangered tree species in many European countries with restricted occurrence mainly due to intensive human land-use and the effects of forest management which changed the structure and species composition of the remaining forests (Jahn 1991; Svenning and Magárd 1999; Thomas and Polwart 2003). The main reasons for the decline of yew are widespread deforestation, light competition, selective felling of yew and browsing by herbivore (Bugala 1978; Tittensor 1980; Jahn 1991; Dhar et al. 2007). Research studies on endangered tree species usually focus on the environmental conditions of the population, the regeneration status and the causes of declination (Haeggström 1990; Vacik et al. 2001). Studies concerning the structural diversity of English yew and its relation to the viability of this endangered tree species have not been done so far. According to Lilpop (1931), Król (1978) and

Brzeziecki and Kienast (1994) yew is highly shade tolerant and can easily grow under shade conditions. However, the reproductive activity of English yew can be enhanced by better light availability (Svenning and Magård 1999) and its growth is influenced by competition (Svenning and Magård 1999; Dhar et al 2006). Firbas (1949), Averdieck (1971) and Deforce and Bastiaens (2007) reported that competition with Fagus and Carpinus species was one of the main reasons for yew decline in north-western Europe. Saniga (2000) described that a removal of 18-20% of the standing volume (especially F. Sylvatica and P. abies) reduced the inter-specific competition and allowed to increase the average height of yew.

At present yew is a rare and endangered tree species in Austria as well (Niklfeld 1999; Schadauer et al. 2003; Russ 2005). The gene conservation forest network in Austria allows to maintain such endangered tree species in-situ by silvicultural activities and conservation measures (Müller and Schultze 1998; Herz et al. 2005). A limited number of studies on the successful management of yew populations in gene conservation forests are available (e.g. Vacik et al. 2001; Dhar et al. 2006). In this context it is especially important to consider the relation between vitality, competition and structural aspects in conservation planning for improving the management of gene conservation forests of endangered tree species. The objectives of this contribution are (i) to compare the ecological condition of English yew populations in three gene conservation forests based on selected components of structural diversity (ii) to analyse the intra-specific and inter-specific competition and its relation to the vitality of English yew and (iii) to develop recommendations for conservation management based on the results of the analysis.

2. Materials and Methods

2.1 Characterisation of study areas

Three gene conservation forests have been selected from different geographic locations in Austria in order to study the relationship between vitality and competition (Table 1). The sites are situated in the Southern Alps of Carinthia (A), in the northern rim of the Alps of Upper Austria (B) and in middle hills of Styria (C). On each study site all living individuals of *Taxus baccata* (DBH $\geq$ 5.0 cm) were identified and marked. The data on the stand characteristics have been obtained on a regular grid of permanent sample plots.

Table 1. Characteristics of the gene conservation forests

stand	are [ha]	other trees species DBH ≥ 5.0cm [n*ha^{-1}]	basal area [m^2*ha^{-1}]	tree volume [m^3*ha^{-1}]	number of yews DBH ≥ 5.0cm [n*ha^{-1}]	vitality of yews [%]			
						1	2	3	4
reserve-A	18.3	1239 (+/-13%)	31.4	276	45	5.6	39.3	37.1	18.0
reserve-B	2.6	661 (+/-20%)	36.7	384	97	49.0	14.3	30.6	6.1
reserve-C	4.5	1008 (+/- 23%)	41.5	418	492	29.4	37.3	29.4	3.9

1= very vital, 2= vital, 3= less vital, 4= least vital

Study site (A) is located in the northern part of the Villacher Alps at Bad Bleiberg in the area of that so-called "Leininger Riese" on 940-1160 m a.s.l. with a total area of 18.4 ha and a density of 45 n*ha^{-1} English yews (828 individuals in total). The pole stand mainly consists of 58 % European beech (*Fagus sylvatica* L.) and 26 % Norway spruce (*Picea abies* (L.) H. Karst.), Scots pine (*Pinus sylvestris* L.), European larch (*Larix decidua* Mill.), Silver fir (*Abies alba* Mill.) comprise a total share of 12 % whereas only 4 % of the tree number ha^{-1} are English yew (*Taxus baccata* L.). The annual average rainfall and temperature is 1420 mm and 5.9°C.

The second study site (B) is located in the Northern Alpine Mountains on an area of 2.6 ha with a density of 97 n*ha^{-1} yews (253 individuals in total). European beech (*F. sylvatica* L.) is the dominating tree species (68 %), Silver fir (*A. alba* Mill.) has a proportion of 18 % and English yew (*T. baccata* L.) 13 %. Norway spruce (*P. abies* (L.) H. Karst.) and a mixture of broadleaved trees (*Acer pseudoplatanus* L., *Fraxinus excelsior* L. *Sorbus aria* (L.), Crantz., *Quercus* sp.) play a minor role in regards to species composition . The elevation of the site is 480-530 m a.s.l, the average annual rainfall and temperature is 1573 mm and 8.2°C.

The third study site (C) is situated in the Eastern Alpine Mountains with an estimated area of 4.5 ha at 580 to 700 m a.s.l. and a density of 492 n*ha^{-1} yews (2236 individuals in total) respectively. The pole stand of reserve C is dominated by 36 % European beech (*F. sylvatica* L.), 18 % Norway spruce (*P. abies* (L.) H. Karst.) and 33 % English yew (*T. baccata* L.). Some small proportions of Scots pine (*P. sylvestris* L.), European larch (*L. decidua* Mill.), Silver fir (*A. alba* Mill.) and broadleaved trees (*A. pseudoplatanus* L., *Ulmus glabra* Hudson, *F. excelsior* L. *S. aria* (L.) Crantz.) are part of the forest as well. The annual average rainfall and temperature is 1060 mm and 7.7°C respectively.

For further details according to the characterisation of the study sites the reader might refer to Vacik et al. 2001, Dhar et al. 2006 and Aigner 2007.

2.2. Quantifying forest structure

For quantifying the forest structure a regular grid of permanent sample plots with 30×30 m for reserve B and reserve C (in total 22 and 48 plots) and with 50×50 m for the reserve A (72 plots) were set up. At each sample plot the nearest male and female yew to the centre of the circular plot was selected as a reference tree (reserve A: n=140, reserve B: n=35 and reserve C: n=96) for the neighbourhood analysis. Tree height and DBH of each reference tree and the three neighbouring trees as well as the distance between the four trees were measured. The structural group of four (a male and female reference tree and their three neighbouring trees) was considered as computational unit for the calculation of the structural indices like species mixture (mingling), DBH and height differentiation as well as distance to neighbours (Table 2) according to Füldner (1995). As both male and female yews are important for the reproduction process, it was necessary to include both to an equal share in the analysis.

Mingling (DM_i) describes the species mixture of English yew and its neighbouring trees. A structural group of four allows to describe the mingling with four discrete elements (0.00, 0.33, 0,66 and 1.00). The bigger the mean DM_i- value is, the more different tree species are intermingled with yew, indicating a higher inter-specific competition (Pommerening 1997).

The diameter differentiation (TD_i) and heights differentiation (HD_i) allows to describe the relation between the diameter at breast height and the tree height of English yew and its surrounding trees (Füldner 1995). According to Pommerening (2002) we interpreted the positive and negative diameter differentiation values in order to analyse the dominance of the neighbouring trees with respect to yew. The differentiation was categorized according to the classes small differentiation (0.0-0.3 - the average size of a neighbour is 0-30 % larger or smaller than the reference tree), middle differentiation (0.3-0.5 - the average size of a neighbour is 30-50 % larger or smaller than the reference tree), large differentiation (0.5-0.7 - the average size of a neighbour is 50-70 % larger or smaller than the reference tree) and very large differentiation (0.7-1.0 - the average size of a neighbour is 50-70 % larger or smaller than the reference tree).

The tree-tree-interval (D_i) is characterized by the spatial arrangement of trees in the forest stand and allows interpreting the spatial relationship between yew and its neighbours. (Pommerening 1997).

Table 2. Indices for stand structure based on the structural group of four (according to Füldner 1995 and Pommerening 2002)

Attributes of stand structure	Calculated formula	Interpretation
Mingling	$DM_i = \frac{1}{n} \times \sum_{j=1}^{n} v_{ij}$	$v_{ij} = \begin{cases} 0 \rightarrow \text{tree i and neighbour j of the same species} \\ 1 \rightarrow \text{tree i and neighdour j of different species} \end{cases}$ n = Total number of neighbor tree (n = 3) $Mi \in [0,1]$
Distance to neighbours	$D_i = \frac{1}{n} \times \sum_{j=1}^{n} s_{ij}$	s_{ij} = distance of i th yew from j th neighbour n = number of sample trees
DBH differentiation	$TD_i = \frac{1}{n} \sum_{j=1}^{n} (1 - r_{ij})$	$r_{ij} = \frac{\text{Smaller DBH}}{\text{Higher DBH}}$ n = number of sample trees
Height differentiation	$HD_i = \frac{1}{n} \sum_{j=1}^{n} (1 - r_{ij})$	$r_{ij} = \frac{\text{Highest height}}{\text{Lowest height}}$ n = number of sample trees

The vitality of the trees is described according to four classes (1 = very vital, 2 = vital, 3 = less vital and 4= least vital). The vitality class of each individual English yew was assessed on a combination of the parameters crown length (relative percentage of the living crown), foliage density (relative percentage of living green needles) and crown formation (different types of crowns) qualitatively (Dhar et al., 2006). Each tree was classified according to a forest stand layer. The stand layers were identified in relation to the top tree height on a sample plot by three classes. The 1st class is indicating trees of the top layer of the stand, the 2nd class is representing the middle layer and the 3rd class is indicating the third layer.

3. Results

The three study areas showed significant differences (p = 0.05 %) (Fig. 1) according to the DBH-distribution of the English yews (DBH ≥ 5.0 cm). Reserve A and B have a wider range of the DBH distribution compared to reserve C. In reserve A and B about 40 % of the yews have a DBH below 15 cm whereas in reserve C it is 97 %. Considering the height class distribution reserve A significantly differs from the other two reserves A and B.

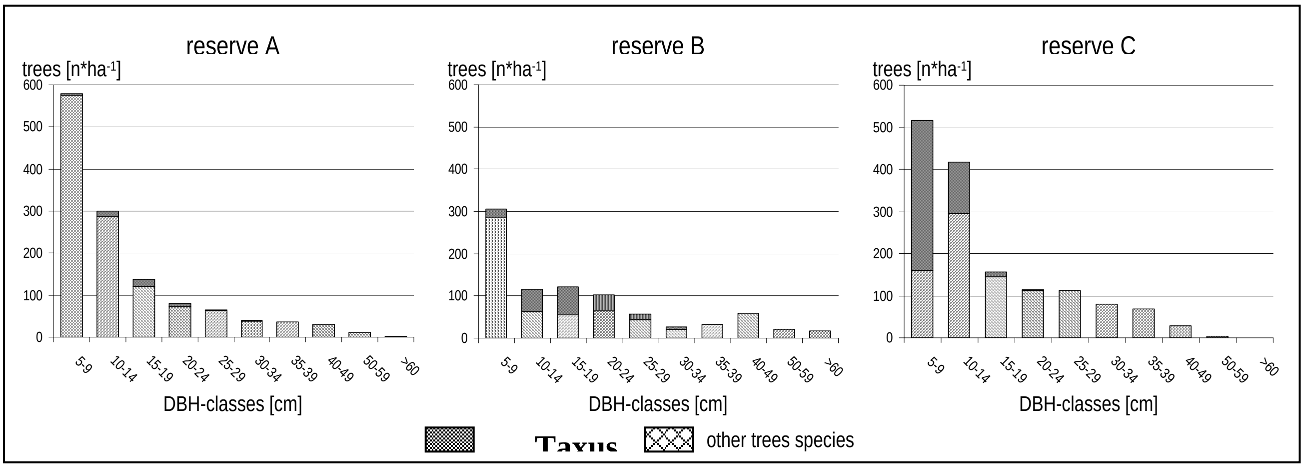

Figure 1. DBH distribution for all trees in the three gene conservation forests

According to the height distribution reserve C has the highest proportion in the lowest height classes, however the range of the values is only to a small extend higher for the other reserves (Fig. 2). Similar differences can be found according to the mean DBH value, the average tree height and the average percentage of the living crown of all English yews with a DBH ≥ 5.0 cm. In reserve A the mean DBH value, the average tree height and the average percentage of the living crown were 16.3 cm, 7.6 m and 68 % whereas 17.0 cm, 7,5 m and 70 % in reserve B and 8.8 cm, 6.3 m and 84 % in reserve C respectively. Reserve A was significantly different according to the mean tree height of yew and reserve C was significantly different in respect of the mean DBH value of yew (p = 0.05 %).

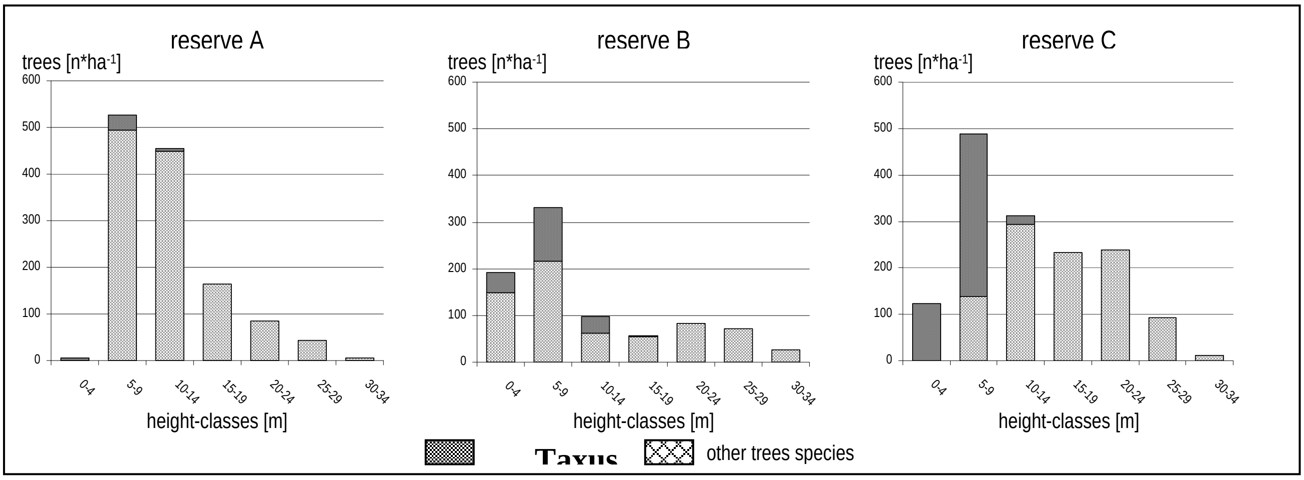

Figure 2. Tree height distribution for all trees in the three gene conservation forests

The tree density and the density of the yew population vary for all three sites. Although reserve A has the highest density of trees (other tree species than yew) with 1239 $n*ha^{-1}$, followed by reserve C (1008 $n*ha^{-1}$) and B (661 $n*ha^{-1}$) the density of yew is lowest for site A (45 $n*ha^{-1}$) followed by site B (97 $n*ha^{-1}$) and C (492 $n*ha^{-1}$).

With respect to results of the structural group of four the mingling value DM_i indicates different results for the three sites (Fig. 3). The relatively high proportion of the DM_i class 1.0 for site A (72.1%) indicates that yew is facing a high intra-specific competition compared to the other sites. In reserve C the reference yew trees of the structural group of four are mixed more intensively with itself as there was found a relatively high proportion of the DM_i class 0.0 (Fig. 3). The mean tree-tree-interval (D_i) indicates that all study sites are significantly different. Reserve B which has the lowest tree density has on average higher D_i values (3.02 m) whereas on the study sites A (2.37 m) and C (1.74 m) with a higher tree density the reference trees have smaller medium distances to its neighbouring trees (Fig. 3).

The results of the diameter differentiation TD_i for all three-study sites indicate that generally yew has a high negative differentiation and only in the reserves A and B some reference trees had a medium to large positive differentiation (Fig. 4). Reserve B has in general a quite balanced distribution between the classes which is directly linked to the wider range of the diameter distribution at this site.

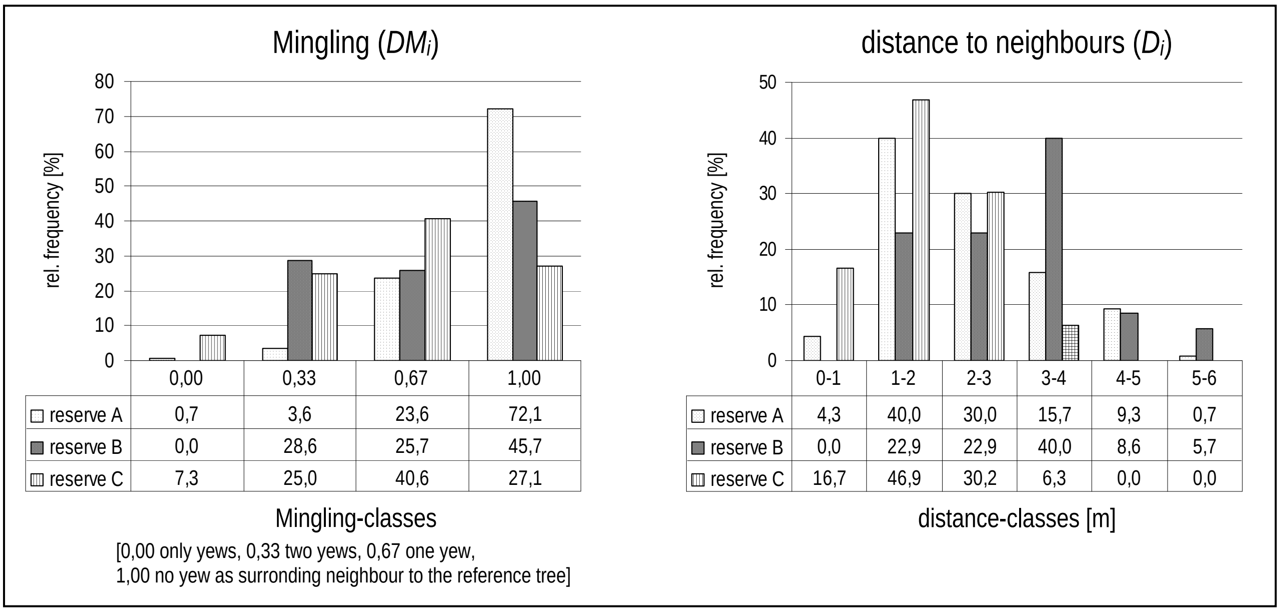

Figure 3. Mingling (DM_i) and distance to neighbours (D_i) for the reference tree English yew in the gene conservation forests

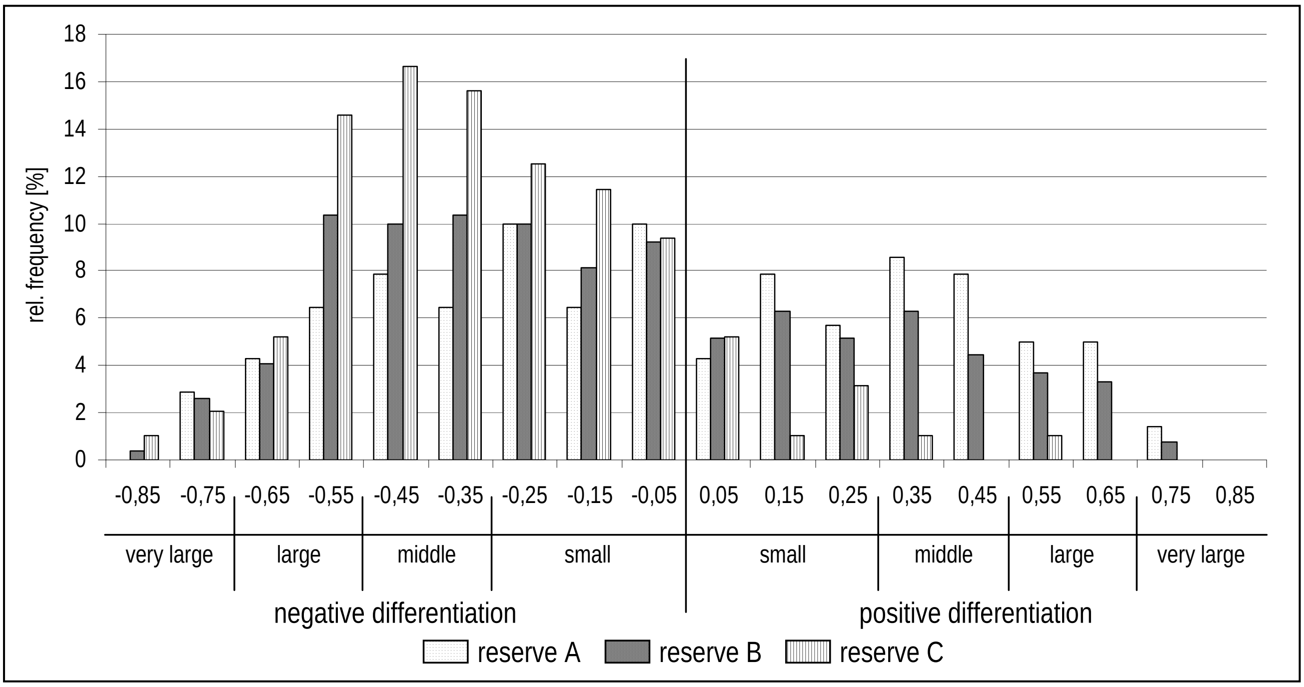

Figure 4. Diameter differentiation (TD_i) for the structural group of four in the three gene conservation forests

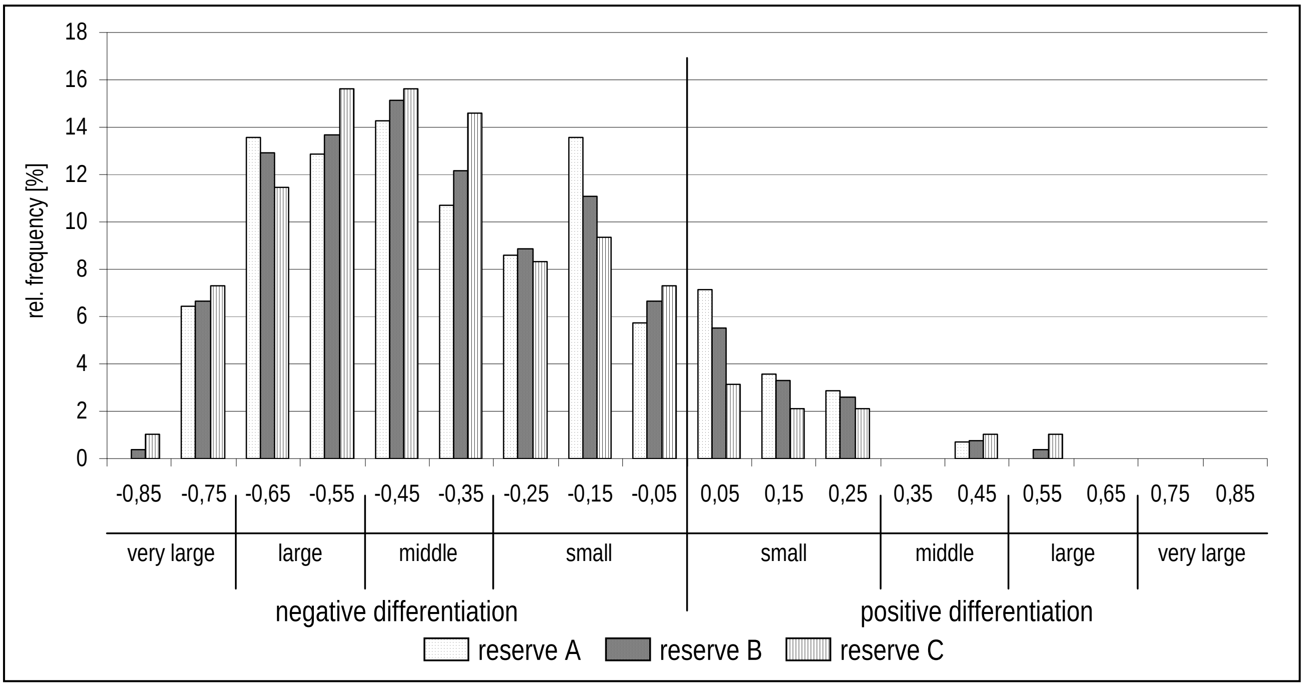

Figure 5. Height differentiation (HD_i) for the structural group of four in the three gene conservation forests

The tree height differentiation HD_i for the structural group of four shows a similar pattern for all three reserves whereas the negative differentiation is dominating and only a small number of reference trees are taller then their neighbouring trees (Fig. 5).

With respect to the health, reserve C shows a very good condition which is significantly different from reserve A and B (p 0.05 %), more than 66 % of the total yew population is very vital to vital whereas at study site A only 45 % of all individuals are represented in a vital to very vital health classes (Table 1). The vitality in reserve B is better than in reserve A although the competition between the tree species in reserve B is higher. Regarding the detailed analysis of reasons for the vitality of an individual yew tree there were found some significant differences. Figure 6 indicates the relation between the vitality class, the tree-tree interval (D_i) and the negative height differentiation HD_i for each individual reference tree of the structural group of four independently from the reserves studied. It can be found that the vitality of each individual yew is influenced by the inter-specific competition of the neighbouring tree species. The yews with a low vitality index (class 4) indicate a small mean distance to their neighbours (1.75 m) and a high mean negative tree height differentiation (up to -0.46). With an increase of the tree-tree distance the yews have been assigned a better vitality index and the tree height differentiation is getting lower. Table 3 indicates the mean values of *DMi*, TD_i and HD_i for each vitality class and the significant differences found. The results indicate that with an increase of the negative tree height differentiation the tree-tree distance has to increase as well to find yews with a high vitality. There is a non-significant trend towards better vitality with an increase of the tree-tree distance and with lower negative tree height differentiation (Fig. 6).

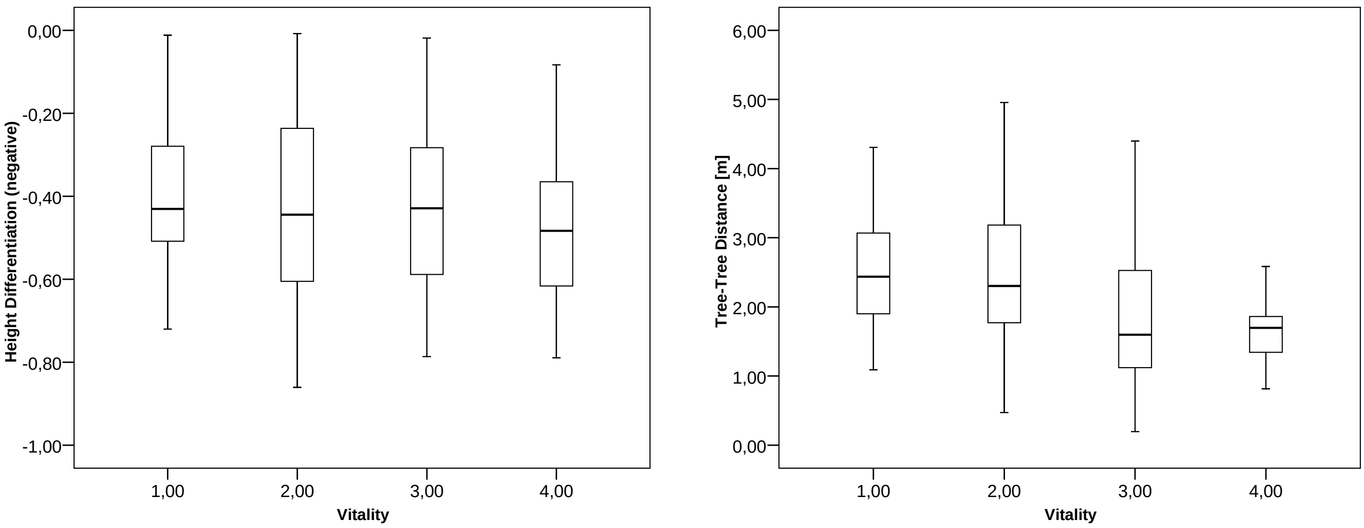

Figure 6. Box Plots for the tree-tree distance and the negative height differentiation for each yew from the structural group according to the vitality class

Table 3. Mingling (DM_i), Diameter differentiation (TD_i) and Height differentiation (HD_i) for each vitality class (numbers in parenthesis indicate standard deviations; different letters indicate significant differences (Duncan Multiple Range Test, p≤0.05)

Vitality class	Number of yews [n]	Mingling [DM_i]	distance to neighbours [D_i]	Diameter differentiation [TD_i]	Height differentiation [HD_i]
1	61	0.67	2.39 (±0.96) [b]	-0.10 (±0.36)	-0.29 (±0.29)
2	117	1.00	2.39 (±1.01) [b]	-0.10 (±0.41)	-0.34 (±0.28)
3	76	0.67	1.96 (±1.16) [ab]	-0.17 (±0.36)	-0.37 (±0.26)
4	17	1.00	1.75 (±0.62) [a]	-0.07 (±0.37)	-0.46 (±0.19)

In comparing the vitality class for all yews according to different forest stand layers and the tree height classes it can be seen, that the relative proportion of vital yews is increasing with the tree height of English yew. This trend is independently from the category of the forest stand layer (first, second, third) the individual yew was assigned to during the field sampling. In considering only the crown length (as one component of the vitality) it can be observed that in the height class 10-14m the mean crown length of yews is 59 % for yews in the first stand layer, 67 % in the second layer and 78 % in the third layer. The results indicate that with an increase of the individual tree height of yew the chance to find a very vital to vital yew is linked to the social status of yew. Yews with a low vitality class (3 and 4) are mostly co-dominant or sub-dominant tree species (Fig. 7).

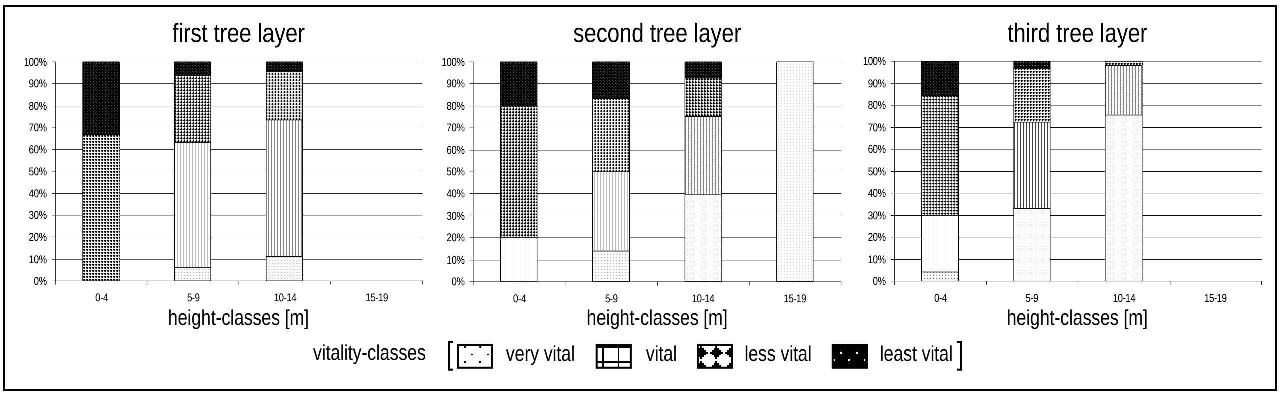

Figure 7. Relative proportion of the vitality class in different forest layers according to tree height

4. Discussion

Structural diversity is an important indicator for forest management as the understanding of tree species distribution and individual growing conditions is linked (Pretzsch 1995). This study analysed the magnitude of the competitive effects of neighbouring trees on the vitality of English yew as a function of the distance to and the size of neighbouring trees. The gene conservation forests analysed in that study show quite different environmental conditions for English yew, but the effects of the intra- and inter-specific competition are comparable. The mingling value indicated that reserve A has the highest species diversity and more than 72 % of all structural groups of four had all neighbours from different tree species while in reserve C only 27 % of such cases could be found. According to tree species mixture in reserve A high inter-specific competition is represented whereas reserve C illustrated a high intra-specific competition due to the overall high density of yews in the young stand development phase. Reserve B with the lowest tree density has the highest average DBH for yew, which is followed by reserve A and C respectively. Although yew is a shade tolerant tree and grows in the understory of the respective stands the results of our study indicate a link between intra- and inter-specific competition and tree growth. These results were found by other authors as well (compare Kórl 1978; Brzeziecki and Kienast 1994; Svenning and Magård 1999) and indicate that maximal growth of yew is related to a better light availability as well (Pridnya 1984; Saniga 2000).

The diameter differentiation allows the interpretation of the relationship between the competition of the reference tree and its neighbouring trees. Highest range of positive diameter differentiation was found in reserve A, followed by reserve B and reserve C. On the other hand reserve C showed a wide negative differentiation, which is followed by B and A. The range of the positive height and DBH differentiation is smaller then the negative differentiation which supports the observation that yew is not a dominant species in the three populations although English yew showed high number of individual species (e.g. 492 n ha^{-1} in reserve C). Regarding the cases of a positive differentiation it can be found that the yews which are taller than the neighbouring trees are mostly surrounded by yews as well. There are almost no cases within the positive differentiation where the neighbouring trees are not yews. However, the results indicate that with an increase of the height differentiation the tree-tree distance has to increase as well to find yews with a high vitality. Yews with a low vitality class indicate a small mean distance to their neighbours (1.75 m) and a high mean negative tree height differentiation. Obviously it can be assumed that the vitality of yew is more related to inter-specific competition as yew itself does not affect the vitality of its neighbouring yews. There is a trend observed, that yews with a high inter-specific competition have a shorter crown length then yews with low inter-specific competition which support the process of natural pruning. However, to our interpretation there is not a direct link between the distance of neighbours and the process of natural pruning of yew. According to the limitation of our data (only one observation) we could not test the role of neighbouring trees regarding natural pruning and further investigations should help to give more insight to that question.

English yew is a slow growing long living tree species and mostly found in the third layer of temperate broadleaved forests (Svenning and Magård 1999;Thomas and Polwart 2003). In that context we would have been generally expected that the vitality of yew is lower with an increase of the tree height as the intra- and inter-specific competition increases with an increase of the tree height. This hypothesis could be proved by our findings. We have found that the yews growing in the third layer have a more or less higher relative proportion of the very vital to vital vitality index then the other two layers as the competition with the co-dominant and dominant tree species is higher. These findings can be justified by the fact that yew might be mostly adapted to the situation in the third tree layer as a shade tolerant tree (Lilpop 1931; Kórl 1978; Brzeziecki and Kienast 1994). But although yew is adapted to the environmental situation Iszkulo (2005) mentioned that the average height and diameter of yew is lower at darker light conditions compared to those with better light conditions.

The findings of this study support the ongoing discussion that traditional conservation strategies may not be sufficient in order to maintain a population of slow growing, long living tree species predicted to be in long term decline (Vacik et al. 2001; Dhar et al. 2008). The range of management options should reflect all possible activities for maintaining yew, from minimal protection to a maximum of conservation activities. According to the analysis of the current environmental condition the major threats for the population must be identified and management strategies should be developed based on the know how of local experts and research findings. In this context the analysis of the relationship between vitality of English yew, competition and structural diversity allows to adapt conservation management strategies (Montes et al. 2005). The activities in the gene conservation forests should focus on moderate selective thinning in order to reduce the inter-specific competition. Especially the growing conditions for the co- and subdominant yews should be improved to increase seed production and allow continuous regeneration. According to Drapier (1993) and Wilhelm and Ducos (1996) this kind of treatment is particularly beneficial for the growth and conservation of target species. A “do nothing” strategy would reduce the viability of the yew population on the long run by increasing the competition within or among the species. However, the silvicultural activities have to be done in a moderate way as intensive thinning would lead to a reduction of the vitality of yew as well (e.g. loss of needles, risk for snow breakage, damages to bark) according to the rapid change of light conditions.

In general it could be shown that a combination of different structural indicators supports an integrative assessment of the gene conservation forests, which leads to a better evaluation of management practices with respect to the viability of the yew population. In the last few decades an impressive number of structural indices have been developed to quantify spatial forest structure and it has also been suggested that they can be used as surrogate measures for quantifying biodiversity (Pommerening 2002). The structural attributes of forest stands are increasingly recognized as being of theoretical and practical importance in the understanding and management of forest ecosystems because structure is the attribute most often manipulated to achieve management objectives following the establishment of a forest stand (Franklin et al. 2002). The repeated structural analysis of the gene conservation forests by the use of the structural group of four allows therefore to monitor the effect of thinning operations on the structure and viability of the populations.

5. Acknowledgement

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8.4 Genetic variation of English yew (*Taxus baccata* L.) populations in the eastern Alps and its implications for conservation management

Submitted to Ecological Research

Genetic variation of English yew (*Taxus baccata* L.) in the eastern Alps and its implications for conservation management

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Abstract: The English yew (*Taxus baccata* L) is an endangered rare tree species in Austria. More than 600 bud sample were collected from seven populations in three regions of the eastern Alpine mountains for estimating genetic structures by using isozyme gene markers. Nine gene loci encoding for seven enzyme systems were investigated. The revealed 32 alleles indicate a higher multiplicity of the east alpine gene pool compared to other European regions. English yew showed a high level of genetic variation with a mean number of alleles per locus (*A/L*) of 2.7. Total 76.4 % of the loci were polymorphic, the average expected heterozygosity was (*He*) 0.274 and the mean observed heterozygosity (*Ho*) 0.238. The relative proportion of genetic differentiation among the regions was found with 6.2 %, the level of gene flow was high (*Nm* = 3.78) and the level of inbreeding (0.130) among the regions medium. It is concluded that the obligatory out crossing (dioecious plant), the long generation time, the ability to regenerate from stump, the seed dispersal by bird and rodent might contribute to the high level of genetic variation within the population. The transfer of plant material is discussed as active conservation measure.

Key words: Endangered species, Geographic variation, Conservation, Isozymes,

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1. Introduction

English yew (*Taxus baccata* L.) is a slow growing, shade tolerant, long-living dioecious conifer tree of the temperate forests. It grows as subdominant but sometimes habitat-determining species in a range of different forest types (Thomas and Polwart 2003). In Austria yew is predominantly found in Beech (*Fagus sylvatica* L.), Silver Fir (*Abies alba* Mill.) Norway spruce (*Picea abies* L.) -dominated forests in the montane zone. In recent time the distribution of yew has been severely reduced due to natural disturbances and human interventions. The reasons for yew decline have been discussed in many papers (see Svenning and Magard 1999; Garcia and Obeso 2003; Thomas and Polwart 2003; Mysterud and Obstbye 2004; Dhar et al., 2006; 2007). Bugala (1978) suspected that a low level of genetic variation is one of the main reasons of yew decline as through the reduced number of individuals the loss of genetic variation leads to a loss of viability. In this context several studies (Lewandowski et al. 1995; Hertel and Kohlstock, 1996; Chung et al. 1999) have been done in order to test this hypothesis.

The estimation of genetic variation for isozymes of plants within and among population components can provide a basis for the analysis of the genetic diversity of populations (Hamrick et al., 1991). These estimates of isozyme diversity, along with information on population biology and ecology of plants, can also be used as yardstick to measure the effectiveness of *in-situ* and *ex-situ* conservation programmes of tree species. Studies of isozyme gene markers already contributed to our understanding of the genetic structure and geographic variation of forest tree species in different parts of the Alpine mountains (e.g. Müller-Starck 1995; Breitenbach-Dorfer et al. 1997, Hussendörfer 1999) and helped to analyse the migration pattern of tree species after the last glacial period (Kral, 1974; Ravazzi 2002).

A spectacular progress has taken place in the use of molecular markers like AFLPs or RFLPs (Nybom 2004) in the analysis of forest genetic variation, although the application of protein electrophoretic technique in population genetics during the past 20 years is still a competitive technique (Müller-Starck *et al.* 2005). Isozyme markers are a cost efficient tool and particularly recommended for genetic diversity studies (Glaubitz and Moran 2000). Moreover, studies with DNA markers matched the results of isozyme studies on geographic variation (e.g. Aagard et al. 1998; Li and Adams 1989). Variation of isozyme gene markers within and among populations has been extensively studied with conifer trees (Hamrick et al. 1992; Ledig 1998) but regarding yew only few studies have been made.

Most of the studies on the genetic structure of yew observed a high level of genetic variation for English yew (e.g. Leinemann and Hattemer 2007), but low variation for yew species from the

American continent (e.g. Senneville et al. 2001). El-Kassaby and Yanchuk (1994) found moderate levels of genetic diversity in Pacific yew (*T. brevifolia*) compared to that present in associated temperate-zone species. Similar results where obtained by Wheeler et al. (1995), who stated that Pacific yew shows notably less allozyme diversity than most other gymnosperms with similar life-history characteristics. Hertel and Kohlstock (1996) investigated genetic variation and geographic structure of English yew in North-Eastern Germany, where they observed differences between populations from the Baltic Sea shore and the inland. Further studies on the genetic variation of German relic-populations (e.g. Cao et al. 2004) and Swiss populations were published (Hilfiker et al. 2004), but information on the genetic variation of English yew from the Eastern Alps is still missing.

In this study seven English yew populations from the Eastern Alps were analyzed by isozyme gene markers. The obtained data are used to describe the actual level of genetic variability of the English yew populations and provide a better understanding of the genetic relationship among the Austrian populations. In this context it will be analyzed whether English yew follows a similar migration pattern than the associated tree species, e.g. Silver fir (*Abies alba* L.: Breitenbach-Dorfer et al. 1995), after the last glacial period. Conclusions on an effective conservation management for the endangered tree species will be given.

2. Materials and methods

2.1. Populations

All together 7 populations and more than 600 samples from different regions in the eastern Alps were collected (Table 1). We selected indigenous populations representing the southern (“Bad Bleiberg”), the eastern (“Stiwoll”, “Hirschwang”, “Piesting”), as well as the northern border (“Losenstein”, Almtal”, “Mondsee”) of the easternmost section of the Alps (Figure 1), which are herewith referred to as “regions”. Yew can generally be found there scattered in the forest (e.g. “Hirschwang”, “Piesting”) or as small “core populations” of more than 100 individuals (e.g. “Mondsee”: Aigner 2007) or even as remarkable “core populations” of more than 1000 individuals (e.g.” Stiwoll”: Dhar et al. 2006), surrounded by far-scattered yew individuals.

Table 1: Survey of the characteristics of the studied English yew populations

Pop. No.	Name of the site	Total area [ha]	Altitude [m]	Population size	Sampling unit	Sample size
1	Bad Bleiberg	18,5	900-1300	828	stand	75
2	Stiwoll	4.5	580 – 700	2236	stand	109
3	Hirschwang	scattered	700 - 900	approximately 80	side valley	40
4	Piesting	scattered	400 - 650	> 100	valley	61
5	Losenstein	39.6	540 – 680	1815	stand	122
6	Almtal	3.2	460 – 490	> 2000	stand	121
7	Mondsee	2.6	480 – 530	253	stand	95

Twigs from trees with a dimension of more than 5 cm diameter at breast height were selected at random for sample collection with the target to collect every third tree for the "small" populations (e.g. "Hirschwang") or more than 100 trees from the "remarkable" populations (e.g. "Stiwoll"), respectively (Table 1). Sampling of "Bad Bleiberg" is the only exception, where a cluster sampling (every second tree) was done in a limited part of the stand due to high snow cover (Table 1).

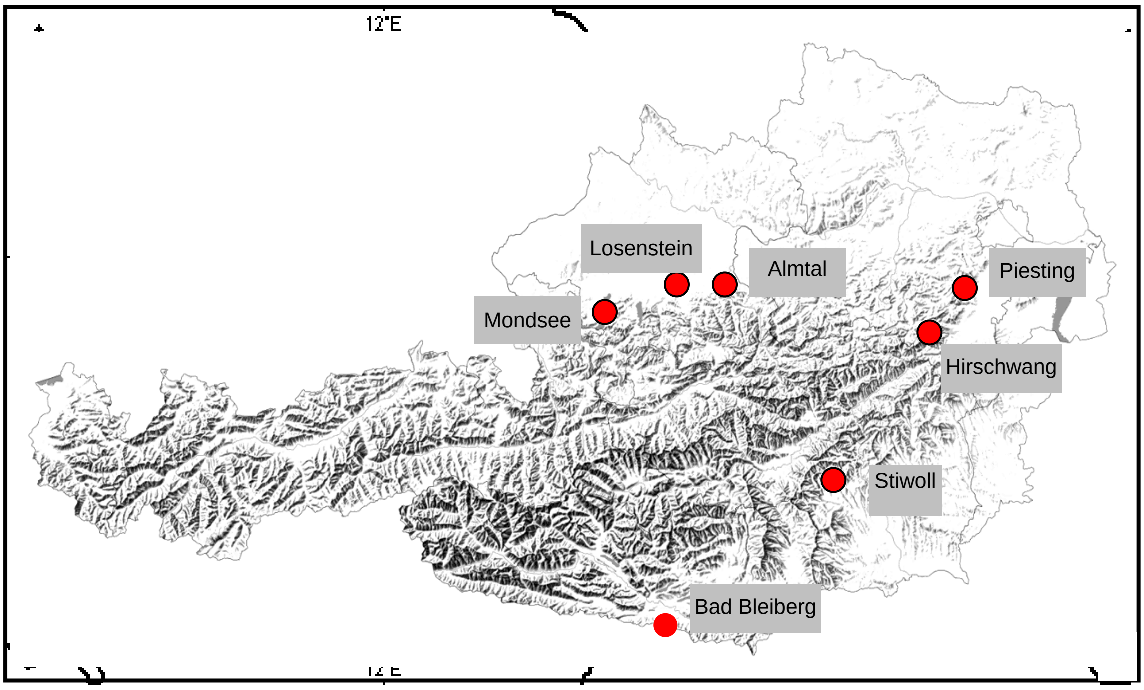

Figure 1: Location of the seven populations of English yew (*Taxus baccata* L.) studied in the range of Eastern Alpine Mountains

2.2 Electrophoresis

The apical meristem from two to three dormant buds per sample were taken for homogenization in the ice-cold Eppendorf tubes with 30 µL TRIS-HCL 2-Mercaptoethanol (0.15 %) extraction buffer (pH-7.4). Enzymes were separated by horizontal starch gel electrophoresis as described elsewhere (Hertel 1996; Konnert 2004).

Six Enzyme systems were selected for this study (Table 2), which are known to exhibit geographic variation (e.g. Breitenbach-Dorfer et al., 1997, Izawa et al. 2007). The mode of inheritance of the isozymes was verified by studying segregation of the macrogametophyte (Lewandowski et al. 1992; Hertel 1996; Klumpp in prep.). The alleles were numbered sequentially from the most anodal to the most cathodal allele for each gene locus and rf values were used for their identification (see Konnert 2004).

Table 2: Survey of enzyme systems and enzyme coding gene loci in buds of English yew

Enzyme	Gene locus	Observed No. of alleles	E. C. number
Aspartate-aminotransferase	AAT- A	2	2.6.1.1
	AAT- B	4	
Isocitrate-dehydrogenase	IDH-A	4	1.1.1.42
	IDH-B	5	
Leucine-aminopeptidase	LAP-A	3	3.4.11.1
	LAP-B	3	
Phosphoglucomutase	PGM - A	5	2.7.5.1
6-Phosphogluconate-dehydrogenase	6-PGDH- A	2	1.1.1.44
Shikimate-dehydrogenase	SKDH-A	4	1.1.1.25

2.3 Genetic parameters and statistical procedure

We used GSED-1.1 (Gillet 1998) computer program for data analysis. The genic multiplicity (M) was scored as the total number of observed alleles per deme (Hattemer et al. 1993, loc. cit. pp 262). Intra-populational variation was measured by means of the observed heterozygosity (H_o) and the genetic diversity (v; Gregorius and Roberds 1986), which is identical to the effective number of alleles (n_e; Crow and Kimura 1970). In addition, the intra-population differentiation (Gregorius 1987) was calculated, which is equal to Nei's "gene diversity" (H_e; Nei 1973) in case of large sample sizes. Both parameters are designated in the most common international way as ne and He consecutively. In order to quantify the potential of a population for producing genetically diverse gametes, the hypothetical gametic multilocus diversity (**v_{gam},** Gregorius 1978) was calculated. Allelic frequencies were used to score the average genetic distance (d_0, Gregorius 1974) over the studied gene loci. The distribution of genetic diversity within and among the regions was calculated according to Nei (1973) and F statistics according to Wright (1965): total genetic diversity (H_T) and its distribution within (H_S) and between (D_{ST}) the populations, the proportion of inter-population differentiation (G_{ST}) and the Wright fixation index (F) for each locus and each region were calculated by using the FSTAT computer programme (Goudet 2001). Positive values indicate an excess of homozygosity where as negative values indicate an excess of heterozygosity. The gene flow (Nm = (1-G_{ST} / 4 G_{ST})) was estimated indirectly by using the Nei's G_{ST} , where N = the effective number of population size and m = the proportion of the population repliced by migrants per generation (Slatkin and Barton 1989).

For the analysis of the relatedness among the 7 regions a hierarchical structure was constructed using the dendrogram according to Sneath and Sokal (1973). The unweighted pair group method (UPGMA) was used to determinate the variation in the genetic distance (d_0, Gregorius 1974) among the populations. Additionally we measured the variation among populations by differentiation among (sub-) populations (Dj, Gregorius and Roberds 1986)

3. Results

3.1 Genetic variation within the populations

In total 9 loci were investigated with the use of the 6 enzyme systems. Among them only two loci AAT-A and LAP-A were monomorphic in almost all populations except the stand "Stiwoll" where all 9 loci were polymorphic. LAP-B and 6-PGDH-A were found to be major polymorphic loci. The average percentages of polymorphic loci (P) for each population were 76.4 (Table-4), where the maximum was found in Stiwoll (100 %) and the minimum in Bad Bleiberg, Piesting and Almtal (67 %). This lower degree of polymorphism was due to the absence of the variation in SKDH-A for Bad Bleiberg and Almtal, and for AAT-B in Piesting.

A total of 32 different alleles were detected in the gene pool of the Eastern Alpine populations with an overall average of 24 alleles per deme (Table – 3). In some regions private alleles (Slatkin and Takahata 1985) have been found: the northern region (Losenstein, Almtal, Mondsee) has SKDH-A4 as a rare private allele and the eastern region (Hirschwang, Piesting) is characterized by the rare allele IDH-B5 (Table – 3). The mean number of alleles per locus (A/L) ranges from 2.4 to 2.8 for each sampled population with an overall average of 2.7 (Table-4). The effective number of alleles *ne* was 1,37 on average and did not vary much with the exception of "Bad Bleiberg", where the lowest value was found.

Table 3: Allele frequencies of 9 investigated gene loci in 7 populations of English yew from the border of the eastern Alps

Allele	Bad Bleiberg	Stiwoll	Hirschwang	Piesting	Losenstein	Almtal	Mondsee
AAT-A							
1	1.00	0.826	1.00	1.00	1.00	1.00	1.00
2	--	0.174	--	--	--	--	--
AAT-B							
1	0.120	0.165	0.112	0.049	0.451	0.120	0.216
2	0.860	0.835	0.863	0.951	0.549	0.864	0.774
3	0.020	--	0.013	--	--	0.017	0.011
4	--	--	0.013	--	--	--	--
IDH-A							
1	0.120	0.170	0.150	0.385	0.086	0.240	0.289
2	0.787	0.789	0.762	0.492	0.828	0.715	0.426
3	0.053	0.041	0.075	0.049	0.082	0.029	0.132
4	0.040	--	0.013	0.074	0.004	0.017	0.153
IDH-B							
1	0.120	--	0.075	0.066	0.123	0.145	0.074
2	0.087	0.023	0.050	0.049	0.078	0.004	0.126
3	0.780	0.922	0.863	0.877	0.766	0.835	0.800
4	0.013	0.055	--	--	0.033	0.017	--
5	--	--	0.013	0.008	--	--	--
LAP-A							
1	--	0.147	--		--	--	--
2	1.00	0.849	1.00	1.00	1.00	1.00	1.00
3	--	0.005	--		--	--	--
LAP-B							
0	--	0.009	--	--	--	--	--
1	0.733	0.885	0.438	0.566	0.492	0.620	0.389
2	0.267	0.106	0.563	0.434	0.508	0.380	0.611
PGM-A							
1	0.007	--	0.013	0.041	0.016	--	--
2	0.013	0.115	0.150	0.082	0.111	0.140	0.111
3	0.047	0.050	0.100	0.025	0.025	0.074	0.005
4	0.920	0.826	0.738	0.852	0.848	0.777	0.884
5	0.013	0.009	--	--	--	0.08	--
6-PGDH-A							
1	0.320	0.683	0.363	0.492	0.369	0.471	0.595
2	0.680	0.317	0.637	0.508	0.631	0.529	0.405
SKDH-A							
1	0.007	0.069	--	0.098	0.057	0.008	--
2	0.947	0.927	0.925	0.820	0.857	0.946	0.911
3	0.047	0.005	0.075	0.082	0.066	0.029	0.047
4	--	--	--	--	0.020	0.017	0.042
Genic multiplicity (M)	25	25	24	23	24	25	22

The observed heterozygosities (*Ho*) within the populations varied from the 0.178 to 0.272 with a mean of 0.238. The highest *Ho* value was observed in "Losenstein" (0.272) whereas the lowest value was found in "Bad Bleiberg" (0.178). On the contrary, expected heterozygosities (*He*) ranges from 0.230 to 0.304 with an average 0.274. The highest *He* value was found in "Mondsee" (0.304) and the lowest value in "Bad Bleiberg" (0.230). So, the observed heterozygosities were always lower than the expected heterozygosities for all populations, resulting in positive values of Wright's index (*F*). This indicator (F) for inbreeding amongst close relatives showed the highest value for the "Bad Bleiberg" deme (Table – 4).

Table 4: Genetic variations in 7 yew populations from the eastern Alps

Population	Parameters						
	Poly. Loci 95 %	*A/L*	*ne*	Hypo. Gamete. Diversity	*Ho*	*He*	Wright's Index [*F*]
Bad Bleiberg	67	2.8	1.29	12.57	0.178	0.230	0.228
Stiwoll	100	2.8	1.36	17.26	0.232	0.267	0.124
Hirschwang	78	2.7	1.36	21.24	0.242	0.270	0.105
Piesting	67	2.6	1.38	27.72	0.260	0.279	0.066
Losenstein	78	2.7	1.42	31.98	0.272	0.299	0.089
Almtal	67	2.8	1.36	21.50	0.228	0.267	0.149
Mondsee	78	2.4	1.43	42.60	0.257	0.304	0.155
Average	76.43	2.7	1.37	24.98	0.238	0.274	0.131

P = percent of polymorphic loci; *A/L*= mean number of alleles per locus; *ne* = effective number of allele per locus; *Ho* = observed heterozygosity; *He* = Hardy-Weinberg expected heterozygosity or genetic diversity; *F* = Wright's Fixation index

3.2 Genetic structure and inbreeding

The population fixation index value (F_{IS}) ranged from –0.075 to 0.666 with an overall average 0.130 which is indicating that the distribution of the alleles in most of the loci is not close to the Hardy-Weinberg equilibrium due to high frequency of homozygotes (Table-5). Negative (F_{IS}) values were observed for the loci AAT-B and LAP-A. The overall F_{IT} values are positive and range from 0.47 to 0.673. The F_{ST} values used to measure the amount of population differentiation varied from 0.015 to 0.165 with an average of 0.076. The value of total genetic diversity (H_T) ranges from 0.499 to 0.042 with an overall average for all loci of 0.292. The genetic diversity with respect to the inter-locus variation (H_S) in each region varied from 0.471 to 0.037. The proportion of the total genetic diversity among the populations (G_{ST}) varied between 0.014 and 0.147, the mean value among the regions was 0.062. The estimated gene flow based on the Nei G_{ST} indicated a quite high value (3.78).

Table 5. Gene diversity statistics for each locus of all seven-yew populations

Locus	H_T	H_S	G_{ST}	F_{IT}	F_{ST}	F_{IS}
AAT-A	0.049	0.041	0.147	0.419	0.165	0.304
AAT-B	0.307	0.280	0.089	0.047	0.113	-0.075
IDH-A	0.482	0.450	0.067	0.185	0.078	0.116
IDH-B	0.293	0.289	0.014	0.673	0.020	0.666
LAP-A	0.042	0.037	0.124	0.120	0.142	-0.025
LAP-B	0.484	0.433	0.105	0.208	0.131	0.088
PGM-A	0.290	0.286	0.016	0.051	0.015	0.037
6PGDH-A	0.499	0.471	0.055	0.126	0.068	0.063
SKDH-A	0.178	0.175	0.018	0.053	0.020	0.033
Mean	0.292	0.274	0.062	0.196	0.076	0.130

3.4 Genetic differentiation among the populations

The snail diagram (Fig. 2) depicts the gene pool differentiation (*Dj*) of the 7 observed English yew populations in Austria. The site “Stiwoll” is more strongly differentiated compared with other populations which indicates the uniqueness of this population. “Losenstein” and “Mondsee” both are outside from the average differentiation and all demes sampled from other regions were less differentiated amongst each other, especially “Almtal”.

Estimation of genetic distance among the populations provides a further measure for the assessment of the degree of differentiation (Gregorius 1974) between the yew populations (Table-6). The values ranged from 0.064 to 0.190 among all regions. The lowest distance was observed between “Almtal” and “Hirschwang” (0.064), which is followed by the pair

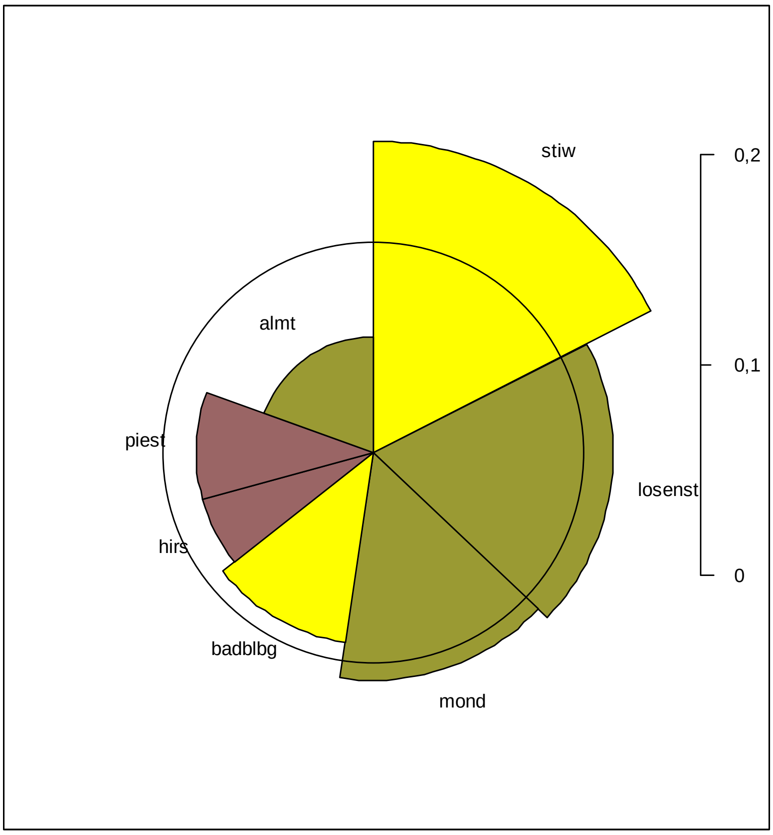

Figure 2: Genetic differentiation (*Dj*) among seven populations of English yew from the border of the Eastern Alps

Table 6. Genetic distances among 7 investigated English yew populations from the eastern Alps.

Population	Population					
	Stiwoll	Hirschwang	Piesting	Losenstein	Almtal	Mondsee
Bad Bleiberg	0.144	0.080	0.118	0.101	0.071	0.142
Stiwoll		0.165	0.170	0.190	0.133	0.185
Hirschwang			0.101	0.086	0.064	0.109
Piesting				0.130	0.082	0.100
Losenstein					0.111	0.129
Almtal						0.112

"Almtal" and "Bad Bleiberg". The highest value was found between "Losenstein and Stiwoll", and "Stiwoll" showed distinct distance with all populations. The dendrogram allowed to visualize the genetic distance of the geographically isolated populations (Fig 3). The genetic relationships among the 7 populations was analysed with the UPGMA clustering technique. The dendrogram indicates that the sampled trees from the population of "Stiwoll" are genetically distinctive with other populations whereas populations from “Hirschwang” and “Almtal” are closely related although they are geographically not close to each other (see Fig. 1).

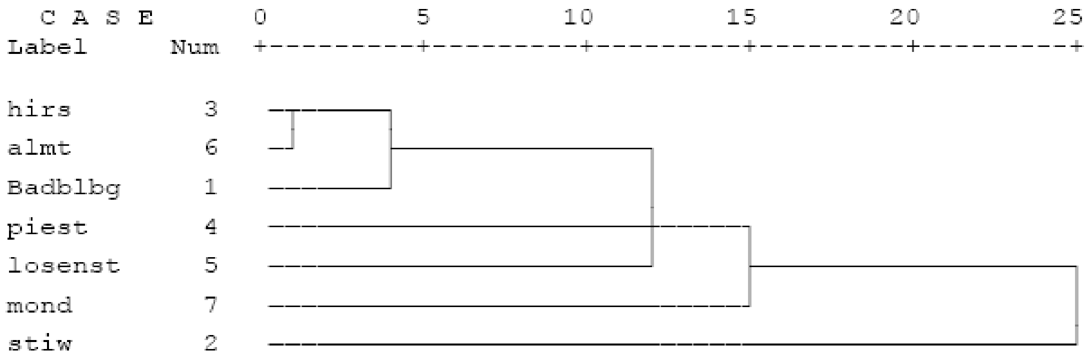

Figure 3: Cluster diagram (UPGMA) based on the genetic distance (*D_0*, GREGORIUS 1974) of seven populations from the border of the Eastern Alps

4. Discussion

4.1 Genetic variation within the population

This study describes the first results of the genetic variability of yew populations in Austria and assesses the geographic variation. Compared with other studies on gymnosperms (compare Hamrick et al., 1992) this study on yew populations presents a high level of genetic diversity. Our results (*A/L* = 2.7, *P* 95 = 78.6 %) of English yew are comparable with other studies on yew (Table – 7) in central Germany (e.g. Cao et al. 2003) and Poland (Lewandowski et al. 1995). Moreover our results exhibit higher values of genetic diversity compared to American and Asian species of the genus *Taxus* (e.g. Wheeler et al. 1995; Chung et al. 1999), as mentioned above (see Table – 7).

It is mentionable that genetic diversity within the population is mainly influenced by the geographic distribution of the species, mating system, the process of seed dispersal and the method of reproduction (Hamrick et al. 1992). We observed a high level of genetic variation within Eastern Alpine populations but some differences to other studies in eastern and central Europe with regard to the comparison of the observed (*Ho*=0.238) and expected (*He*= 0.274) heterozygosity (Table-7). Some of the European studies have found a lower value for the expected heterozygosity (*Ho* = 0.340, *He* = 0.316, Cao et al. 2003) or balanced values (e.g. *Ho* = 0.286, *He* = 0.279, Lewandowski et al. 1995) similar to studies on other woody plants

Table 7: Survey on the genetic variation of different *Taxus* species

Species	No. of Gene loci	Parameters					Hypo. gamete diversity	Literature
		Polym loci *P* 95 (%)	*A/L*	*ne*	*Ho*	*He*		
T. baccata	**9**	**76 . 43**	**2.7**	**1. 37**	**0. 238**	**0. 274**	**24. 98**	**This study**
	18	61.1	2.2	1.37	0.286	0.279	--	Lewandowski et at. 1995
	6	80.6	2.6	1.48	0.340	0.316	--	Cao et al. 2004
	5	--		1.45	0.302	0.308	7.84	Tröber et al. 2004
T. cuspidata	23	45.0	1.4	1.78	0.154	0.192	--	Chung et al. 1999
	14	45.7	1.7	--	0.172	0.168	--	Lee et al. 1999
T. *brevifolia*	21	42.3	1.7	--	0.085	0.166	--	El-Kassaby & Yanchuk 1994
	22	33.5	1.5	--	0.122	0.124	--	Wheeler et al. 1995
T .canadensis	22	26.5	1.32	--	0.102	0.098	--	Senneville et al. 2000

(Hamrick et al. 1992). For the Asian and American studies it is obvious (Table 7), that there are findings with balanced values of both heterozygosity parameters (e.g. Senneville et al. 2000) or cases of relatively lower values in *Ho* (El-Kassaby and Yanchuk 1994; Chung et al. 1999). A closer look to the studies reveals the fact, that needle or apical meristeme based analyses obviously lead to lower values of *Ho* in comparison to *He* in American and Asian species (e.g. El-Kassaby and Yanchuk 1994, Chung et al. 1999) and to balanced values for macrogametophyte based studies (e.g. Senneville et al. 2000). Is there any influence on the results caused by the choice of the tissue or by a sampling technique? For monoecious plants it is known, that the interpretation of a zymgram from diploid tissue can be biased for only some few allele combinations (e.g. Konnert 2004) and therefore only slight differences in the results may emerge. In spite of the fact, that genetic structures of male and female yew groups were found to be comparable in a study from northern Germany (Hertel and Kohlstock 1996), there seems to be an influence in assessing population genetic parameters, when the sex of the sampled individuals is disregarded. This effect may be boosted, when large isolated populations are sampled (Table 4: Stiwoll; see also Cao et al. 2004).

Hamrick et al., (1992) reported that the geographic location is the most influential factor for genetic diversity. In addition slow growing and shade tolerant individuals like English yew have higher opportunities for the accumulation of mutation (Ledig 1986) as well as a greater environmental adaptability (Korl 1978). The breeding system is directly associated with the variation within a population of long living woody plants (Brown 1979; Hamrick et al. 1992). Hamrick et al. (1992) mentioned that long living woody plants with both sexual and asexual modes of reproduction show a high level of genetic diversity within the population compared to those of sexual reproductive species. English yew allows both sexual and asexual modes of reproduction and the sprouting from stumps, roots and branches indicates a high probability for genetic diversity (Chung et al. 1999; Cook 1983). But the mixture of sexual and asexual reproduction seems to lead to one of the obvious characteristics for the dioecious yew: the deficit of heterozygotes in large populations and the ability to balance the ratio of heterozygotes and homozygotes in the endangered, small relic-populations (see Cao et al. 2004) or in metapopulations out of scattered individuals combined with core populations (Table 4: Piesting, Losenstein).

4.2 Genetic Structure

From this study it was found that the expected heterozygosity (*He*) is higher then the observed heterozygosity (*Ho*). The result from the Wright's fixation indices support the general trend that many out-crossing species show heterozygosity values which are lower than the expected, although that heterozygosity theoretically predicted should be favoured in out-crossing plants (Brown 1979). Wright's F_{IS} value shows significant deficiency of heterozygotes at one polymorphic locus (IDH -B) and the combined F_{IS} value over all loci was 0.130, which reflects a substantial deficit of heterozygotes (Table 5). These deficiencies within populations indicate that selection for homozygotes, family structures within a restricted neighborhood, and consequently mating among relatives may occur within the populations as English yew has a dioecious sexual system. A similar trend has been observed for *T. cuspidate* (Chung et al. 1999) and *T. brevifolia* (El-Kassaby and Yanchuk 1994). This interpretation is confirmed by the fact, that the unscheduled cluster sampling of "Bad Bleiberg" resulted in the highest *F*-value of this study (Table 4).

The proportion of total genetic diversity partitioned among regions (G_{ST}) is 0.062 which means that only 6.2 % of the total identified genetic variation can be explained with the interregional gene differences. The majority of genetic variation (93.8 %) resided within the regions observed. The mean G_{ST} value for the English yew is comparable with other woody plants with similar ecological traits as well as similar life history (G_{ST} = 0.073 for gymnosperm; G_{ST} = 0.065 for populations with regional geographic range; G_{ST} = 0.077 for populations with out crossing wind pollinated system; G_{ST} = 0.051 for seed dispersal by animal ingestion, Hamrick et al 1992). But the values are lower than results from studies with woody species with gravity-dispersed seeds (G_{ST} =0.131) and higher than the widely distributed woody species (G_{ST} =0.030) (Hamrick et al. 1992). Compared with other *Taxus* species such as *T. cuspidate* G_{ST} = 0.056 (Chung et al. 1999), G_{ST} = 0.067 (Lee et al. 2000) and G_{ST} =0.077 for *T. brevifolia* (El-Kassaby and Yanchuk 1994) our results are within that range. The indirect estimation of gene flow (*Nm* = 3.78) is high (according to Ellstrand 1992) and quite similar with other investigations (El-Kassaby and Yanchuk 1994; Chung et al. 1999; Lee et al. 1999). El-Kassaby and Yanchuk (1994) observed that *T. brevifolia* showed a high level of gene flow due to seed dispersal through birds and animals. As many studies regarding the seed dispersal of English yew prove that seeds were dispersed by birds and rodent (see Bartkowiak 1978; Fuller 1982; Snow and Snow 1988; Hulme 1996) it is quite likely that seed dispersal by birds and animals enhance the long-distance gene flow for the English yew. According to Grant (1958) seed transport is a better mode of gene flow then the pollen (see also El-Kassaby and Yanchuk 1994, Leinemann and Hattemer 2007).

4.3 Geographic variation and conservation management

English yew populations from the Eastern Alps can be described as a patchwork of scattered populations, isolated populations and metapopulations out of scattered trees and core populations, alike the situation in Switzerland (Hilfiker et al. 2004). Our findings on the allelic structures (Table 3), where we found alleles additional to the already described ones and where we found a relatively high multiplicity, confirm the high value of the east Alpine region for the conservation of English yew in Europe. The east Alpine region played an important role for the reconquest of Europe by forest tree species after the last glaciation. Mediterranean species can be found their as endemic species (e.g. *Pinus nigra*: Frank and Zukrigl 2006) and introgression zones between ecotypes from different glacial refuge can be found in this region (e.g. *Abies alba*: Konnert and Bergmann 1995). Clear geographic variation patterns, as they are known from *Abies alba* (Breitenbach et al. 1997), for instance, cannot be proved with our data. The dendrogram depicting the hierarchical structure of genetic relatedness among the seven populations with respect of the genetic distance did not match with the geographical position of the different demes (see Fig-1 and Fig-2). The population of “Stiwoll” was the only distinct yew population in our study. Two clusters were found, where only one (“Piesting”, “Losenstein” and “Mondsee”) is reflecting a geographic region: the north-eastern region (Fig. 1). The private alleles found at loci IDH-B and SKDH-A (Table 3) indicate basically a trend of geographic variation which needs to be confirmed by further studies.

English yew was subjected to severe exploitation in the past, in particular during the middle age when the timber was used for arms (bows: Scheeder 1996). Historical records give evidence, that the Eastern Alps were heavily exploited during the late middle age (Hilf 1922), the Upper Austrian lake district as well as the area around “Stiwoll” were famous for yew timber in those days. Therefore it is not surprising that the populations from these areas (Stiwoll, Losenstein and Mondsee) are much more differentiated than the rest of the investigated Austrian populations (Figure 3). It can not be excluded, that the findings of the present differentiation are biased by historical human influence, even though the level of the gene pool differentiation is similar to that reported from German relic-populations (Cao et al. 2004).

The effect of environmental and natural changes in certain parts of a population life cycle is a key question both in population management and life history evolution. Population viability risk management (PVRM) allows the evaluation of potential effects on the viability of populations from alternative courses of action (Vacik et al. 2001, Dhar et al. 2008). It can be concluded that the English yew populations of the eastern Alps show a high level of genetic variation like other European studies but the presence of a medium level of inbreeding could create a problem for the *in-situ* management of the gene conservation forests in the future. The few stands with successful recruitment should be analysed in order to understand better the basics of a successful conservation management of English yew. Those studies needs to include tests on the transfer of plant material (provenance tests) in order to avoid future problems and to increase the efficiency of conservation management measures.

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8.5 Population Viability Risk Management (PVRM) for in-situ management of endangered tree species – a case study on a *Taxus baccata* L. population

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Population viability risk management (PVRM) for in situ management of endangered tree species—A case study on a *Taxus baccata* L. population

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Abstract

Population viability risk management (PVRM) provides a framework for explicitly including qualitative information about the possible outcomes of a management decision with regard to the viability of an endangered population in conservation management. Multi-criteria decision-making (MCDM) techniques enables managers to select the most preferred choice of action in a context where several criteria apply simultaneously. In that context a combined approach of the PVRM concept and a MCDM technique is presented for the development, evaluation and finally ranking of the in situ conservation strategies. We discuss the concept based on a case study for the maintenance of a gene conservation forest of an English yew population (*Taxus baccata* L.) in Styria, Austria. As part of the PVRM the analytic hierarchy process (AHP) is used to evaluate six conservation strategies with regard to the viability of the yew population. The viability of the population is evaluated based on the results of an analysis of the current environmental, social and economical state and a characterization of the ecological parameters of its population. The most significant risk factors (illegal cutting, browsing by game, tree competition, light availability and genetic sustainability) are structured and prioritised according to their impact on the viability of the yew population applying the AHP. Effects of the six conservation strategies on the viability of the yew population are determined through a qualitative assessment of the probability of a decrease of the population along with four different environmental scenarios. In this context strategy IV combining selective thinning, protection measures, game control with public relation activities seems to be the most effective alternative. The benefits of the combined approach of the PVRM concept with the AHP for the rational analysis of conservation strategies for this endangered tree species are discussed.
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Keywords: English yew (*Taxus baccata* L.); Analytic hierarchy process (AHP); Forest management; Nature conservation; Endangered species

1. Introduction

In conservation management the assessment of the viability of endangered populations is a major concern for planning and decision-making. Population viability is related to the probability of a continued existence of a geographically well-distributed population over a specified time period, whereas population viability analysis (PVA) is the formal process by which the likelihood of persistence of the population, metapopulation or species over a specified period of time is estimated (Bustamante, 1996; Marcot and Murphy, 1996). According to Malcolm and Hunter (2002) population viability analysis includes a systematic approach to understand the process that makes a population vulnerable to extinction. PVA is neither a monolithic concept nor a cookbook procedure. It was originally introduced by Mark L. Shaffer in 1978 for the evaluation of extinction probabilities of grizzly bears (*Ursus arctos*) in the USA. Applications dealing with risk assessment, hybridisation and management of critically endangered animals, vaccination against infectious diseases, timing and intensity of pest control, frequency and cause of mouse, rat and stoat irruptions in a forest ecosystem, or survival prospects of populations under threat of predation are described (compare Keedwell, 2004). At present population viability analyses for plants are scarce (Pfab and Witkowski, 2000; Menges, 2000). The models and methods vary both in terms of complexity of

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the underlying models and the quantity of data needed to parameterise them (Burgman et al., 1993; Morris et al., 1999; Bessinger, 2002). One of the most limiting factors of PVA is the need for a large quantity of field data (Akcakaya and Sjögren-Gulve, 2000; Ellner et al., 2002). Therefore many of the models used in population viability studies rely on monitoring data from a short period of time which might lead to the fact that not all dynamics of a species population are captured (Fiedler et al., 1998; Menges, 2000). In qualitative assessments of population viability a mix of professional judgment and empirical evidence is used to pose working hypotheses concerning population responses to proposed management actions. The qualitative information is often not directly linked to the duration of study and amount of data needed. Examples of qualitative population viability assessments include the evaluations of the persistence of fungi, lichen, bryophyte, non vascular and vascular plants, invertebrates, fish and wild life species and species groups in recent region-wide conservation planning exercises (Thomas et al., 1993; FEMAT, 1993).

The host of factors that potentiality influences the viability of species, and how those factors are influenced by management activities, thus are case-specific (Marcot and Murphy, 1996). In the context of conservation management, decisions about an appropriate management strategy to maintain a threatened species have to be taken, but most of the population viability studies do not include the management aspect intensively (compare the review given in Menges, 2000). Because resource managers often make decisions with less than complete information, assumptions founded on concepts of conservation management are often substituted for empirical data as a basis for action (Schulte et al., 2006). However, measuring survival rates of management activities for plant conservation in combination with a qualitative population viability analysis is difficult (Menges, 2000).

Decision analysis is a tool originally developed for guiding business decisions under uncertainty (Beha and Vaupel, 1982) but can be used for the management of endangered species as well (Maguire, 1986). It offers a framework where political, financial, and scientific information can be analysed. Ecological theory, objective data, subjective judgements, qualitative information and financial aspects are used to support the management process (Thibodeau, 1983). Multi-criteria decision-making (MCDM) techniques enables resource managers to select the most preferred choice of action in a context where several criteria apply simultaneously. In a rational decision making environment, the most preferred choice is generally bounded by the management objectives, and the constraints that limit the choices and the achievement of the objectives (Mendoza and Prabhu, 2000). The analytical hierarchy process (AHP) is a MCDM method which allows the pairwise comparison of management alternatives with respect to single decision criteria based on a ratio scale (Saaty, 1995). Mendoza and Sprouse (1989) are pioneers for using this technique for the analysis of a forest management decision problems and nowadays AHP is applied in a wide array of decision problems related to multi-objective forest management (Mendoza and Prabhu, 2000; Kangas and Kangas, 2002; Wolfslehner et al., 2004) and conservation management (Kangas and Kuusipalo, 1993; Zadnik, 2006; Zhu et al., 2001; Abiyu et al., 2006). However, MCDM techniques are not often used in relation to population viability studies to allow a rationale, transparent and comprehensive planning and decision-making processes.

Marcot and Murphy (1996) introduced the concept of population viability risk management (PVRM), which provides a framework for explicitly including qualitative information about the possible outcomes of a management decision with regard to the viability of a population. Actually the PVRM concept is familiar to the conservation biologist for the management of endangered wildlife populations but recently this method was applied in the conservation of endangered trees species (Menges, 1990; Vacik et al., 2001). Although there are many uncertainties that might caution against believing specific projections of population futures, comparative approaches can distinguish between alternative management strategies in a way that is more comprehensive than considering single life history responses (Menges, 2000).

The objective of this contribution is to present the use of the analytical hierarchy process (AHP) as part of a PVRM framework for endangered tree species. The PVRM approach allows the evaluation of different conservation management strategies in order to maintain species at risk, and to identify courses of action, which improve the viability of the population. We will draw our example of the proposed approach for the management of an endangered English yew (*Taxus baccata* L.) population in Austria. The viability for the English yew population will be assessed based on the results of an analysis of the current environmental, social and economical state. Sensitivity analysis will be used to select a compromise solution out of six in situ conservation strategies.

2. PVRM

There is no universal guideline or single method for conducting PVRM, as all factors potentially influencing the viability of a population are case-specific. However, Marcot and Murphy (1996) proposed a general nine-step approach to guide conservation managers' for selecting conservation strategies. We adapted this general procedure for the management of endangered tree species and linked it to the formal steps of decision analysis as follows.

2.1. Identifying the species at risk and relevant regulations

A preliminary step in conservation planning is the selection of the target species and species relevant regulations and laws. Information about small numbers of species, limited geographic distribution, downward populations trends and sensitivity to human pressures are used to identify the species at risk. Geographic approach to protection (GAP) analysis (Scott et al., 1993) or red and blue lists of endangered species can be used to support this process. This step includes the definition of the range of an acceptable viable condition to meet the policy regulations or legal mandates, and identification of the key agencies or institution that are responsible to carry out the work

Table 1
General importance of ecophysiological characteristics of English yew with regard to risk susceptibility and viability of a population

Ecophysiological characteristics of yew	Comments	Influence on disposition
Slow growth	The slow growth of yew reduces the capabilities to compete with other neighbouring tree species for resources which suppress the overall growth and development (Thomas and Polwart, 2003)	↑↑↑
Vegetative regeneration capacity	A high vegetative regeneration-capacity helps yew to survive after severe damages of trunk and crown and increases the overall chances for natural recruitment as well (Suszka, 1978; Dhar et al., 2006)	↓↓
Hard resistant wood	Yew is slight susceptibility against wood rottenness after stem damages	↓
Weak needles	The needles of yew are intolerant to severe and prolonged frost (Skorupski and Luxton, 1998) and icy wind (Bugala, 1978) and do not protect against high transpiration rates (Leuthold, 1980; Zoller, 1981)	↑↑
Shade tolerance of juvenile plants	Seedlings can survive in low light intensity up to few years after germination, but light is an important factor for its growth and survival in the years to follow (Krol, 1978; Boratynski et al., 1997; Thomas and Polwart, 2003; Iszkulo et al., 2005; Iszkulo and Boratynski, 2006)	↓
Shade tolerance of adult plants	An adult yew can survive in unfavourable light conditions for a long time (Lilpop, 1931; Krol, 1978; Brzeziecki and Kienast, 1994)	↓↓
Resistance to fire and abiotic damages	A high resistance to fire and the high vegetative regeneration-capacity allows yew to survive intensive abiotic damages (Gilman and Watson, 1994)	↓
High drought tolerance	The high drought tolerance allows yew to overcome severe shortcomings in water availability (Gilman and Watson, 1994; Thomas and Polwart, 2003)	↓
Dioecious sexual system	The major advantage of a dioecious sexual system is the reduction of the inbreeding depression (Darwin, 1876). High levels of heterozygoty might be found even in small populations. Disadvantages are the loss of fitness via one or other sex function and the lack of mobility which can lead to extinction of small populations on the other hand (Charlesworth, 2001)	↑
Susceptibility to diseases, pest and biotic damages	Diseases are not a major concern although yew is notably susceptible to *Phytopthera* sp. root diseases (Strouts, 1993) and ramorum dieback (*P. ramorum*) (Lane et al., 2004). Thomas and Polwart, 2003 noted that big bud mite (*Cecidophyopsis psilaspis* Nalepa: Eriophyidae) considered as a serious pest of yew in northern and central Europe. However, *Taxus* mealybug, black vine weevil, *Taxus* scale and can cause some damages (Gilman and Watson, 1994)	↑
Wide physiological amplitude	Yew has a wide physiological amplitude which allows yew to spread out on a wide range of sites (Thomas and Polwart, 2003)	↓↓
Susceptibility to browsing and grazing	Kelly (1981), Haeggström (1990), Mysterud and Østbye (2004) and Dhar et al. (2006) reported that yew is very susceptible to browsing and Watt (1926) pointed out that grazing can drastically affect the net growth rates which leads to strong negative effects on recruitment and adult survival in deer populated areas	↑↑↑

(↑) Increase disposition (risk of extinction); (↓) decrease disposition (risk of extinction).

and coordinate their activities. It might include a formal definition of a minimal viable population (MVP); a contingent upon decisions of tolerable risk of extinction and a defined time period for a give population at a certain site (Shaffer, 1981). Many studies try to avoid the calculation of a MVP, as the concept does not include uncertainties regarding the data used and other model assumptions (Menges, 2000).

2.2. *Description of the ecological conditions of the target species and their environment*

In this phase detailed information regarding the general ecophysiological characteristics of the target species and the specific environmental conditions at a given site is mandatory to determine the viability of the population. Literature studies, expert know how and experiences from long term monitoring plots are used to describe the ecophysiological characteristics (e.g. growth potential, light requirements, regeneration strategy, sexual system, susceptibility to damages and infestations) of the tree species (for detailed information see Table 1). Information regarding the history of forest management, the population structure, the socio-economic conditions and possible reasons for viability concerns or decline of the populations have to be identified. The concept of "risk of extinction" is often used to define the targets for recovery by estimating the loss of reproductive capacity or loss of genetic diversity. Field inventories and investigations should help to describe the population size (number of species ha^{-1}), sex ratio (male/female), vitality (health condition of the tree by means of crown length, defoliation and damage), structure (regarding tree height, diameter distribution), human interventions (e.g. illegal logging) and public awareness (see also Morrison et al., 1992). With this information a comprehensive qualitative assessment according to different levels of the population can be undertaken (see FEMAT, 1993; Thomas et al., 1993). The assessment of ecophysiological characteristics of the tree species might help to determine the degree of risk susceptibility (Vacik et al., 2001). The effects of current environmental conditions on the viability of the population are conducted to describe the risk susceptibility for extinction and the overall viability of the population (see Table 2).

Table 2
Assessment of the current ecological state of the English yew population and the effect of management strategies with regard to the viability of the population

	Relation to evaluation criteria	Effect on viability	Long-term effects of management strategies (planning horizon 20 years)					
			0	I	II	III	IV	V
Environmental characteristics of the present yew population								
Huge number of yew 492 number of species ha^{-1} and the other trees species in total (959 number of species ha^{-1})	Leads to high inter specific competition	−−−	−−−	−−−	+	+	++	++
	Causes moderate intra specific competition							
	Can increase the probability of demographic and genetic change processes and a high genetic sustainability	−	−	−	+	+	++	++
	Assures continuous recruitment by	++	−−	−−	+	+	+++	+++
	continuous production of seeds	+++	+	+	++	++	+++	+++
	Causes a lack of light availability which has negative influences on assimilation, growth and strobilus development	−−−	−−−	−−−	+	+	++	+++
Number of male and female individuals show a female biased sex ratio (1.56)	Which fosters continuous production of seeds as the dioecious sexual system needs a balances ratio of male and female	+++	+	+	+	+	+	+
	Can increase genetic sustainability as the pollination is related to the distribution of male and female individuals	++	0	0	++	++	+++	+++
97.1% of the yew population belong to the third tree layer and 2.9% to the second layer	Which indicates gaps in the vertical structure of the population, yew is missing in the dominant height class	−−	−−	−−	+	+	++	++
A narrow diameter distribution and an average DBH of 8.8 cm	Limits population viability as a broad DBH structure is missing	−−	−−	−−	+	+	++	++
Natural regeneration (>30 cm height < 150 cm) is missing	Which hampers the balanced structure of the population, due to the absence of natural regeneration no supplement trees can build up the future population	−−	−−	−/+	+/−	+/−	+++	+/−
The very vital to vital condition of more than 79% yew trees	Causes continuous production of seeds as good vitality indicates healthy condition	++	0	+	++	++	+++	++
	Reduce the diseases susceptibility	+	0	+	+	+	++	+
	Supports the inter specific competition as it helps to compete with other tree species for growth and development	+	0	+	++	++	+++	++
	Supports the intra specific competition as it increases the overall fitness of the population	−	0	+	++	++	+++	++
Socio-economic characteristics of the present yew population								
Intensive harvest operation in conservation management	Cause soil disturbance which increase the likelihood of juvenile establishment	+	−	−	+	+	++	+++
	Cause damages to the pole stand and increase vulnerability/risk for diseases	−−	+	+	−	−	−	−−−
	Cause damages to the regeneration and increase vulnerability/risk for diseases	−	+	+	−	−	−	−−−
Low people awareness causes direct (illegal cutting) and indirect (browsing by game) human disturbances	Which increases the risk of illegal cutting	−	−	++	−	−	++	−
	Which increases the risk of browsing and leads to an absence of seedlings	−−−	−−−	+++	−−−	−−−	+++	−−−
Regulations according to Gene conservation forests	Increase public acceptability which reduces human pressures (illegal cutting, browsing)	++	−−	++	−−	−−	++	−−
	Causes investments as additional money is needed to maintain the viability of the gene conservation forest and income is reduced by conservation activities	+	+	−−	−	−	−−−	−

(+) Positive effect, increase viability; (−) negative effect, decrease viability; (0) no effect.

2.3. Development of conservation management alternatives

A range of management options should reflect all possible activities for maintaining the species at risk, from minimal protection to a maximum of conservation activities. According to the analysis of the current environmental condition the major threats for the population are identified and management strategies are developed based on the know how, experiences of local experts, and managers (see Vacik et al., 2001; Abiyu et al., 2006). This approach requires the identification of key conservation management decision sequences that affect environments and populations as well as the estimation of various responses of the species to each management decision. The PVRM concept allows the evaluation of the potential effects of management activities on the viability of populations from alternative courses of action.

2.4. Evaluation of viability effects of alternative management

This step entails estimating the likelihood of continued existence for the population in the planning area if the conservation activities are implemented. The effect of management alternatives on the viability of the population with regards to size, distribution, persistence and resources are analysed. Unfortunately such data and models are not available and an extrapolation from existing data sets and qualitative expert knowledge is used to predict the effects on the viability. Different techniques like Decision Trees (e.g. Vacik et al., 2001), Scoring (Given, 1994) or the AHP (Abiyu et al., 2006) can be used.

The AHP provides a framework for selecting an appropriate conservation strategy by means of a decision hierarchy of interrelated evaluation criteria (Mendoza and Prabhu, 2000). The strategies are at the lowest level of the hierarchy and evaluated against all criteria which have an influence on the viability of the population. To evaluate the effects on the viability pair wise comparisons are made between all strategies on a scale of relative importance where the decision maker has the option to express the preferences between two elements on a ratio scale from all elements equal likely (equivalent to a numeric value of 1), to one element being absolute likely (equivalent to a numeric value of 9) compare to others (Saaty, 1995). The overall likelihood of a conservation strategy to maintain an endangered population is determined by synthesizing the individual judgments based on the priorities of the pairwise comparisons and the relative weights of the decision criteria.

2.5. Array and select an alternative

Based on the general evaluation of the conservation strategies to maintain an endangered population the sensitivity analysis allows determination of an overall compromise solution. As uncertainties and assumptions have to be considered in the decision making process the effect of the evaluation criteria on the overall preference of a strategy has to be studied (Reed et al., 2002). The analysis of the effects of different sets of relative weights for the evaluation criteria used in the AHP helps to reduce the uncertainty involved in the process. Finally the array of acceptable alternatives that meet the decision criteria are identified and selected for the course of action.

2.6. Implementation and monitoring

In the implementation phase the actions of the favoured management alternative are implemented by the local forest authority or conservation managers. As a consequence long term monitoring will allow evaluation of whether the assumptions used in PVRM approach have been valid or not.

3. Application

Our present study follows the PVRM concept in order to select an appropriate management strategy for an endangered tree species in Austria.

3.1. Species at risk

In our study the target species is English yew (*Taxus baccata* L.), a slow growing long lived, evergreen, dioecious, wind pollinated-gymnosperm tree which is catalogued as a rare and endangered species, prone to extinction from Austria (Niklfeld, 1999; Schadauer et al., 2003; Russ, 2005) and elsewhere (Svenning and Magárd, 1999; Thomas and Polwart, 2003). It is scattered throughout Europe (Bolsinger and Lloyd, 1993), northern Africa (Sauvage, 1941) to the Caspian region of southwest Asia (Mossadegh, 1971). It has gained a considerable importance as a source of anti-cancer drugs (Rikhari et al., 1998) and high aesthetic value (Dovciak, 2002) of timber, but at present declining throughout most of its range (Tittensor, 1980; Hulme, 1996; Dhar et al., 2007). The reasons for decline of yew refer to the over use in the past centuries as well as unsuccessful regeneration, browsing pressure, illegal cutting and lack of appropriate management strategies (Thomas and Polwart, 2003; Dhar et al., 2006). An overview of the ecophysiological characteristics of yew and how they influence the viability of a population are given in Table 1.

3.2. Present status of the yew population in Stiwollgraben

The Austrian gene conservation forest network is used for maintaining the biodiversity of endangered tree species populations in Austria (Müller and Schultze, 1998). Among these gene conservation forests "Stiwollgraben" is located in the southeastern part of Austria about 20 km far from the city of Graz. The primary focus of this forest is the in situ conservation of English yew (*T. baccata* L.) by silvicultural treatments. The assessment of the current population is based on an intensive study of the environmental characteristics of the population (Dhar et al., 2006) which allowed a detailed survey of the population's structure, growth potentiality, regeneration capa-

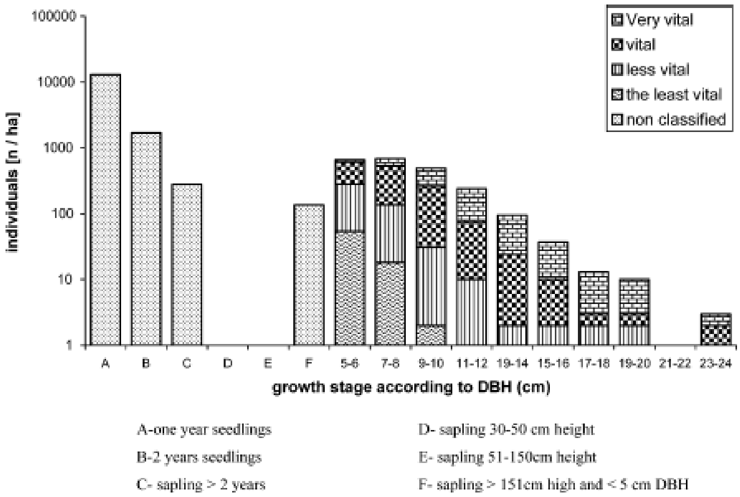

Fig. 1. Vitality of yew population according to the diameter distribution in logarithmic scale (modified from Dhar et al., 2006).

city and negative aspects that influence the viability of the population (e.g. browsing, illegal cutting, competition, biotic and abiotic factors, see Table 2). The forest occupies 4.5 ha of land with a mixture according to basal area of *Fagus sylvatica* (34%), *Picea abies* (23%), *Pinus sylvestris* (15%), *Taxus baccata* (12%), *Larix decidua* (11%) and isolated individuals of *Abies alba*, *Acer pseudoplatanus*, *Ulmus glabra*, *Fraxinus excelsior* and *Sorbus aria* comprising 959 tree individuals ha^{-1} with a total volume of 418 m^3 ha^{-1}. In total 2 236 yews with DBH $\geq$ 5 cm have been found, whereas the vitality condition of the pole stand is very good, more than 79% trees were assessed as very vital to vital whereas 17.4% of the yew belongs to the less vital and 3.4% represent the least vital (see Dhar et al., 2006). The tree height ranges from 1.6 m to 14.4 m with a narrow diameter distribution from $\geq$5 cm to 25 cm. However, saplings in the height class 30–50 cm and 51–150 cm were not observed although 13,019 one-year-old seedlings ha^{-1} were found (Fig. 1). The top height of the dominant tree species was on the average 28 m. As a consequence of the current environmental situation the main problems were interspecific competition with other dominant and co-dominant tree species, illegal cutting by man, lack of natural regeneration due to browsing and probably the loss of genetic variation (Lewandowaski et al., 1995). For details on the environmental characterisation please refer to Dhar et al. (2006).

3.3. Development of management strategies

According to the analysis of the current environmental condition the major threats for the yew population at the gene conservation forest in ''Stiwollgraben'' have been identified in Table 2. All management strategies (Table 3) are based on the result of personal field experience and different research activities on this tree species in Austria (Vacik et al., 2001; Dhar et al., 2006) as well as throughout the world (Czartoryski, 1978; Mitchell, 1988; Campbell and Nicholson, 1995; Svenning and Magárd, 1999; Thomas and Polwart, 2003). The idea was to develop different strategies by altering the main characteristics driving the viability of the population. Therefore we combined various activities in order to develop six management strategies (Table 3). The 'do nothing' option (0) keeps the forest stand untouched in order to have a reference. In the 'wildlife' option (I), we assumed that building of an exclusion fence for game control and public awareness will be a good combination for conserving the yew population with less human intervention. However strategy no (II) 'minimum strategy' deals with the

Table 3
Strategies for conservation management of English yew population

Characteristics	Strategies					
	0 (do nothing)	I (wild life strategy)	II (minimum strategy)	III (single tree selection system)	IV (conservation strategy)	V (timber production strategy)
Wild Life management	No	Fence + game control	No	Fence	Fence + game control	No
Thinning intensity	No	0%	10%	No	30%	50%
Selective thinning	No	No	No	Yes	Yes	No
Careful harvesting	No	No	Yes	Yes	Yes	No
Site preparation	No	No	No	Yes	No	No
Regeneration	Natural	Natural	Natural	Natural	Natural + artificial	Natural + artificial
Public awareness	No	Yes	No	No	Yes	No

decrease of the competition by thinning and applying careful harvesting in order not to hamper the health of the yew trees. The 'single tree selection' option (III) is a combination of silviculture measures including selective felling and active soil preparation as well as control of herbivore pressure by building exclusion fence. The 'conservation' option (IV) is more related to protection instead of forest production. It covers continuous tree felling and reduction of 30% total stand volume during the management action. Additionally it includes activities like hunting and raising public awareness, which might be help to enhance the acceptability of the local people. The 'Timber production' (V) option reduces the competition with dominant and co-dominant species by felling of all other tree species and also includes artificial regeneration for increasing the genetic variation.

3.4. Evaluation of management strategies

3.4.1. Hierarchy structure of forest conservation priority evaluation

The AHP has been used to select an appropriate conservation strategy by means of a decision hierarchy of evaluation criteria and qualitative expert judgements. To identify how the management alternatives affect the viability of the population with regard to size, distribution, persistence, and resources the evaluation hierarchy was developed on the basis of the general environmental analyses of Tables 1 and 2. According to the PVRM concept Table 2 describes the possible causes and effects in relation to risk susceptibility and viability of the yew population. The criteria "genetic sustainability", "vitality of pole stand", "establishment and viability of seedlings" and "socio-economic factors" have been linked to the viability of the population. The indicators (e.g. risk factors, light availability) were selected according to the degree of risk susceptibility of the yew population in relation to general ecological state respectively. The relative weight for each indicator of the parent criterion has been determined by pairwise comparisons of the local foresters considering the actual importance of the factors in the case study area. In that context for the criterion 'vitality of pole stand', indicators 'damage during cutting' had the highest importance (0.53), with respect to the sub criterion 'risk factor'. On the other hand 'spatial structure' achieved the highest importance (0.57) regarding the sub criterion 'balanced structure' (Table 4).

The six management strategies at the lowest level of the hierarchy are evaluated against all indicators, influencing the viability of the population. The effect of each management strategy was qualitatively assessed by an expert team of conservation and forest management specialists (land owner, foresters of the local forest authority, forest experts, scientific researchers) according to each indicator in the context of a workshop in the case study area (Table 2). As a result of this workshop the number of symbols for each indicator indicates the intensity of the effect of the management strategies for increasing (+) or decreasing (−) the viability. These qualitative assessments have been used by the authors as an input for the pairwise comparisons of the management strategies according to each element in the AHP model at the lowest level of the evaluation hierarchy. Pairwise comparisons have been made between all strategies on a scale of relative importance between two strategies on a ratio scale from all elements equal likely (equivalent to a numeric value of 1), to one element being absolute likely (equivalent to a numeric value of 9) compared to others. The overall likelihood of a management strategy to

Table 4
Priorities of criteria and indicator in the general AHP model and for different scenarios

Criteria	Priority	General priorities			
		Sub criteria		Indicator	
Genetic sustainability	0.25	Maintenance of GS	0.50		
		Enhance of GS	0.50		
Vitality of pole stand	0.25	Risk factors	0.32	Damage during cutting	0.53
				Diseases	0.08
				Bark peeling	0.16
				Illegal cutting	0.23
		Competition	0.56	Intraspecific	0.50
				Interspecific	0.50
		Balanced structure	0.12	Vertical structure	0.33
				Spatial structure	0.57
				DBH structure	0.10
Establishment and viability of seedlings	0.25	Light availability	0.34		
		Risk factors	0.30	Browsing	0.68
				Harvesting damage	0.24
				Diseases	0.08
		Soil disturbances	0.06		
		Balanced structure (height)	0.09		
		Continuous production of seeds	0.21		
Socio economic factors	0.25	Know how	0.10		
		Public acceptability	0.30		
		Investment	0.60		

Table 5
Priorities for criteria of scenarios A–E as well as overall priorities, rank and average for management strategies 0–V

Scenario	Priorities of criteria for scenarios				Overall priorities and rank for management strategies					
	Genetic sustainability	Vitality of pole stand	Survival rate of seedlings	Socio economic condition	0	I	II	III	IV	V
A	0.25	0.25	0.25	0.25	5 (0.100)[a]	6 (0.098)	4 (0.114)	3 (0.187)	1 (0.286)	2 (0.214)
B	0.70	0.10	0.10	0.10	5 (0.066)	6 (0.065)	4 (0.088)	3 (0.198)	1 (0.369)	2 (0.215)
C	0.10	0.70	0.10	0.10	6 (0.072)	4 (0.111)	5 (0.111)	2 (0.212)	1 (0.346)	3 (0.148)
D	0.10	0.10	0.70	0.10	6 (0.065)	4 (0.122)	5 (0.097)	2 (0.228)	1 (0.296)	3 (0.191)
E	0.10	0.10	0.10	0.70	2 (0.198)	6 (0.089)	3 (0.161)	5 (0.108)	4 (0.140)	1 (0.303)
Average rank					4.8	5.2	4.2	3.0	1.6	2.2

(A) Overall result, equally prioritized; (B) priority on genetic sustainability; (C) priority on pole stand; (D) priority on survival rate of seedlings; (E) priority on socio economic condition.
[a] Numbers in parentheses indicating the overall priorities for the management strategies according to each scenario.

maintain the endangered population was determined by synthesizing the individual judgments based on the priorities of the pairwise comparisons and the relative weights of the decision criteria and indicators.

3.5. Selection of management strategies by sensitivity analysis

In order to select a suitable management strategy with increases the viability for the yew population, different environmental scenarios has been evaluated which regard to overall objective. The scenarios are characterized by different combinations of priorities for the evaluation criteria genetic sustainability, vitality of pole stand, establishment and viability of seedlings and socio-economic factors. Scenarios A reflect the actual situation of the criteria influencing the viability of the population. Scenarios B–E indicate different priorities for the evaluation criteria. In each of the scenarios one of the criterion was set to a maximum value to observe the impact of each scenario for the viability of the yew population (Table 5). The overall performance of a management strategy was determined by synthesizing the preferences of the original expert judgments and the relative weights for each criterion of the five scenarios.

In applying the AHP model for all five scenarios it was possible to identify the sensitivity of the model and the management strategies on the viability effects of the yew population. From the scenario analysis it was predicted that management strategy IV achieved almost the highest priorities in all scenarios except for scenario E (Fig. 2). Strategy V is the second best alternative with regards to scenarios A, B, and E, which is followed by strategy III where scenarios C and D was the second best choice. Whereas strategy I attained the lowest priority among the management strategies with respect of scenarios A, B and E. According to ranks and mean ranks of the management strategies based on the results of the sensitivity analysis, it is evident that strategy IV dominates all other strategies independently from the preferences given to the main evaluation criteria genetic sustainability, vitality of pole stand and viability of seedlings (Table 5).

4. Discussion

The results of the PVRM approach indicate that management strategy IV is the best for maintaining the viability of the yew population in the gene conservation forest at Stillwollgraben. The reasons for the estimated positive effects on the

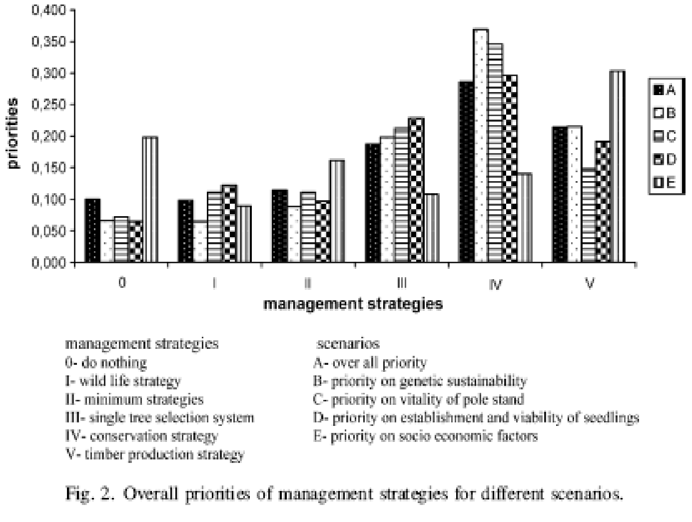

Fig. 2. Overall priorities of management strategies for different scenarios.

viability of the population are the effects on the genetic variation, the enhanced light availability and the reduced browsing pressure by building a fence. Genetic sustainability might be enhanced by the artificial regeneration of yew which increases genetic variation within the species. The thinning operation might lead to a better environmental condition of the mature yews and will increase the seed production additionally (see Vacik et al., 2001). A balanced structure according to vertical structure, patchiness and DBH-distribution provides a good vigour for the pole stand and increases the light availability on the forest floor additionally. According to Iszkulo and Boratynski (2006) insufficient amount of light under the canopy trees can lead to a reduction of the number of yew seedlings even taking into account the shade tolerance of yew. The risk factor browsing is considered as another important parameter for the viability of yew populations. Kelly (1981) and Sarmaja-Korjonen et al. (1991) noted that yew is very susceptible to browsing effects. Herbivore damage is known to increase the mortality risk of individual plants (Watkinson, 1986), induce dormancy in plants (Ehrlén, 1995) and eliminate species from the plant communities (Moolman and Cowling, 1994). Therefore excluding herbivores from the yew population would result in higher rate of adult survival. The management strategy IV also includes also activities to increase the public awareness. This would lead to a reduced number of illegal cuttings and will increase the overall knowledge concerning the conservation management of yew, which is a very important for the overall viability of the population. In that context many authors reported increased public awareness activities are the most effective way for conservation of yew populations (e.g. Campbell and Nicholson, 1995).

The sensitivity analysis indicated that the ‘‘timber production’’ management strategy (V) seems to be best with respect to socio-economic aspects and achieved an average rank of 2.2 considering the different scenarios. This strategy outperforms the other alternatives with respect to the economic return as well as less investment. The primary objective of this management strategy is not to maintain the yew population, however in some cases such a strategy might ensure the viability of yew populations although it is the second best choice.

The PVRM approach allowed the evaluation of different conservation management strategies in order to maintain species at risk and to identify courses of action, which improve the viability of the population. We could demonstrate the benefits in linking this general procedure for the management of endangered tree species to the formal steps of a decision analysis The multi-criteria method AHP allows the use of both qualitative and quantitative information in comparing the importance of criteria or the performance of alternatives. It is possible to consider more qualitative aspects in conservation management like acceptance level knowledge and quantitative information about the productivity and income of different management strategies at the same time. In qualitative assessments of population viability a mix of professional judgment and empirical evidence was used to model population responses to proposed management actions. The effect of environmental and natural changes in certain parts of a population life cycle is a key question both in population management and life history evolution. Therefore it is essential to identify the appropriate instance of a population life cycle where most management efforts should be taken in order to ensure and maintain the maximum population viability. Sensitivity analysis with the AHP is therefore a method of choice when considering uncertain information and risks in conservation management and a large quantity of field data is missing.

It is evident that maintaining the population of yew (*T. baccata*) will require intensive management to prevent its extinction. A more appropriate management programme will have to be implemented to consider the factors influencing the viability of the yew population. In addition, herbivores must be excluded from the population to eliminate the detrimental effect of herbivores damage (Pfab and Witkowski, 2000). Based on the results of the present PVRM approach the local foresters have carried out different treatments in order to maintain the yew population at this site. Different thinning operations, a fence for reducing the browsing pressure and other conservation activities have implemented. With the help of the research a long term monitoring programme was set up, to evaluate the positive effects of the conservation activities on the viability of the population.

Nevertheless, forest ownership is an additional crucial issue in conservation management as in Austria almost 75% forest are privately owned. Therefore it is important that government provides long-term financial incentives for maintaining forest resources in gene conservation forests.

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8.6 Timeline of publications

Table: Timeline of the scientific publication process for the four papers of this thesis

Contribution	Submission	Editor statements (peer review)	Accepted for publication
Paper I	15th May 2006 Dendrobiology	Minor revision	21st August 2006
Paper II	25th June 2007 Journal of Forestry Research	Minor revision	27th July 2007
Paper III	20th May 2008 European Journal of Forest Research	Major revision	--
Paper IV	26th November 2008 Ecological Research	Under review	--
Paper V	24th August 2007 Forest Ecology and Management	Minor revision	29th January 2008

9. Curriculum Vitae

Amalesh Dhar

Education

M. S. in Agronomy	:	June, 2003, Department of Agronomy, Bangladesh Agricultural University (BAU), Mymensingh.
B.Sc. in Agriculture	:	1998 (Examinations held in 2001), Faculty of Agriculture, BAU, Mymensingh.
Higher Secondary Certificate	:	1994, Science Group, Dhaka Board,
Secondary School Certificate	:	1992, Science Group, Dhaka Board,

Organizational affiliation

1. Society for Conservation Biology
2. Bangladesh Agriculturist Association
3. Asia Pacific Forestry Researchers

Awards

1. North South Dialogue Scholarship Programme, Austrian Exchanges Service (ÖAD), Agency for International Cooperation in Education and Research. Austria. (from November 2004 to October 2008
2. Institute scholarship, Vienna, Austria. (from November 2005 to October 2006 and July – December 2008)
3. One world Scholarship, Österreichische Orient-Gesellschaft (ÖOG), Austria (from October 2006 2004 to July 2008

Professional Experience

1. Worked as a PhD research fellow in a project entitled Biodiversity of forest communities with English Yew (*Taxus baccata* L.) at the Institute of Silviculture, Department of Forest-Soil Science, University of Natural Resources and Applied Life Sciences. Perter Jordan Strasse 82, A-1190 Vienna, Austria. Since November 2004 to December 2007.
2. Worked as Specialist Officer in a project entitled Jamalpur Sharpur Agriculture Extension Project, Social Organization for Development (SOD), Jamalpur, Bangladesh since November 2001 to October 2004.

Networking Experiences

a. Training Programme on Administration Office Management and Communication from Graduate Training Institute at Bangladesh Agricultural University.

b. PRA training programme in Bhogobanganj Village, arranged by Department of Agronomy, Bangladesh Agricultural University, Mymensingh.

c. Extension field training regarding Administration, case study, technology transfers, Farmer Information Need Assessments (FINA) etc**.** Department of Agricultural Extension Education, Bangladesh Agricultural University, Mymensingh.

d. Training on " How to write Scientific Paper" By Dr. R. Marrs, Biological Conservation. Eger, Hungary.

Publications

2008

Dhar A., Ruprecht H., Klumpp R., Vacik H. 2008. The Population Genetic Consequences for Conservation of an Endangered *Taxus baccata* L. population in Austria In: IUFRO Conference on Biodiversity in Forest Ecosystems and Landscapes from August 5-8, 2008 at Thompson Rivers University, Kamloops, British Columbia, Canada, p 41.

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2007 **Dhar A.,** Ruprecht H., Klumpp R., Vacik H. 2007. Comparison of ecological condition and conservation status of English yew population in two Austrian gene conservation forests. ***Journal of Forestry Research*** 18 (3) 181-186.

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Dhar A., Ruprecht H., Klumpp R., Vacik H. 2007. Population structure, vitality and genetics of *Taxus baccata* L. at "Stiwoll" valley in Austria. In: Organization Committee of Ecosysummit 2007 (Eds.), Ecological Complexity and Sustainability - Abstracts of EcoSummit 2007, p 64, EcoSummit 2007 - Ecological Complexity and Sustainability: Challenges and Opportunities for 21st-Century's Ecology, 22-27 May 2007, Beijing, China.

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2006 **Dhar A.**, Ruprecht H., Klumpp R., Vacik H. 2006. Stand structure and natural regeneration of English yew (*Taxus baccata* L.) at Stiwollgraben in Austria. ***Dendrobiology***, 56: 19 – 26.

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2003 **Dhar A.,** Salam M.A., Bhuiya M.S.U., Asaduzzaman M. 2003. Effect of Number of seedlings hill^{-1} and level of nitrogen from different sources on the performance of transplant *aman* rice under SRI method. ***Journal of Science foundation***, 1 (2): 57-62.

Unpublished papers:

1. Dhar, A. and Bhuiya, M.S.U. (2001) Effect of different level of nitrogenous fertilizer on the growth and yield of Soybean (***Glycine max***)

2. Dhar, A. and Islam. M. (2000) Investigation of socio-economic condition and farmer's knowledge on rice cultivation in a village of Mymensingh Sadar Thana.

Participation in Conferences Workshop and Seminars

1. Biodiversity in Forest Ecosystems and Landscapes Conference from August 5-8, 2008 at Thompson Rivers University, Kamloops, British Columbia, Canada
2. "From the Mountains to the Sea", 22nd Annual meeting, Society for Conservation Biology from 13th to 17th July 2008, The University of Tennessee at Chattanooga, USA
3. Student Conference on Conservation Science, 25 – 27 March 2008, University of Cambridge, United Kingdom
4. Workshop on " Facilitation Skills " by Dr. Robert Anderson (New York) from 4-5 April 2008, Afro-Asian Institute (AAI) Graz, Austria
5. 27. Tagung der Arbeitsgemeinschaft Forstgenetik und Forstpflanzenzüchtung, 10–13 October 2007. Vienna, Austria
6. 21st Annual meeting Society for Conservation Biology, 01- 5 July 2007, Port Elizabeth, South Africa.
7. Workshop on "Leading and Developing People" by Dr. Robert Anderson (New York) from 19-20 April 2007, Afro-Asian Institute (AAI) Graz, Austria
8. 1st European Congress of Conservation Biology 22-26 August 2006, Eger, Hungary.