MAB Secretariat
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POPULATION DYNAMICS OF THE ENDANGERED ENGLISH YEW (*TAXUS BACCATA* L.) AND ITS MANAGEMENT IMPLICATIONS FOR BIOSPHERE RESERVES OF THE WESTERN CARPATHIANS

FINAL REPORT
ON
YOUNG SCIENTIST AWARD 2002 RESEARCH STUDY
BY

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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. 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 east as Spain 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 1000 years in age. Its tough and long-lasting timber was used by humans already during the Stone Age for axe handles. Later, yew timber was extensively used for building, and its high aesthetic appeal made it a popular decorative material as early as the times of Ancient Egypt. However, the yew was not always sought after only for its desirable properties. Yew leaves, bark and seeds contain toxic alkaloids and historically shepherds intentionally destroyed yew trees to avoid sheep poisoning.

These multiple pressures caused the English yew to experience one of the sharpest declines of all European tree species (Paule *et al.*, 1993). In the present, only the names of villages, hills and streams derived from the word "yew" in different European languages indicate how widespread the yew must have once been. However, the battered species has recently returned to the forefront of socio-economic interest, as the drug Docetaxel derived from its leaves has proved to be immensely valuable in the treatment of cancer (Kingston, 2001; Kaye *et al.*, 1997, Eisenhauer & Trudeau, 1995). Unfortunately, the supply of yew leaves is currently limited because natural yew populations are depleted. Moreover, the remaining yew populations tend to be composed of older trees and show little regeneration, thus indicating that the extent of the species will further shrink in the future (Majer, 1980; Tittensor, 1980; Aksoy, 1982; Štefančík, 1987). The reasons for sparse yew regeneration on even the best yew sites are not fully understood at the present time. However, only a complete understanding of natural causes and consequences of yew population dynamics can elucidate the reasons behind the current yew regeneration failure, and thus help us to tailor appropriate management and conservation techniques so that this species will flourish in European forests once again.

Central Slovakia is especially suited for research into yew population dynamics since it contains a large number of yew populations in varied environmental settings and management intensities, including the largest yew population in Europe (Harmanecká dolina; Paule *et al.*, 1993). The yew populations in central Slovakia occur both within regularly managed forests, and also within nature reserves where little human intervention has happened in decades. Several significant yew populations are within the jurisdiction of two regional biosphere reserves (Slovak Karst and Poľana) where the unification of management and nature conservation is one of the priorities of the MAB programme (UNESCO, 1996). Slovak nature reserves, including those with significant yew populations, in broader transition zones of Slovak biosphere reserves (such as Poľana Biosphere Reserve) have been recently administratively associated with the biosphere reserves and thus they provide an excellent opportunity both to extend the MAB philosophy over a broader landscape, and to use this landscape for research that assists biosphere reserve management.

Previous studies suggest that the current lack of yew regeneration is chiefly due to inappropriate forest management methods, dense forest canopy, and intensive deer browsing due to large deer densities (e.g. Pitko, 1960; Štefančík, 1987; Allison 1990a,b; Korpeľ, 1995;

Saniga, 2000). However, these studies usually focused only on a restricted geographical area and/or lacked statistical evaluation of results so that the relative importance of these factors could not be assessed and general guidelines for management of yew populations could not be put forward. Research carried out in other countries has suggested also other factors. The intensity of yew seed predation can be large enough to significantly reduce the likelihood of successful yew regeneration (Hulme and Borelli, 1999; DiFazio *et al.* 1998; Hulme, 1997, 1996). In addition, adult yew trees may in fact inhibit the establishment of new yew regeneration underneath them (Tittensor, 1980). While the yew seed predation has not been studied in Slovakia yet, the so-called negative *neighborhood effects* (Frelich *et al.*, 1993) of the yew overstory on its own regeneration have not been explicitly studied anywhere in the world yet. Understanding the effects of adult trees on long-term success of regeneration is especially important in rare or endangered species that are usually protected within areas of high density of adult trees that may themselves negatively influence successful establishment and survival of young trees (e.g. Dovčiak *et al.*, 2001, 2002, 2003). In conclusion, while a number of ecological mechanisms was proposed as a cause for the current yew regeneration failure, at the present time we do not understand the relative contributions and interactions of these mechanisms that are relevant in producing the observed yew population dynamics. In addition, some of these proposed mechanisms were not studied yet in some of the best European yew forests.

RESEARCH OBJECTIVES

This study investigates a number of ecological mechanisms that were postulated as significantly influencing yew population dynamics. The main objective is to construct a fully integrated model of yew regeneration dynamics where all significant mechanisms will be statistically evaluated and their relative contribution to the observed dynamics and their interactions will be statistically quantified. A similar model was recently developed (and is currently in print in prestigious *Canadian Journal of Forest Research*) by the author of this study for white pine (*Pinus strobus* L.) that occurs in mixed conifer-broadleaved forests of the U.S. western Great Lakes area (Dovčiak *et al*., 2003). Yew regeneration model will integrate the effects (on yew fructification and yew seedling germination and survival) of overstory canopy density and composition, the density of adult yew trees (yew neighborhood effects on local neighborhood and forest matrix scales), physical environmental characteristics (such as soil depth, slope, aspect, and microtopography), variation in ground layer characteristics (such as herbaceous, woody or moss cover and litter depth), deer pressure, seed predation pressure, and forest management intensity in the regeneration failure of yew across a gradient of conditions of these factors. The model will relate the densities of several seedling size classes to these potential predictors in order to increase our understanding of possible temporal dynamics of yew regeneration under different levels of individual factors.

RESEARCH METHODS

SITE SELECTION

Yew populations appropriate for research were selected based on records from Forest Management Plans, biosphere reserves, and the State Nature Conservancy in eight locations. Care was taken to incorporate populations that have high but spatially varying densities of adult yew trees and that the range of conditions across yew distribution is Slovakia is sampled (Figs. 1 and 2). Four research sites were placed in the centre of the yew distribution in the western Carpathians (in the vicinity of the valley of Harmanec) and another four sites were placed close to borders of yew distribution in the western Carpathians (Fig. 2). The southernmost population is located within the Slovak Karst biosphere reserve and 3 out of the four centrally located research sites are administered by the Poľana Biosphere Reserve. Thus, a significantly wide range of growing conditions encountered by yew in this region were sampled (Tab. 1). In order to keep the study manageable, only those yew populations were sampled that occur on limestone bedrock, which appears to be associated with the best western Carpathian yew populations (Lukáčik and Nič, 1997).

SAMPLING DESIGN

Within each site, a number of research plots were located along transects in order to encompass the variation in stand conditions. The four centrally located sites were studied in 2002 in more detail than originally proposed due to the ease of logistics given the belated arrival of funding (that arrived in September 2002, after the field season). Thus, based on the size and shape of the sites, 20 (on 3 sites) and 19 (on 1 site) circular plots (each with a 7m radius), were placed ~60m apart along 2-3 transects (a total of 79 plots). In 2003, additional 4 sites were added along the edges of yew distribution in Slovakia. Since sampling at these sites required significant travel time and more complex logistics, these sites were studied in less detail using 10 plots at 3 sites and 15 plots at one site (total of 45 plots). Original idea to sample these outlying populations by using only 10 plots was modified ad hoc in the Slovak Karst site (TANA) due to extremely well developed stratification of yew adult and seedling distributions along cliffs faces; cliffs are an important yew habitat and specifically studying them in more detail is likely to provide a material for a separate smaller paper (cliffs were sampled also on some plots on thhe detailed sites in 2002). The total sample for the 2002 and 2003 field seasons is 124 plots.

OVERSTORY PLOTS

Overstory density and composition was characterized on all plots in two separate ways. First, basal area of the forest surrounding plot centers was characterized by variable plot method due to Bitterlich (1994). Metric basal area factor of 1 was used in order to encompass fairly broad area around the plot center. This sampling characterizes the overstory composition in a ecological way, as large trees are part of the sample even if they occur further from the center point, while the smaller trees occurring too far are not included in the sample. Second, the diameter distribution of all trees was characterized by measuring the diameter at breast height (dbh; at 1.3m) with a forestry caliper for all trees >2cm dbh. In addition, for yew trees the presence of fruits was noted, and bark stripping by deer was evaluated by estimating the percentage of bark remaining along the stem circumference. For a sub sample of yew trees, the number of fruits as well as the dimensions of tree crowns were quantified. Overall percent canopy cover on overstory plots was estimated for upper and middle canopy in broad categories (0-10, 11-50, 51-90, and 91-100%). Further, percent slope, slope aspect, slope position (slope toe, foot, back, shoulder, or head), and the distance (max. 30m) from the plot center to the nearest cliff or stream was estimated. The number of adult yew trees within a ring with boundaries 7-30m from the center of the overstory plot and the percent overstory canopy cover within a ring with boundaries 7-15m from the center of the overstory plot were also recorded.

UNDERSTORY PLOTS

A smaller circular understory plot with a 1m radius was placed in the center of each overstory plot. The number of seedlings of yew was counted in different size-class categories in 2002 (germinants, older seedlings: <10cm, 11-20cm, 26-50cm, 51-100cm, and >100cm (that were later pooled for analyses as needed). Soil and litter depth was measured in the plot center and in four locations equidistantly spaced ~50cm away from the plot center. The ground cover was characterized as a percentage of the plot surface (1-5, 6-25, 26-50, 50-75, 75-100%) covered with shrubs, herbs, ferns, grass, moss, leaf litter, bare soil, bare rock, decaying wood, coarse woody debris, and tree trunks.

SEEDLING TRANSECTS

Since the understory plots could not sufficiently characterize seedling distributions due to generally very low yew seedling density, seedlings were surveyed along 4 transects radiating along the four cardinal directions from the plot center. The dimensions of these seedling transects were 1x5 m (starting 1m away from the plot center to prevent transect overlap) on 7 sites, and 2x6m on one site (Plavno-PLA) where seedling survival was studied between 2002 and 2003 and thus larger seedling sample was needed. Immediate seedling regeneration settings were evaluated by measuring the percent cover of coarse woody debris, understory woody layer and non-woody layer within a 0-25cm height above the ground (on circular plots with 0.25cm radius) and within a 25-100cm height above the ground (on plots with 0.5m radius); microtopography was described for each seedling as either flat surface, mound, pit, tree base, or log base (if seedlings occurred within 50cm downslope of a tree stem or a log); the substrate that the seedling was growing out of was characterized (litter and bare soil were the only substrates encountered). The level of browse (high: >25% of seedling impacted, medium: 11-25% of seedling impacted, low: <10% of seedling impacted, and unbrowsed) and the type of the herbivory (insect, rodent, or deer) was determined for each seedling. Seedlings that were followed for their survival at Plavno (PLA) were marked and numbered using a flat plastic marker placed within 10cm of each seedling. Marked seedlings were resurveyed twice in 2003;

in the spring after snowmelt, and in the fall after the hot summer in order to evaluate percent survival of seedlings in different regeneration settings.

SEEDLING HERBIVORY STUDY

In addition to studying the impacts of factors in the immediate environment, an experiment was set up to study the impact of different types of herbivores (deer, rabbits, and small rodents) upon seedling survival in Plavno. For this purpose, individual herbivore types were excluded from access to a subset of seedlings >1 year old, and seedling survival rates were evaluated at the same time when general seedling survival was resurveyed (i.e. after the snowmelt and in the beginning of fall 2003). At each of the 20 overstory plots, 4 marked seedlings within the understory plot or seedling transects were randomly selected and assigned one of the herbivore type exclusion treatments: I. rabbits, deer, and small rodents excluded, II. rabbits and deer excluded, III. deer excluded, IV. none excluded. At plots with <4 marked seedlings, additional seedlings were located within the overstory plot or within its close proximity. For treatments I and II, exclosures were constructed from green plastic-coated mesh wire (mesh size ~1.2cm and ~3cm respectively) wrapped into a dome-like shape ~15cm in diameter and ~25cm tall. The dome was fastened onto a wooden stake, which was pounded into the ground so that the targeted seedling would be in the center of the dome and the bottom of the exclosure would firmly sink into the soil. In treatment III, four wooden stakes were pounded in corners of a ~30x30cm square centered on the targeted seedling so that their tops were approximately 15cm above the ground. Mesh wire (mesh size ~3cm) was fastened to the top of the stakes, thus preventing the access of deer from above, but allowing access to rabbits from sides of the exclosure. In treatment IV, unexclosed seedlings were marked with an additional wooden stake to mimic the potential visual impact on herbivores of stakes used in the construction of exclosures.

FRUITING AND PREDATION SURVEYS

To determine fruiting success, potential seed inputs, and seed predation within different environmental settings, more detailed fruit surveys were carried out in Plavno on a subsample of yew trees >2cm dbh. Within each overstory plot, the closest yew tree to the plot center in each of the 4 quadrants outlined by the seedling transects (i.e. Northeast, Southeast, Southwest, and Northwest quadrants) was selected and the number of fruits on it was counted using binoculars. In addition, percent of tree crown covered by this visual survey was estimated and yew tree dbh, height, crown length and average width, and percent of crown shaded by other adjacent trees of the same canopy layer were recorded. The number of twigs harvested by small mammals (squirrels) was counted under each selected yew tree along a 1m wide transect of a length corresponding to the average crown radius. The transect was placed under the average „representative“ part of the crown. On each transect, the number of fruit remains (stalks with arrilus remains on them) was determined on up to 5 twigs located systematically along the transect. Since some overstory plots did not contain any yew trees, yew trees within a few meters outside of the boundary of the overstory plot were also used in the survey as long as the overstory composition and density seemed comparable to those of the overstory plot.

SEED PREDATION STUDY

In early October, seeds were placed within seed trays at each of the 20 overstory plots in Plavno for 3 days. Trays were ~8cm in diameter, perforated at the bottom to allow rainwater drainage, filled with sand to resemble natural setting, and fastened to the ground surface with an 8cm long nail. Seed trays were placed 3m away from the overstory plot center in 3 out of the 4 main azimuth quadrants established by the seedling transects (i.e. Northeast, Southeast, Southwest, and Northwest quadrants). The assignment of treatments to the quadrants was randomized. Except for the missing deer exclusion treatment, seed predation treatments were similar to those for the seedling predation study, but in this case squirrels rather than rabbits were excluded. For the 3 treatments, I. squirrels and small rodents excluded, II. squirrels excluded, and III. none excluded, the same design of exclosures as that described for the herbivory treatments was used. Additionally, 20 seed trays were located without exclosures beneath coarse woody debris, and beneath predated (with twigs underneath) and non-predated (without twigs underneath) yew trees and beneath forest canopy that did not contain any yew trees.

RESULTS AND DISCUSSION

Due to the belated disbursement of MAB UNESCO research funds in September 2002 (after the field season 2002 was almost over), the original calendar of activities had to be modified in order to accommodate an additional field season (2003) that was required to meet the original project objectives that could not be satisfactorily met by the less intense field work in 2002 than originally anticipated. Since the completion of the 2003 fieldwork, the data was entered in the database, merged with the 2002 data, and the first analyses of the pooled dataset were performed. However, the completion of the yew regeneration model still requires an additional time, as it required data from both field seasons, and thus it was started only recently, as the 2003 data became available for the analyses. In the original proposal, there were several months planned for the data analysis and paper writing. Therefore, only partial results can be presented at this time.

SEEDLING DENSITY

The density of germinants (yew individuals germinated in the year of the survey, thus <1 year old) and the density of different seedling size-classes (>1 year old) varied significantly among the research sites (Fig. 3). In addition, germinant/seedling density patterns among the sites appeared to be discordant, i.e. sites that appeared to support the highest densities of germinants (POL or PAV) did not support the highest densities of older seedling size classes (cf. Houle 1998, Dovčiak *et al*., 2001 for similar regeneration patterns of other species). On the other hand, the research sites with on average ≥0.2 seedlings <10cm tall per m^2 (KAM, TANA) appeared to have also successful seedling recruitment into size classes >25cm tall. The sites where the density of seedlings <10cm tall was significantly less than 0.2 seedlings/m^2 (TANE, HAR) had virtually no larger seedlings present. Seedling densities reported in this study are comparable to those reported elsewhere for the yew populations in the region (Saniga 2000a,b; Korpeľ 1995) but by an order of magnitude smaller than the densities reported from other regions (Boratynski *et al*. 2001). The variation among the sites, and among the studies warrants the interest in exploring the relationships of germinant and seedling densities to the other ecological factors measured in this study.

OVERSTORY AND YEW BASAL AREA

Yew reproductive activity and recruitment can be enhanced by better light availability (e.g. Svenning and Magard, 1999), which is related to overstory density/basal area and species composition (Pacala *et al*. 1993, 1994). While the research sites in this study varied in the overall basal area of live trees (Fig. 4), it is interesting to note that the successful recruitment to the largest seedling size class (>25 cm in height) occurred on sites with both the highest and the lowest basal area (KAM and TANA, cf. Figs. 3 vs. 4). Similarly, the basal area of overstory yew is the highest on the sites with high overall overstory basal area and on sites where the overall basal area is low (Fig. 4). More detailed analyses on plot level (as opposed to site level) are under way to determine if this confusing trend is due to other factors playing more crucial role in yew regeneration dynamics than the overstory basal area, or if it is the result of pooling the data. The basal area of dead yew trees may potentially be indicative of unsuitable stand conditions (such as dense overstory or bark stripping by deer). The basal area of cut stems is currently being used in analyses as an indicator of management intensity (and another predictor for yew seedling densities).

OVERSTORY SPECIES COMPOSITION

Overstory composition is an important indicator of site history and environmental conditions. Different tree species, have different properties in intercepting light, for example, and thus they create different understory light conditions underneath them (Lieffers *et al.* 1999). In addition, litter quality and quantity and associated soil properties may also be significantly different. In this study, the cover and thickness of litter layer will be related to both overstory species composition and yew seedling density. Research sites are mostly composed of *Fagus sylvatica*, *Picea abies*, *Abies balsamea* and *Taxus baccata* as major species, but they vary in the proportion of the composition taken up by these species (Fig. 5).

TRENDS IN OVERSTORY SPECIES COMPOSITION

A Non-metric Multidimansional Scaling (NMS) ordination was performed on the tree species plot data to compress the variation in tree species composition into smaller number of axes of variation. This technique is particularly well suited to highly non-normally distributed data (e.g. in case of many zero values, such as in cases of less frequent tree species). From the ordination it is apparent that 2 axes are sufficient to account for the majority of variation (Tab. 3). Plots from all sites, with the exception of KAM, are scaterred within generally the same ordination space (Fig. 6), thus it appears that site level differences in species composition do not necessrily reflect a complete difference in composition of entire sites, but that the sites are patchy in their nature and similar plots are alternating with dissimilar ones.

The major tree species appear to separate well in the ordination space along the two axes (Fig. 7). While *Fagus sylvatica* tends toward the lower right corner of the ordination space, *Abies alba* is centered within the upper left corner, and *Taxus baccata* in the upper right corner. Thus, it appears that these species clearly differ in their ecological requirements and tend to make well defined distinct communities under some conditions. However, *Taxus baccata* does not form monospecific stands (and its affinity to either of the two axes of variation is much weaker than that of beech or fir). The association of beech and yew has been recognized in the past and was termed as Taxo-Fagetum forest type (Korpeľ 1995). It is not clear when this association yields to pure beech forests that are clearly separated out in the ordination space. It appears that *Picea abies* has the most overlap among the community types built by these 4 major species; it separates well only along axis 2 as it tends toward upper portions of the ordination space.

Most less frequent tree species do not participate strongly on defining the gradients in the ordination space. Of interest is the participation of pioneer species (*Sambucus sp*., *Corylus avellana*) in separating out several plots in KAM (Fig. 8). These could point to history of past human disturbance, although that may not necessarily mean substandard condition for yew presence (cf. Mitchell, 1990). On the other hand, yew regeneration has been found to be facilitated by fleshy-fruited shrubs (Garcia *et al*. 2000), and *Sambucus* could potentially play such a facilitative role. Of interest is also the trend in *Larix decidua*, that appears to separate within the same space as *Taxus baccata*, however this trend is statistically very weak (Fig. 8).

TRENDS IN YEW REGENERATION IN ORDINATION SPACE

Yew regeneration separates also quite well within the ordination space (Fig. 9). The previously noted discordance in the densities of germinant and seedling size classes is even more apparent. While germinants tend toward the upper portion of the ordination space (Fig. 9A), somewhat resembling the pattern of spruce, this pattern is much weaker for the following seedling size class (<10cm tall) (Fig. 9B). Larger seedling size-classes (Fig. 9CD) do not separate in the ordination space along the axis 2, but instead along the axis 1, somewhat resembling the pattern of fir. Thus, again, it appears that yew germination is most successful in different conditions than are those favoring yew survival and recruitment. The regeneration of Himalayan yew was found to be better in moist and shady microsites and on undisturbed locations (Rikhari *et al*. 1998; 2000). Such microsites may be more likely to occur underneath spruce or fir than beech (at least due to altitudinal moisture gradients, but possibly also due to effects of different litter types). Moist microsites were important in the regeneration of other species as well (e.g. Cornett *et al*. 1997; Dovčiak *et al*., 2003).

DEER PRESSURE ON YEW POPULATIONS

Once seedlings are established, they face the risk of being browsed by deer. In this study, the deer pressure was quantified as the mean proportion of bark striped by deer from adult yew trees, and as the mean proportion of yew trees on plots that were striped (regardless of the amount of stripping) (Fig. 10). The two indices of deer pressure appear to be highly correlated. Since bark removal was found to significantly decrease the survival of adult Himalayan yews (Purohit *et al*. 2001), the status of yew trees (dead or alive) will be related to the incidence of bark stripping. Further, these deer pressure indices will be used in overall regression model to predict the density of yew regeneration. From comparing the yew seedling densities across the sites (Fig. 3), it appears that seedlings > 25cm tall appear most on the site (TANA) that has the least deer pressure. However, the pattern does not hold perfectly across the other sites. The clear determination of the role of deer pressure will come from the final model integrates all significant predictors.

ADULT YEW POPULATION DIFFERENCES

In addition to all previous factors, actual individual yew trees differ among the sites, potentially causing differences among them in yew regeneration. Regardless of yew basal area, individual yew trees differ in their size (and thus fruit production). Indeed, the site with the largest yew trees (POL) had the largest germinant production (even though it did not translate to highest recruitment to older seedling stages). Thus, the characteristics of the yew population such as the size of the individual trees will also have to enter the initial comprehensive regeneration model.

YEW NEIGHBORHOOD EFFECTS

Neighborhood effects *sensu* Frelich *et al*. (1993) are the composite effects of parent trees on the success and density of seedling regeneration within their immediate vicinity. Parent trees influence the density of seedlings by determining the density and spatial distribution of seed rain, and by competing with seedlings and redistributing resources such as light, water, and nutrients. The type of neighborhood effect (positive, neutral, or negative) may vary with neighborhood size (Dovčiak *et al*., 2001; Dovčiak 2002). Yew has been hypothesized to have negative immediate neighborhood effects, that is, parent trees decrease the likelihood of seedling establishment within their immediate neighborhood (Tittensor, 1980), but this has not been tested in the field yet. In larger neighborhoods, on the other hand, the density of parent trees could be positively related to yew seedling abundance, as the seed inputs could increase with parent tree density.

Based on the subset of the data collected during the 2002 field season, we tested neighborhood effects of parent yew trees on their own regeneration within the understory plots on two spatial scales: i) the immediate (0-7m) spatial scale of overstory plots, and ii) the broader (7-30m) spatial scale of the forest matrix surrounding the overstory plots. While yew regeneration within the immediate (0-7m) neighborhood is expected to be influenced by both seed rain and competition from parent trees, the broader (7-30m) neighborhood should reflect mostly seed inputs from the forest matrix due to dispersal by birds (Giertych, 2000). A linear regression approach was used to relate the density of seedlings (>1year old, <10cm tall) to the basal area of yew trees within 0-7m overstory plots and to the number of yew trees within the forest matrix (i.e. within the 7-30m neighborhoods).

The relationship of sapling density and yew basal area within the 0-7m neighborhood was best approximated by a parabolic curve (Fig. 12A). This indicates that the intermediate densities of yew parent trees have the highest positive effect on yew seedling density, while extremely high yew basal area causes the success of yew regeneration to decrease significantly. This could be explained by the increase in shading and competition with the increasingly dense yew overstory. On the other hand, yew seedling density increases linearly as the number of yew trees increases within the forest matrix 7-30m away from understory plot (Fig. 12B). Even though the model that incorporates only these two variables is not complete yet (and the work continues to integrate all the previously mentioned variables into a single regression based model), it does explain a considerable amount of variation (R^2=0,17; p<0,003). This model suggests that yew regeneration is most successful in areas of the forest with intermediate parent yew density, that are enclosed within the forest matrix with a high density of yew trees. It seems that forest stands with a uniformly very dense yew population may not be the best regeneration setting for this species. This phenomenon would explain the trends toward the extreme lack of yew regeneration in “the best” (the densest) yew forests, that were noted by scientists, foresters, and nature conservationists in Slovak yew reserves, and elsewhere. The lack of yew regeneration in these reserves may be at least partially due to the fact that the yew density in the reserves is too high.

If these findings are corroborated by additional currently ongoing analyses that are incorporating data from yew transects and the additional 4 yew sites from 2003, improvements in management of yew populations in strict reserves could be achieved in following ways: 1) in addition to high density yew stands, yew reserves also need to always incorporate areas with lower (intermediate) yew densities, where the successful regeneration of this species may be better accomplished, and 2) in homogeneous high density yew stands with low yew seedling density, successful yew regeneration may be achieved within small areas (e.g. with 7m radius) by selectively reducing parent yew tree density within them. However, it is important to understand that these recommendations pertain only to yew populations that do not show successful regeneration. Those populations that regenerate successfully should be strictly protected as yew appears to be sensitive to management (Korpeľ 1995; Busing et al. 1995). Biosphere reserves have a great potential to meet such requirements for such adaptive management (*sensu* Perry et al., 2001) of this endangered and protected species as their statute already postulates that one of their main functions is to integrate research with management and nature conservation (i.e. ecosystem management). Such an approach will lead not only to the conservation of this species in the short term, but also to its successful regeneration and long-term persistence the forests of the region.

RESEARCH OUTCOMES TO DATE

PUBLICATIONS AND CONFERENCE PRESENTATIONS

Dovčiak, M., Carlson, D., Janečka, P., and Paule, L. (2003) Population dynamics of the English yew (Taxus baccata) in the western Carpathians. Abstract. In Lickl, E. and Heinze, B. (eds.) *10th Internationale Eibentagung,* Wien Mariabrunn, August 28-30, 2003. Programm und Materialien. Austrian Federal Office and Research Center for Forests. p. 1.

Dovčiak, M. (2002) Dynamics of forest communities and sustainability principles. In Midriak, R. (ed.) *4th National Conference on Biosphere Reserves of Slovakia,* Rožňava, Slovakia, October 28-29, 2002. Conference Proceedings. FEE Zvolen Tech. Univ., Slovak Karst BR & Slovak National Committee of MAB UNESCO. p. 55-61, (In Slovak).

RESEARCH EXTENSIONS

The research generated interest, and other projects have used synergies from cooperation or started as spin-off projects with their own funding.

1. Genetic studies of yew populations studied within this MAB UNESCO research project. Genetic material has been collected for Prof. Paule (Zvolen Technical University) who is currently analyzing the samples.
2. Studies of bird communities, fruit/seed predation, and seed dispersal by birds in the original 4 sites established in 2002. The bird surveys are starting during this fall as a thesis project lead by Asst. Prof. Kropil (Zvolen Technical University).
3. In spite of the initial lack of funds, the fieldwork for the MAB UNESCO project successfully meshed with a U.S. Fulbright student project on yew fine-scale regeneration setting. The same research sites were used and thus the data sharing for the data analysis and publication has been advantageous for both projects.

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TABLES

Table 1. Research site characteristics

Site	Temperature (°C)*	Precipitation (mm)**	Number of days with snow cover	Elevation (m)
HAR	2-4	1200 - 1600	120 - 140	620-840
POL	4-6	900 - 1000	100 - 120	560-680
KAM	4-6	900 - 1000	100 - 120	750-880
KMJ	4-6	800 - 900	80 - 100	440-580
TANE	6-7	900 - 1000	80 - 100	580-700
TANA	6-7	700 - 800	60 - 80	680-760
PLA	7-8	700 - 800	60 - 80	420-600
PAV	7-8	900 - 1000	80 - 100	400-700

*Temperatures are given as annual means. **Precipitation is given as annual sum.

Table 2. Nonmetric Multidimensional Scaling stress for different numbers of dimensions.

	Stress in real data		Stress in randomized data			
Dimensions	Stress	Change	Mean	Minimum	Maximum	*p*
1	28.062	0.000	42.183	26.154	57.307	0.0200
2	12.287	15.775	15.814	12.387	33.187	0.0100
3	8.141	4.146	8.878	7.284	12.159	0.2000

The most appropriate number of dimensions should have minimum stress value. Monte Carlo significance tests were performed using 99 runs; *p* is a proportion of randomized runs with stress ≤ observed stress.

Table 3. Pearson and Kendall correlations of tree species basal area with Nonmetric Multidimensional Scaling axes.

	Axis 1		Axis 2	
Species	R	Tau	R	Tau
Fagus sylvatica	0.712	0.519	-0.923	-0.834
Taxus baccata	0.271	0.311	0.299	0.251
Abies alba	-0.911	-0.488	0.305	0.236
Picea abies	-0.125	-0.180	0.601	0.447
Acer platanoides	0.041	0.140	-0.111	-0.149
Acer pseudoplatanus	-0.004	-0.061	0.344	0.140
Fraxinus excelsior	0.028	-0.032	0.227	0.104
Pinus sylvestris	0.026	0.008	0.153	0.092
Larix deciduas	0.171	0.116	0.237	0.138
Sambucus sp.	-0.538	-0.241	0.166	0.154
Sorbus aria	0.074	0.079	0.104	0.118
Tilia sp.	0.056	-0.029	-0.072	-0.051
Ulmus montana	-0.008	-0.048	0.123	0.114
Carpinus betulus	-0.053	-0.032	0.075	-0.028
Cerasus avium	0.109	0.100	0.138	0.132
Corylus avellana	-0.410	-0.209	0.138	0.135
Sorbus torminalis	-0.018	-0.069	0.112	0.094
Quercus petrea	0.076	0.100	0.086	0.082

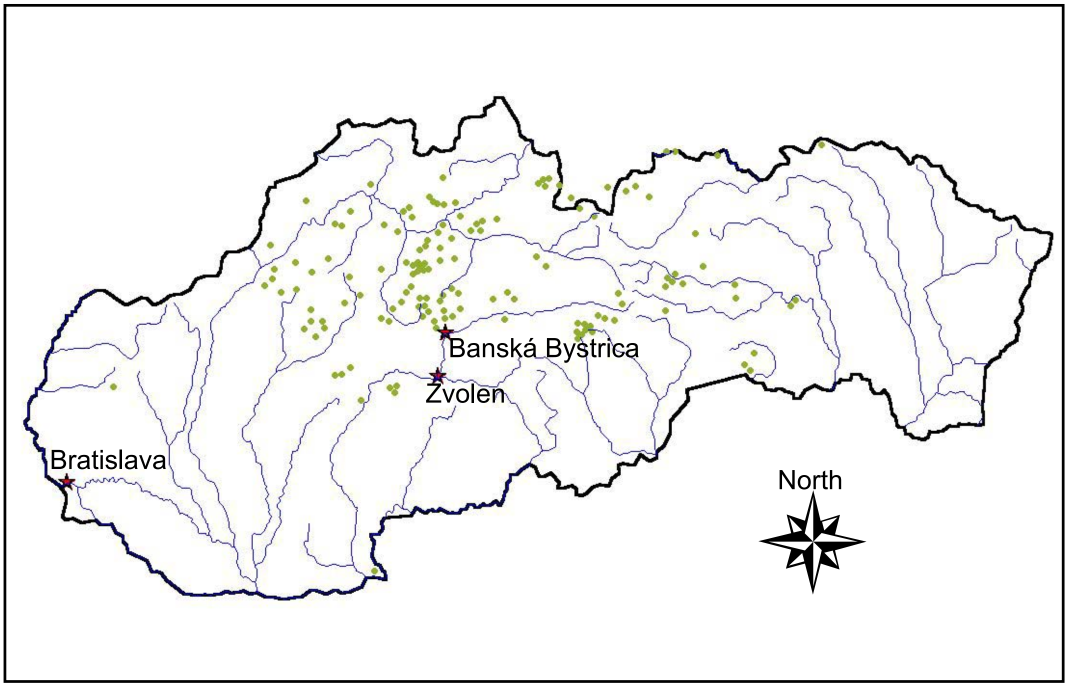


Figure 1. Historical distribution of *Taxus baccata* the in the western Carpathians (green circles). In addition, Slovak border (black line), river network (blue lines), and selected major cities (stars) are depicted.

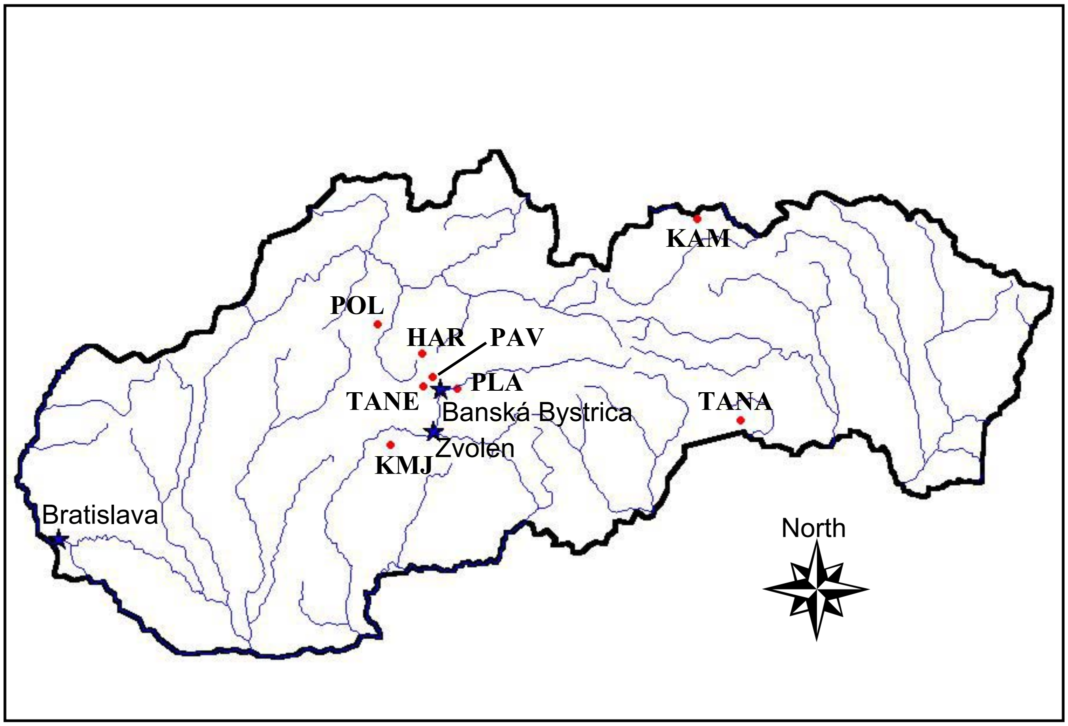


Figure 2. Research site locations (red circles). Legend is the same as in Fig. 1.

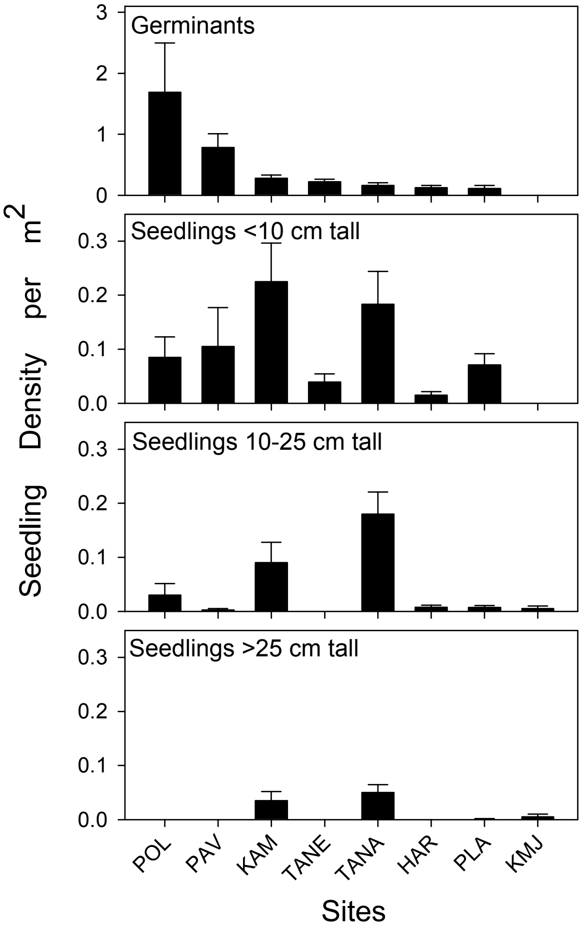


Figure 3. Variation in germinant and seedling density across research sites.

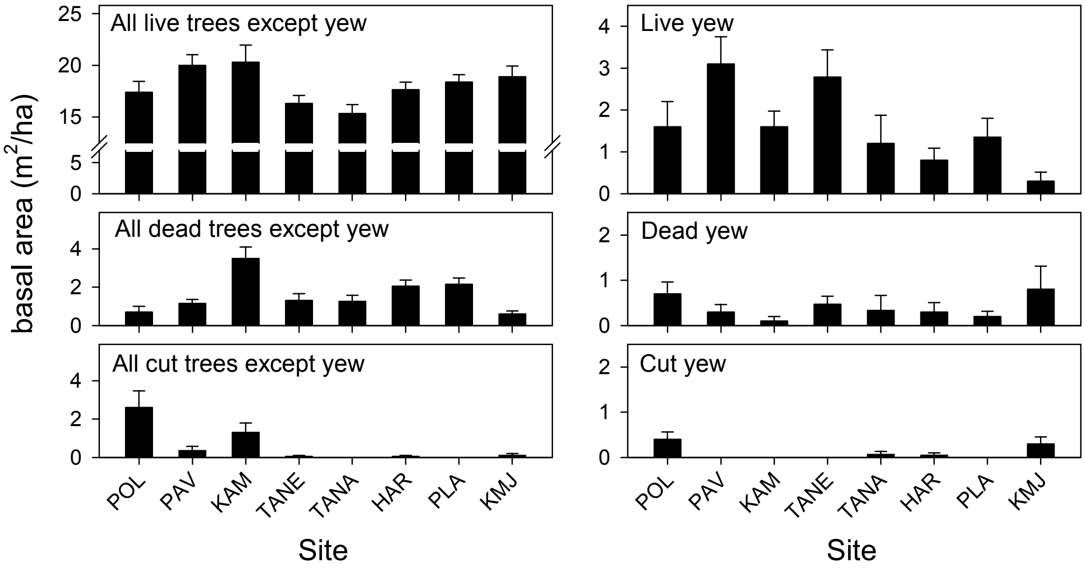


Figure 4. Variation in basal area of live, dead, and cut (individually harvested) trees across research sites. Graphs are presented separately for non-yew and yew trees.

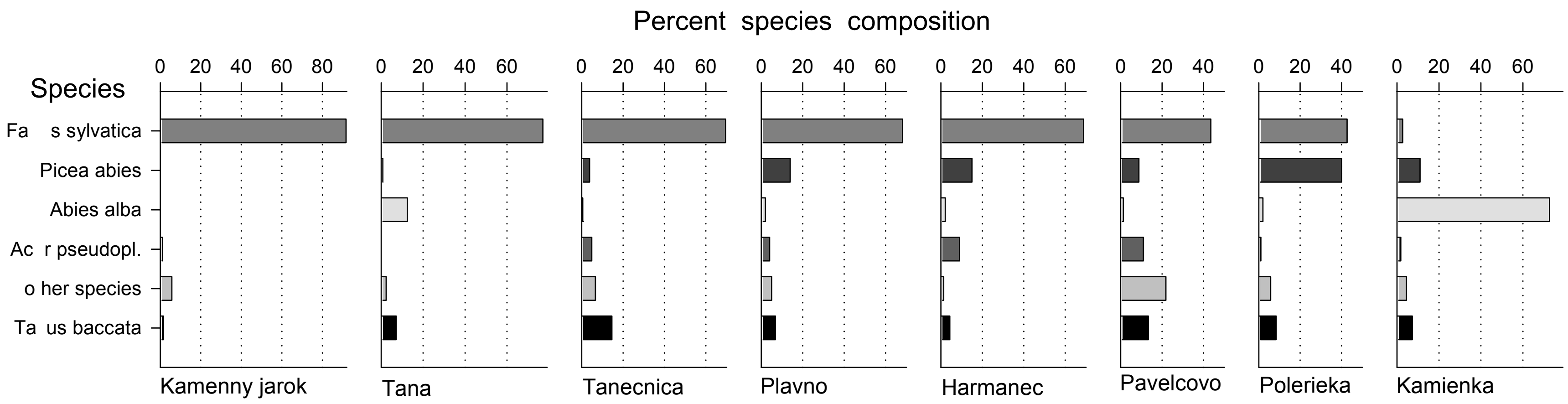


Figure 5. Variation in species composition among research sites. For each research site, species composition is expressed as percent basal area of main tree species relative to overall basal area of all live trees. Main tree species were defined as those that occur at least on ≥25% of all plots (across all sites) and that form ≥5% of basal area averaged over all plots (of all sites). Even though the basal area of *Acer pseudoplatanus* is only 4.3% over all plots, this species was still considered to be one of the main species as it occurs on approximately half of all plots. The remaining, less frequent species were pooled into "other species" category.

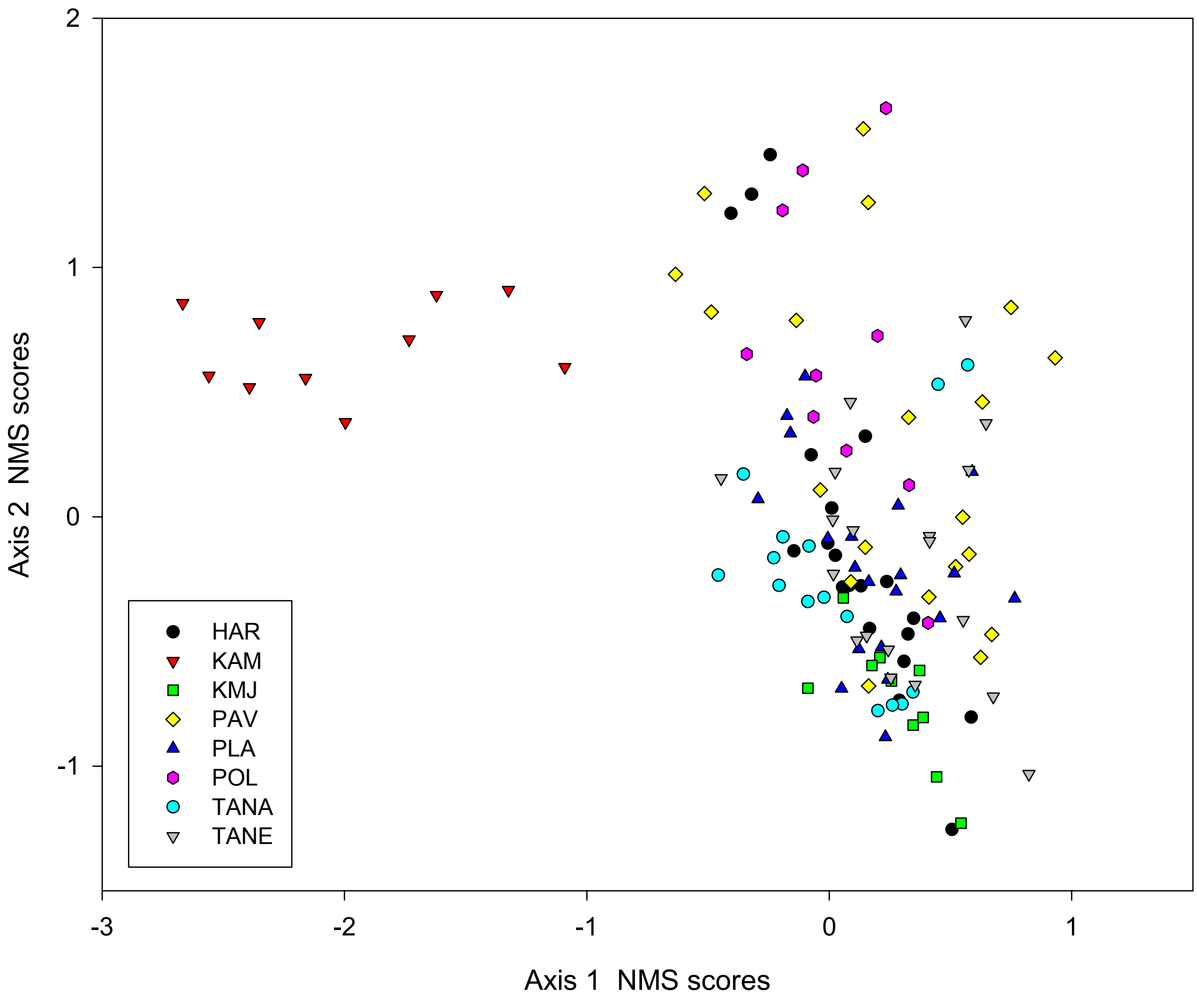
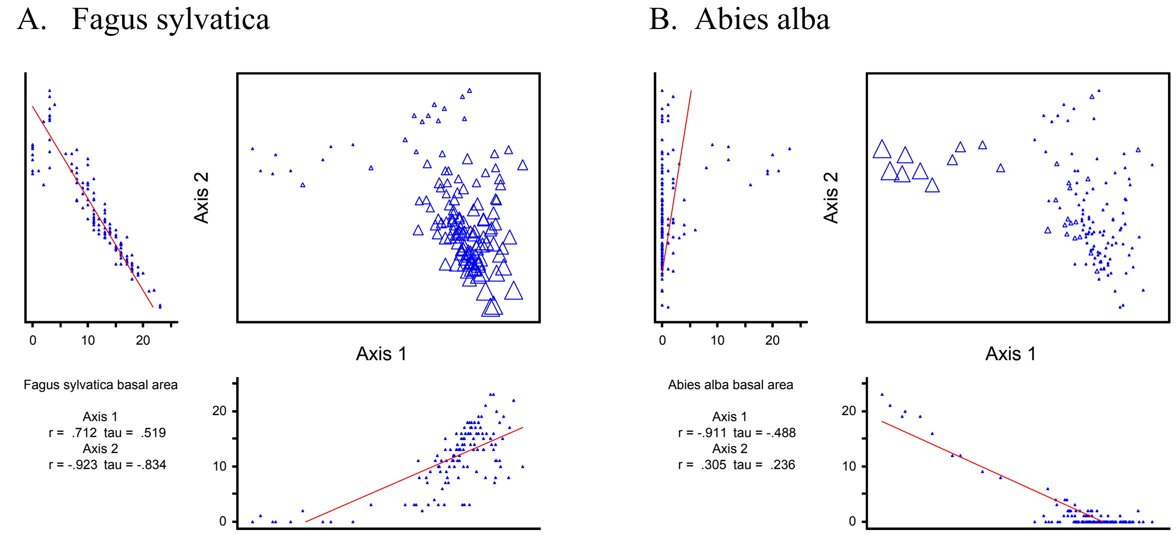
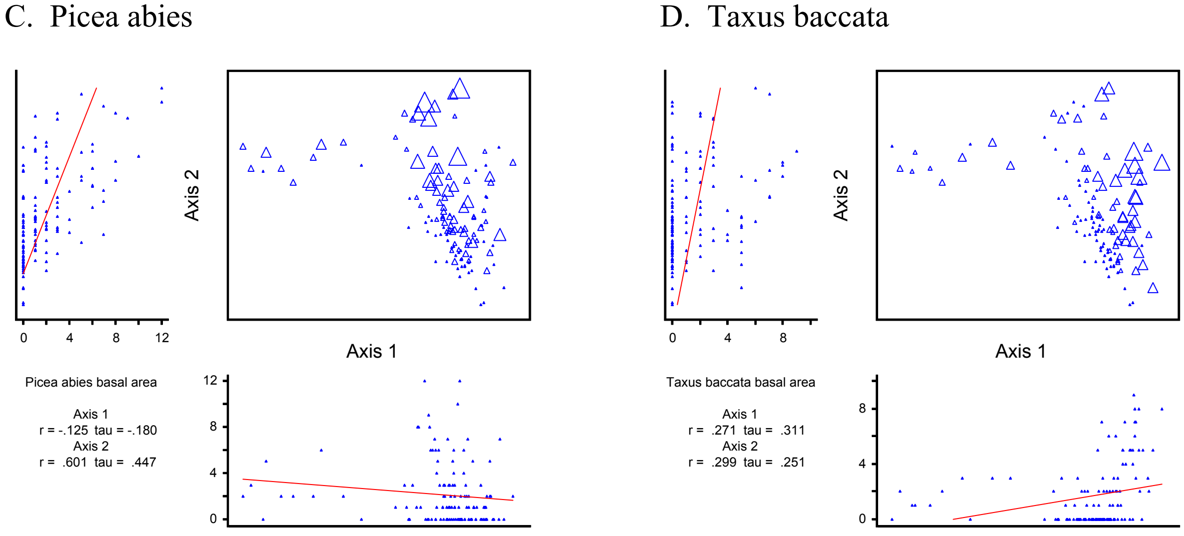


Figure 6. Ordination of individual plots using Non-metric Multidimensional Scaling (NMS). NMS is particularly appropriate for strongly non-normally distributed datasets. Tree species basal area per hectare (measured on the individual plots using variable plot method) was used to perform NMS ordination (124 plots, 18 tree species). Monte Carlo simulations and stress plots suggest that the most appropriate number of axes is two (see Table 2). Plots at different research sites are coded in different symbols and colors (see figure legend). Note that except for plots located in KAM, all other sites encompass plots from majority of the ordination space.



A. Fagus sylvatica

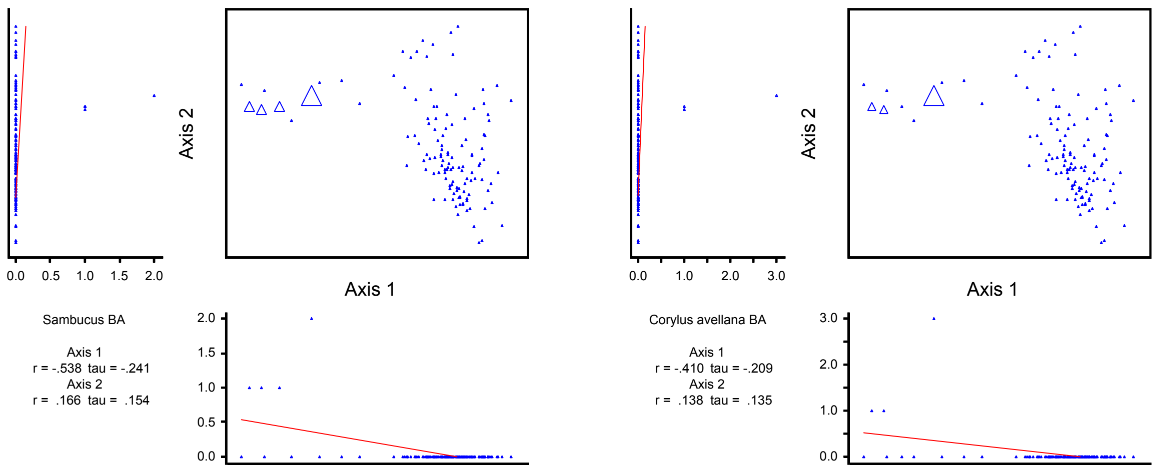
B. Abies alba



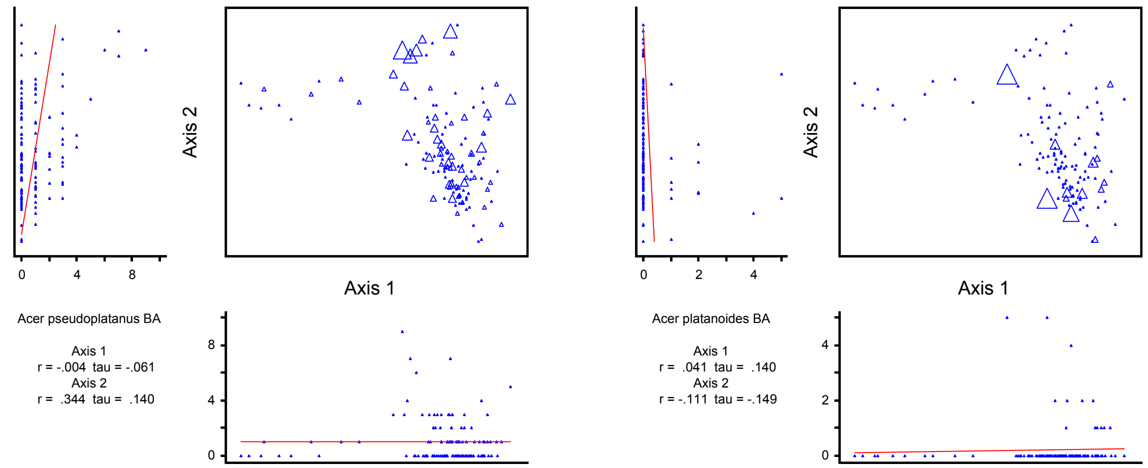
C. Picea abies

D. Taxus baccata

Figure 7. Distribution of major tree species in ordination space. NMS ordination axes and the distribution of plots within the ordination space is the same as in Figure 6. The size of a plot symbol (triangle) corresponds to the species basal area (per hectare) on that plot. For each species, the relationships between species basal area and plot NMS scores along axes 1 and 2 are depicted separately on graphs next to these axes and summarized by correlation coefficients (Pearson *r* and non-metric *tau*).


A. Sambucus sp.

B. Corylus avellana


C. Acer pseudoplatanus

D. Acer platanoides

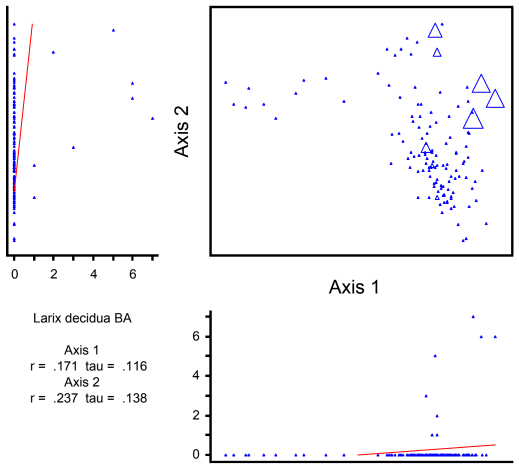
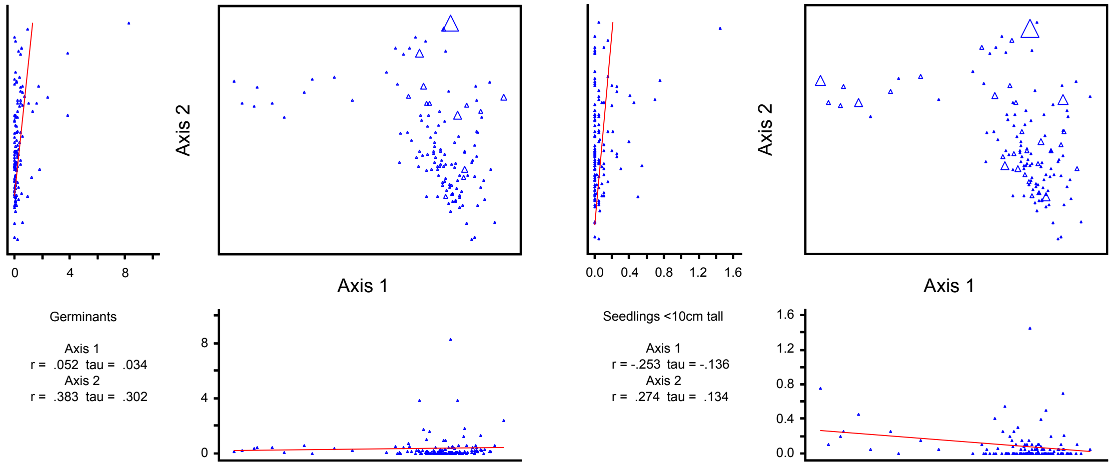

E. Larix decidua

Figure 8. Distribution of less frequent tree species in ordination space. NMS ordination axes and the distribution of plots within the ordination space is the same as in Figure 6. Symbols and graph layout are the same as in Figure 7. BA stands for basal area (m^2/ha).

A. *Taxus* germinants B. *Taxus* seedlings <10cm tall



C. *Taxus* seedlings 10-25cm tall D. *Taxus* seedlings >25cm tall

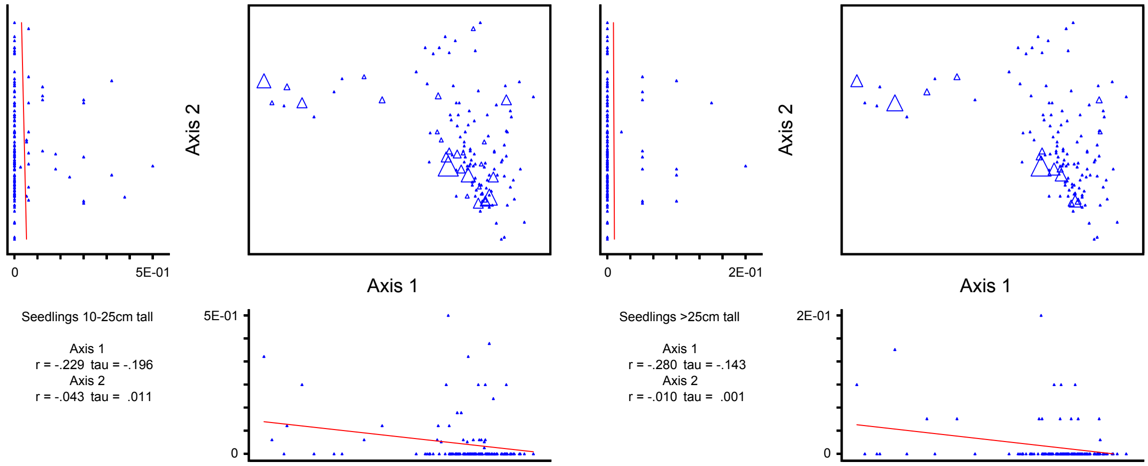


Figure 9. Distribution and density (per m^2) of *Taxus baccata* germinants and seedlings in ordination space. The NMS axes and the distribution of plots within the ordination space is the same as in Figures 6-8. Graph layout is the same as in Figures 7-8. Germinants germinated in the year of survey (and thus are <1 year old) and seedlings <10cm tall are >1 year old (and thus exclude germinants). The size of plot symbols (triangles) is in proportion to germinant or seedling density.

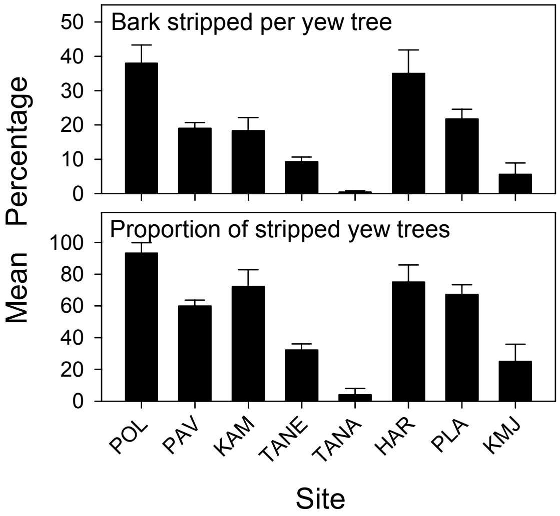


Figure 10. Deer pressure on adult yew population expressed as a) average percentage of bark stripped from individual yew stems, and b) average proportion of yew stems with any level of bark stripping occurrence in the past.

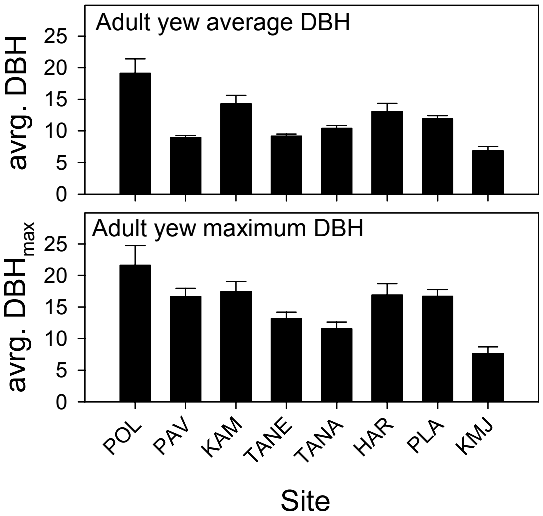


Figure 11. Average stem diameter of sampled yew populations. Diameter was measured at 1.3m height above the ground (DBH) for those yew trees with DBH >2cm. In addition to average DBH, also average maximum DBH was calculated (maximum DBH at each plot averaged for each site) as it may better approximate ecological processes related to yew size such as fruiting or shading.

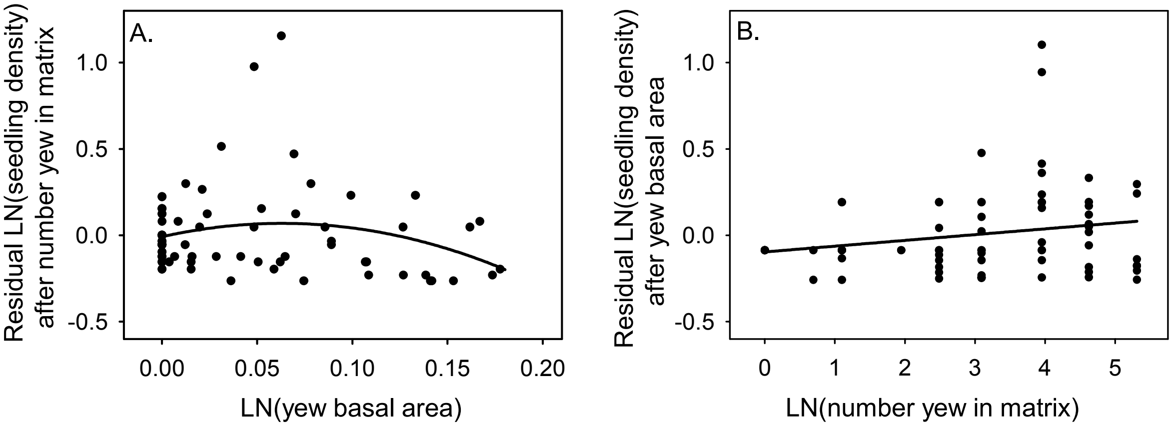


Figure 12. Neighborhood effects of adult yews on yew seedling density. A) immediate neighborhood effects of yew basal area within 0-7m neighborhoods, and B) matrix neighborhood effects of the number of yew trees within 7-30m neighborhoods. The number of seedlings, basal area and number of yew trees in the forest matrix were transformed to natural logarithms to better approximate conditions of normality. Residual density of yew seedlings (on the Y-axis) gives residuals from the partial regression models after the influence of the variable not shown on the graph was extracted (adapted from Dovčiak, 2002). These results are based on the 4 research sites established in 2002; more complex analyses that include 4 sites added in 2003 field season, and that integrate all variables are under way.

PHOTOGRAPHS

FROM

YOUNG SCIENTIST AWARD 2002 RESEARCH STUDY

POPULATION DYNAMICS OF THE ENDANGERED ENGLISH YEW (*TAXUS BACCATA* L.) AND ITS MANAGEMENT IMPLICATIONS FOR BIOSPHERE RESERVES OF THE WESTERN CARPATHIANS

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Fig. 1 and 2. Forest tracts with very high adult yew density, low herbaceous and woody ground cover, and low density of older yew seedlings in the Plavno Nature Reserve within the Polana Biosphere Reserve broader transition zone.

Fig. 3 and 4. Measuring the diameter at breast height (1.3m above the ground) of yew trees within an overstory plot. Plavno Nature Reserve within the Polana Biosphere Reserve broader transition zone.

Fig. 5, 6, and 7. Seedling transects were laid out from the center of the overstory/understory plot (marked with a red stake in the lower left corner) with a 7m long yellow rope. On the most intensively studied site at the Plavno reserve, seedlings were searched for within a distance of 1-7m from the plot center within 1m on each side of the rope (2x6m belt transect) in 2002, and their locations were marked using white plastic markers with the number of each seedling. The regeneration setting for each seedling was recorded. In 2003, marked seedlings were re-surveyed in the spring and fall to study seedling survival during the course of one calendar year.

Fig. 8 and 9. Deer pressure is significant at many of the research sites, and it results in significant bark stripping of yew stems. Wrapping the stems using plastic mesh may significantly reduce further bark stripping (left). As a result of the deer pressure, older yew seedlings are quite rare within all research sites, and further, they are often heavily browsed and assume a shrubby character (right). Plavno reserve.

Fig. 10 and 11. Wind-caused gaps in the overstory (left) are significant habitat for abundant yew fructification if yew trees are left undamaged within them (right). Seeds are distributed by birds to the other parts of the forest. Plavno.

Fig. 12 and 13. Fruit surveys with binoculars at Plavno (left) were used to quantify fruit and seed production under canopy of varying density. Seeds were collected and dried out (right) to be later introduced into the forest to study seed predation pressure (seeds were collected outside of the reserve).

Fig. 14 and 15. Counting the number of seeds left in the seed tray after a 3-day exposure to seed predators (left). The exclosure has a mesh size of ~3cm, which excludes larger seed predators like squirrels, but not smaller rodents. The same exclosures were used for the seedling herbivory experiment. Plavno Reserve.

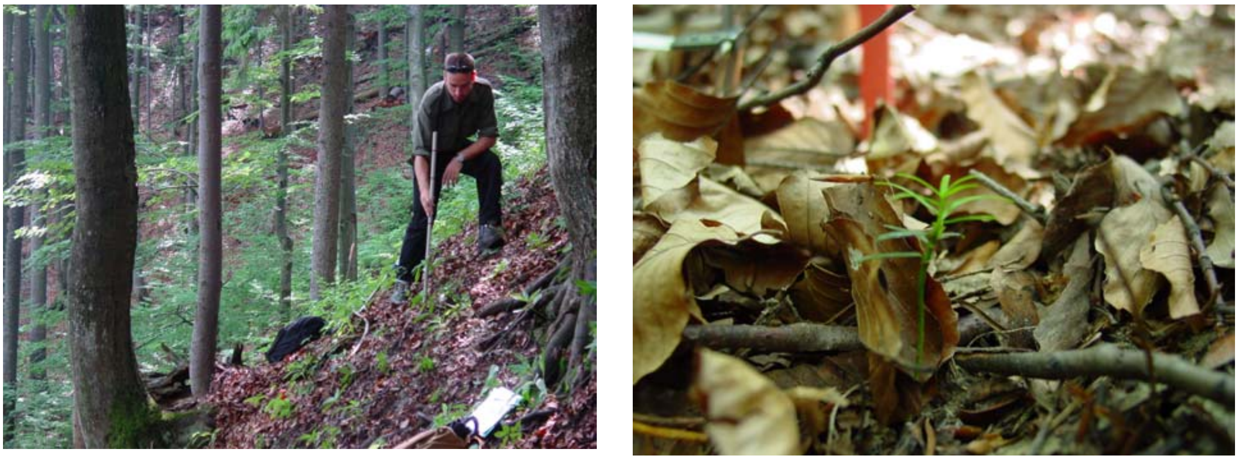

Fig. 15 and 16. Measuring litter layer depth in Harmanec (left). Litter depth and type may be crucial for seedling survival, and especially so for germinant survival (right).

Fig. 17 and 18. Although there was more advanced yew regeneration on sites outside the center of yew distribution in the western Carpathians, deer browse was still significant. Yew seedling growth was larger than browse along the ground where seedling branches are protected by snow (left), while cliffs have been traditionally hypothesized to provide a refuge against deer browse (right). Slovak Karts Biosphere Reserve.

Fig. 19. Doctoral students and other young scientists from the Department of Applied Ecology and Department of Plant Sciences were helpful in accomplishing the field work.