

LETTERS

Protecting the Forests While Allowing Removal of Damaged Trees may Imperil Saproxyllic Insect Biodiversity in the Hyrcanian Beech Forests of Iran

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Abstract

The 1.8 million ha of forest south of the Caspian Sea represent a remarkably intact ecosystem with numerous old-growth features and unique species assemblages. To protect these forests, Iranian authorities recently passed a law which protects healthy trees but permits the removal of injured, dying and dead trees. To quantify the biodiversity effects of this strategy, we sampled saproxyllic beetles and true bugs in 24 plots across the entire altitudinal gradient of Oriental beech. The composition of these communities as well as their overall richness and the richness of endemic and old-growth indicator species were best explained by dead wood volume compared to other environmental variables. Due to the striking evidence that dead wood is the major driver of saproxyllic diversity in these forests, we urge Iranian authorities to reconsider their law, redirecting logging toward healthy medium sized trees. Otherwise, a major loss in biodiversity, similar to that experienced in European beech forests, can be expected.

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Introduction

The extent, age and structural complexity of forests have been reduced severely in many parts of the world (Ódor *et al.* 2006; Brunet *et al.* 2010). Only in recent decades have concentrated efforts been made to understand connections between these changes and biodiversity declines. One lesson to emerge from research in Europe, but relevant to forests everywhere, is that a large proportion of animal and fungal biodiversity (perhaps 20–30%) is “saproxyllic,” or reliant on dying or dead wood at some point during their life cycle (Speight 1989; Stokland *et al.* 2012). Indeed, for key indicator taxa like saproxyllic beetles or fungi, the amount of dead wood has been shown to be the main driver of species diversity, func-

tional diversity and the occurrence of old-growth specialists (Lachat *et al.* 2012; Gossner *et al.* 2013; Bässler *et al.* 2014). Moreover, such species are disproportionately well represented on lists of regionally extinct or threatened taxa (Seibold *et al.* 2015). For this reason, the retention of declining trees and woody debris features prominently in many modern conservation-oriented management strategies. The loss of saproxyllic species from European forests as a consequence of increasing forest-use intensity (i.e., beginning with the fragmentation of a formerly continuous forest landscape, followed by the replacement of original broadleaf forests with conifer plantations and then severe reductions of dying and dead trees in the remaining broadleaf forests; see Seibold *et al.* 2015), serves as a cautionary tale for other regions

interested in protecting their forests from a similar fate. This is especially true for compositionally similar forests growing elsewhere in Eurasia, such as the Hyrcanian forests of Iran (named after the ancient region of Hyrcania, or “wolf land”).

Whereas the temperate broadleaf forests of Europe are dominated by European beech (*Fagus sylvatica*), the Hyrcanian vegetation zone south of the Caspian sea (also called Caspian forests) is largely dominated by Oriental beech (*F. orientalis*)—considered by some to be a subspecies of *F. sylvatica* (Denk 1999; Gömöry & Paule 2010). In recent decades, these Hyrcanian forests have become increasingly valued by conservationists for their many natural features (Nosrati *et al.* 2005). Most remarkable are high densities of large and old trees (Moradi *et al.* 2012; Sagheb-Talebi *et al.* 2014; Figures 1a and b), which are rapidly declining worldwide (Lindenmayer *et al.* 2012), the high number of endemic species (Figures 1c, d, and S2; for plants Jalili & Jamzad 1999) and the large continuous forest cover (Sagheb-Talebi *et al.* 2014). Indeed, this ecosystem is still intact enough to provide habitat for top predators such as the Persian leopard (*Panthera pardus ciscaucasica*).

In December 2013, Iranian authorities passed a law aimed at conserving this important natural area by protecting all healthy trees growing within these forests. Although well meaning, these protections are made at the expense of declining trees and woody debris—substrates that are less economically valued but no less ecologically important. Under the current law, “wood exploitation is only allowed by harvesting damaged trees, including broken, fallen, uprooted, infested and diseased trees (Article 6)” (translation provided by TK) (Figures 1g and h), without regard for the conservation value of these features. This evoked a debate in Iran as, having in mind the European example, such a regulation sets off the alarm of all those working in the field of temperate forest conservation. Although the systematic removal of damaged trees and dead wood since the late 18th century has already extirpated many saproxylic organisms from European forests (Seibold *et al.* 2015), it remains unclear whether a similar decline can be expected in the Hyrcanian forest where the abundance of keystone structures such as old and large trees over a large area might compensate for local reductions in the amount of dead wood (Økland *et al.* 1996; Jonsell 2012). To assess the potential ecological effects of the implementation of this law in Caspian beech forests, we investigated the role of dead wood quantity in comparison to other environmental features in supporting diverse assemblages of saproxylic arthropods. We focused in particular on saproxylic insects (beetles and true bugs) as these organisms are commonly used as indicators of naturalness and forest-use intensity and are highly correlated with the occurrence of other specialists of natural

forests (Martikainen *et al.* 1998; Brunet *et al.* 2010; Paillet *et al.* 2010; Gossner *et al.* 2013; Seibold *et al.* 2014).

Material and methods

Study region and study design

Our study site is embedded in the Hyrcanian forest, which forms a green belt stretching over the northern slopes of the Alborz Mountains and borders the southern coast of the Caspian Sea (Appendix 1, Figure S1). This area is approximately 800-km long and 110-km wide and has a total area of 1.85 million ha (comprising approximately 15% of Iranian forests). The vegetation cover between the Caspian Sea and the Iranian plateau is strongly driven by climatic differences along an elevation gradient ranging from sea level to 2,800 m. In the plains, the *Quercus-Buxetum* community dominates followed uphill by *Quercus-Carpinetum* and *Parrotia-Carpinetum* communities. *Fagus orientalis* starts at about 400 m a.s.l. and dominates *Fagetum hyrcanum* communities between 700 and 1,500 m a.s.l. Above the beech belt, *Quercus macranthero-Carpinetum orientalis* communities dominate (for more details see Sagheb-Talebi *et al.* 2014). The climate of the forests is generally humid with mean annual temperatures ranging from 5.5 to 11.0 °C. Annual precipitation ranges from about 1.4 m at 500 m a.s.l. to 1.15 m at 1,500 m a.s.l., with the altitudinal decline resulting from orographic rainfall influenced by the Caspian Sea (Anonymous 2010). Thus, the maximum precipitation (approximately 1.48 m) is around 700 m a.s.l., at the lower end of the altitudinal range for *F. orientalis*. The dominant soils of the less steep slopes are extremely deep weathered chromic Cambisols whereas steep slopes are characterized by Rendzic Leptosols of intermediate to shallow soil depth (Sagheb-Talebi *et al.* 2014).

We established 24 randomly located circular plots, each with a radius of 20 m, in the Kheyrood forest (36.5 N, 51.6 E, Figure S1), an 8,000 ha educational-experimental forest overseen by the University of Teheran. Plots were separated by at least 150 m (max. >14 km; Figure S1), which has been shown to be sufficient to guarantee spatial independence of arthropod diversity in European beech forests (Gossner *et al.* 2013). Plots were distributed within the elevation range of *Fagus orientalis*, covering the expected range of dead wood volume, density of hollow trees, tree diversity and forest structures in the Hyrcanian beech forests (Table 1), based on previous publications (Amanzadeh *et al.* 2013). Some of the stands are classified as virgin forests and show no signs of any former forestry.

Insect sampling

Within each plot, five trained persons (JM, MMG, SS, ST, RB) searched together for saproxylic beetles and



Figure 1 In Hyrcanian beech forests (a) die back of old trees produces a high diversity of dead wood features and light regimes and (b) large old trees are widely distributed. The forests are characterized by high biodiversity including many endemic species, such as (e) the flat bug *Aradus elburzanus* and (f) the longhorn beetle *Parandra caspia*, as well as dead wood specialists of European conservation concern (d) *Cucujus haematodes caucasicum* and (c) the stag beetle *Aesalus ulanowski*. The new law allows use only of damaged trees (g) with high ecological importance but (h) low economic value.

true bugs for 45 minutes (= 225 sampling minutes/plot) using a broad range of standardised methods covering the different habitats of these species (Gossner *et al.* 2013). Based on our experience in European beech

forests, this length of time is sufficient for collecting a representative snapshot of the saproxylic community present at any given location, including less mobile species (for discussion see Gossner *et al.* 2013).

Table 1 Summary of environmental variables sampled on 24 plots in Hyrcanian beech forests

Variable	Method	Unit	Mean	Range
Elevation	GPS measurement	m	1004	497-1557
Hollow trees	Counting within radius 20 m	Number per plot	0.7	0 - 4
Tree genera	Counting within radius 20 m	Number per plot	2.3	1 - 3
Tree layers	Counting within radius 50 m	Number per plot	2.0	1 - 3
DBH max	Measuring largest tree in radius 20 m	cm	125	50 - 205
Dead wood	Visual estimation in radius 50 m	m ³ /ha	104	5 - 250

Nevertheless, we may have slightly underestimated species richness from Hyrcanian forest plots with the highest volumes of dead wood. Sampling methods comprised beating twigs and branches, sieving bark, fungi, and wood mould from hollow trees, bark-peeling, opening of dead wood, and visually inspecting standing and lying trees and inflorescences. All sampled individuals were identified to species level or at least to morphospecies by experts (see acknowledgements). We classified beetles as saproxylic following reference lists from Europe (Seibold *et al.* 2015), expert knowledge (see acknowledgement) and based on observations during the field sampling. We further classified species as associated with old-growth forests and as endemic to the Hyrcanian forests of Iran and Azerbaijan (for details see Appendix 2).

Environmental data

Six potentially important environmental drivers of saproxylic richness were measured in each plot (Table 1). Based on our extensive experience, four of us (JM, MMG, TK, RB) reached a consensus estimate of dead wood volume >20 cm diameter (m³/ha) present within each plot. For this each person calculated the volume of complete, standing and lying dead trees within the circle by the formula $dbh^2/1,000$ and the volume of logs, snags and larger branches by their estimated length and diameter at mean. The sum of dead wood was up-scaled to 1 hectare. Across the four persons we derived a mean value per plot. Within the same plot radius we also measured diameter at breast height of the largest tree and counted the number of trees with hollows (Gossner *et al.* 2013). One person (RB), a certified and experienced forester, counted the number of tree genera (Brändle & Brandl 2001; Gossner *et al.* 2013) and the number of tree layers within a radius of 50 m (Hölling 2000). Finally, elevation, a strong surrogate for climate (Röder *et al.* 2010), was measured with a Garmin handheld GPS device.

Statistical analysis

All analyses were conducted in R 3.0.2 (www.r-project.com). From the species data matrix we

extracted four dependent variables. For each plot we summed (I) the total number of saproxylic species, (II) the number of old-growth indicator species, and (III) the number of saproxylic endemic species. We also (IV) derived a metric of species composition based on the first axis of a NMDS ordination applied to presence-absence data. As predictors in generalized linear models (performed separately for each dependent variable), we used six environmental variables (Table 1): elevation, number of hollow trees, number of tree genera, number of tree layers, maximum diameter at breast height (DBH), and amount of dead wood. Dead wood volume was log-transformed to reach normality and homoscedasticity. To avoid strong multi-collinearity between predictor variables, we first studied the correlation matrix of all six predictors. With a maximum correlation between pairs of 0.55, collinearity did not exceed the critical value of $r = 0.7$, which justifies their multiple use in the models (Hosmer & Lemeshow 2000). Due to our restricted number of sampling plots (only 24) and six predictors we applied a backward selection with the function *stepAIC* in the add-on package “mass” to find the most relevant predictors out of our set of six in our generalized linear models. For the three richness measures we used a Poisson error distribution due to the character of count data and for the species composition measure (scores of the first axis of the NMDS) a Gaussian error distribution. For the final models we calculated the R^2 and the Pseudo- R^2 for the glms using the function *PseudoR2* in package “BaylorEdPsych.” In order to correctly display the statistics of our multiple regression model for overall richness we used a partial regression plot (residuals of Y on the remaining explanatory variables vs. residuals of the target explanatory variable on the remaining explanatory variables), because this accurately reflects the scatter of partial correlations (Moya-Laraño & Corcobado 2008).

Results

Overall, we recorded 134 species of saproxylic beetles and five species of saproxylic true bugs from our 24 sampling plots (Appendix 2). At least 23 of these species are

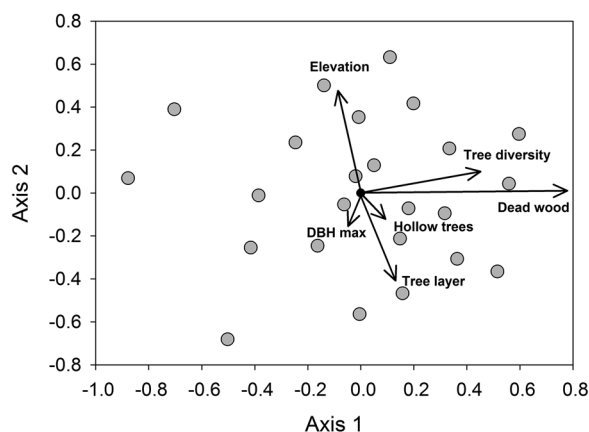


Figure 2 Ordination of species composition of saproxylic beetles and true bugs in 24 plots of Oriental beech stands by a Nonmetric Multidimensional Scaling based on presence–absence data. The environmental variables were fitted to the ordination post hoc.

endemic and 12 could be classified as old-growth indicators (note that some species could only be identified to morphospecies; Appendix 2). The number of species per plot ranged from 6 to 41. The NMDS revealed a high stress value of 0.25 indicating a weak structuring of community composition (Figure 2).

Backward selection revealed dead wood volume and the number of tree layers to be the two most important environmental variables, respectively having positive ($z = 6.1$, $P < 0.001$) and negative ($z = -2.6$, $P = 0.019$) effects on the overall number of saproxylic species (Figure 3; and Figures 1–3 in Appendix 3). The richness of old-growth indicators was significantly affected only by dead wood volume ($z = 2.5$, $P = 0.01$). The richness of endemic species was mainly and positively driven by dead wood volume ($z = 2.91$, $P = 0.003$) and showed a minor positive response to the number of tree genera ($z = 1.7$, $P = 0.07$), but a negative response to the number of tree layers ($z = -2.3$; $P = 0.02$). The backward selection for the first community axis from the NMDS revealed only an effect of dead wood volume ($t = 1.76$; $P = 0.09$). The McFadden pseudo R^2 values for the final models were 0.49 for total richness (Figure 3), 0.16 for old-growth indicator richness, 0.32 for endemic richness, and the R^2 for community was 0.08. For details on model simplification and AIC values see Appendix 3.

Discussion

It is evident from our rapid biodiversity assessment that the Hyrcanian beech forests of Iran support an impressive diversity and frequency of saproxylic insects, including at least 23 (17%) endemic species and 12 (9%)

old-growth indicator species among the 134 recorded species. Frequently encountered endemic species include the rhyssodid *Clinidium marginicolle*, the mycetophagid *Mycetophagus iranicus*, the cerambycid *Parandra caspia*, and the elaterid *Megathous menetriesi* (Appendix 2). Moreover, many species known to be under threat in Europe were encountered more frequently than expected, being recovered from 25–40% of our plots (Seibold *et al.* 2015). Examples, such as the erotyloid *Triplax collaris*, the rhyssodid *Ommoglymus germari*, and the cerambycid *Aegosoma scabricorne*, underscore the continental importance of Caspian beech forests for the conservation of saproxylic insect communities.

For European beech forests, the amount of dead wood has been repeatedly confirmed to be critical for conservation of biodiversity and for maintaining functional diversity of saproxylic communities (Brunet *et al.* 2010; Gossner *et al.* 2013; Bässler *et al.* 2014). Although the amount of dead wood could be expected to be less important in the Hyrcanian forest due to the large forest continuum (forest microclimate connectivity), the higher habitat connectivity and higher densities of large and old trees compared to Europe, we could show for the first time that dead wood volume is the most important driver of saproxylic diversity in this forest type as well.

Sun-exposure has repeatedly been shown to favor many saproxylic species in Europe (Siitonen & Martikainen 1994; Horak & Rebl 2013) and also for forest birds in Europe and Iran (Moning & Müller 2008; Gharehaghaji *et al.* 2012). Recent findings from Germany suggest species adapted to sun-exposed dead wood may be particularly vulnerable (Seibold *et al.* 2015). Because sun exposure generally declines with increasing forest layers, it is perhaps not surprising that we detected negative relationships between the number of forest layers and species richness. The pronounced gap dynamic with dying trees in homogenous single-layered mature stands (Figure 1a) seems to provide the most favorable conditions for a diverse saproxylic arthropod community. Hollow trees support a taxonomically and functionally rich fauna but only a small proportion of the entire saproxylic assemblage specializes on these structures (Müller *et al.* 2014). As we detected only a few hollow tree specialists in the current study, for example, the rare cerambycid *Paraclytus raddei*, our inability to detect a significant relationship between hollow tree abundance and saproxylic insect richness is not surprising. However, we are aware that alternative methods such as traps placed in front of hollow trees over longer periods and searching at night, both of which were not feasible in our study, would likely have revealed more species.

Although interest in conserving the Hyrcanian forest ecosystem is growing (Nosrati *et al.* 2005; Gharehaghaji

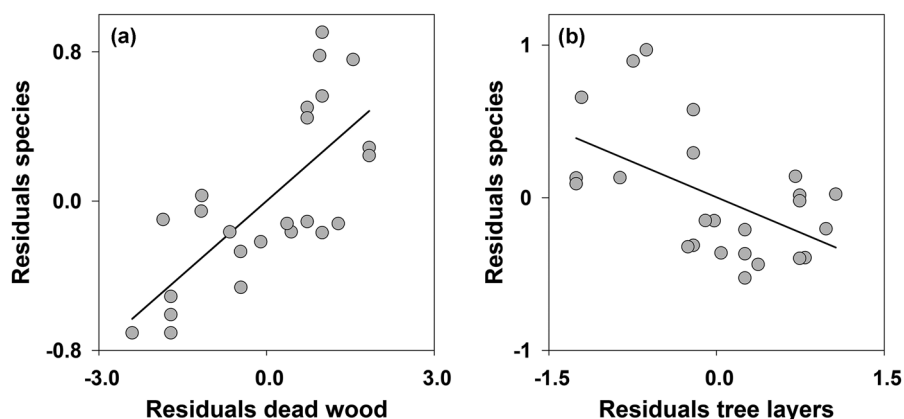


Figure 3 Partial regression plot of species richness and the two backward-selected predictors (a) volume of dead wood and (b) number of tree layers. For a plot of the predicted value versus both variables, see Appendix 3.

et al. 2012), knowledge of the features most important for arthropod conservation is incomplete. The diversity and habitat associations of organisms associated with dying and dead wood, for example, remain largely unstudied in Caspian forests. By contrast, such questions have been intensively studied in the compositionally-similar beech forests of central Europe where research continues to inform and revise management practices. Beginning in the mid-20th century, a “near-to-nature” strategy was developed by European forest authorities to protect and promote ecosystem functions and biodiversity in the face of commercial timber harvesting. This strategy is based on selective cutting that promotes regeneration of native tree species. The near-to-nature strategy in Central Europe followed the slogan “removing the economically poorest trees first” during thinning and logging operations over many decades and this included the regular removal of overmature trees and dead wood (Bässler *et al.* 2014). This has led to a measurable ecological degradation and even formerly widespread species, such as the principal decay fungus of beech, *Fomes fomentarius*, have become regionally extinct (Gossner *et al.* 2013; Bässler *et al.* 2014). The new strategy for Hyrcanian forests depicted by the new law, even if not intending to remove large and old trees but allowing the harvesting of damaged trees, opens the avenue for the reduction of recent dead wood stocks and prevents the creation of new dead wood by harvesting trees with broken crowns, with hollows and trees attacked by wood boring insects or wood-inhabiting fungi. All of these features increase with tree diameter and age (Larrieu & Cabanettes 2012). By restricting wood exploitation only to damaged trees, the ecological degradation may happen even faster in the Hyrcanian forest than in Europe where both dead and healthy trees were used to cover timber demands. When only hollow and dam-

aged trees are harvested, the yield of timber suitable for material utilization is negligible (Figures 1g and h; Knoke 2002; Moradi *et al.* 2012) and thus, far more damaged trees have to be harvested than healthy trees to produce the same amount of timber. Near-to-nature concepts similar to those implemented in Central Europe have been developed also for Hyrcanian forests (Sagheb-Talebi *et al.* 2014), but targeted retention rates for dead wood (1–2% of the growing stock) are likely too low (Müller & Bütler 2010). Indeed, a number of forest ecologists are already calling for the protection of larger quantities of woody debris in these forests (Sagheb-Talebi pers. comm.).

Our findings strongly support the conclusion that Hyrcanian forests represent an important resource for saproxylic assemblages, harboring not only high population densities of species almost extinct in Europe, but also many endemic taxa. Based on this information and with an eye on lessons from the history of European forest management, we feel the new Iranian law, although born of good intentions, is not the best way forward. We believe the law will be doubly ineffective with respect to satisfying demands for forest products as well as protecting the ecological integrity of Hyrcanian forests. By implementing the new law, an extensive removal of damaged trees, “one of the most significant features of natural forests,” will accelerate the ecological degradation of these unique forests, thus contradicting the initial aims of the law. Therefore, we urge Iranian authorities to revise this law in a way that prioritizes the preservation of important features, such as moribund trees and dead wood, harvesting healthy medium sized trees instead. Gap felling aimed at mimicking natural disturbances (Sagheb-Talebi & Schütz, 2002), such as gaps created by wind or fallen overmature trees (Figure 1a) would provide the sunny microhabitats favored by many saproxylic

insects. The increased structural heterogeneity resulting from such an approach would likely also support a wide diversity of other organisms (Moskát & Szekeley 1987; Gossner *et al.* 2013). Balancing the need for economic development with the desire to preserve intact ecosystems is a challenge faced by forest managers throughout the world and satisfying the incompatible goals of various competing interests frequently requires clear zoning and differentiated management (Demaze 2008). Because any kind of logging affects communities in beech forests (Bässler *et al.* 2014) we encourage authorities to conserve at least some of the existing relicts of primeval forests in strictly protected areas covering the full range of climatic conditions and thereby their species in the Hyrcanian forests.

Finally, we would like to stress that the rapid biodiversity assessment reported herein represents just a snapshot of Hyrcanian saproxylic insect diversity. Our findings send a clear message that current laws and practices are unfavorable for conservation but only begin to describe the diversity and requirements of the Hyrcanian fauna. To accelerate progress in this area, we propose establishing a group consisting of national and international beech forests experts to develop a comprehensive and spatially explicit concept for managing the entire Hyrcanian forest. A primary goal of this group should be to avoid repeating the mistakes learned from the history of management in Central European beech forests.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Appendix S1: Distribution of sampling plots.

Appendix S2: Species list and species classification.

Appendix S3: Statistical output.

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