Red-listed tree species abundance in montane forest areas with differing levels of statutory protection in north-western Vietnam

Authors: Hoa Hong Dao, Thi, and Hölscher, Dirk

Research Article

Red-listed tree species abundance in montane forest areas with differing levels of statutory protection in north-western Vietnam

Thi Hoa Hong Dao[1,2]*and Dirk Hölscher[1]

[1]Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany; [2] Faculty of Silviculture, Vietnam Forestry University, Hanoi, Vietnam.
* Corresponding author: E-mail address: tdao@gwdg.de Present address: Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany. Tel: +49 176 9585 4889. Contributing author E-mail address: dhoelsc@gwdg.de Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany. Tel: +49 551 3922121; Fax: +49(0) 551/39-4019

Abstract

Statutes, regulations, and forest restoration represent measures aimed at promoting the conservation of threatened species. We analyzed the abundance of red-listed tree species within three conservation zones with differing levels of protection in the Ta Xua Nature Reserve in north-western Vietnam, a rarely studied region within a biodiversity hotspot. The study area included: (1) the undisturbed core zone; (2) the low intensity traditional forest use buffer zone; and (3) the forest restoration zone. Red-listed tree species richness (IUCN and Vietnamese Red Lists combined) amounted to 16 in the core zone, 10 in the buffer zone, and five in the restoration zone; a similar declining trend was found for all tree species at 193, 173 and 135 for each respective zone. Differences between zones were even more pronounced when species richness was predicted using the Chao2 estimator. Most red-listed species, such as Fujian Cypress (*Fokienia hodginsii*)*,* reached their highest densities in the core zone, but one species (*Quercus platycalyx*) was quite abundant in the restoration zone. For some red-listed tree species, canonical correspondence analysis suggested relationships among the presence of footpaths, canopy closure and basal area, suggesting reduced abundance caused by human activities. Our data indicate that conservation effectiveness is related to the level of statutory protection afforded to a particular area, with full protection ensuring more robust conservation outcomes.

Keywords: core zone, buffer zone, restoration zone, conservation, diversity, selective logging, shifting cultivation

Cite this paper as: Thi Hoa Hong Dao and Dirk Hölscher. 2015. Red-listed tree species abundance in montane forest areas with differing levels of statutory protection in north-western Vietnam. *Tropical Conservation Science* Vol.8 (2): 479-490. Available online: www.tropicalconservationscience.org

Introduction

Conservation areas, such as national parks and nature reserves, are a key component of tropical forest conservation, safeguarding natural ecosystem processes and threatened species [1-2]. However, many designated conservation areas encompass human settlements, which in some cases leads to conflicts between socio-economic and conservation objectives. To address this problem, variations in conservation measures with different forest-use intensities have been developed. For example, at certain locations important to biodiversity, buffer zones have been established where some low intensity uses are permitted in order to maintain local livelihoods and traditions while reducing anthropogenic pressures on protected core areas [3].

Different forest-use practices and intensities can affect species composition and diversity in different ways. In strictly protected areas, old-growth forests that have been exposed to little or no human disturbance are considered irreplaceable for maintaining tropical biodiversity [4]. In some mature forests, selective logging can also allow considerable species diversity [4-5], but it may also cause subsequent degradation and conversion, declining levels of biodiversity [4,6,7], and longer-term changes in species composition, especially of threatened tree species [5,8]. Natural forest regeneration and restoration can play an important role in conservation, particularly after relatively low intensity uses such as shifting cultivation [9-10]. In general, more site-specific quantitative information on the abundance of threatened tree species richness is needed to inform conservation management.

Vietnam is one of the most biodiversity-rich countries of the world [11]. However, natural forest resources have declined dramatically as a result of the Vietnam War, population growth, overexploitation, and the transformation of forested areas into arable land [12]. Many species in Vietnam are therefore facing extinction, with around 356 tree species listed as '*threatened*' to varying degrees [12-13]. To address declining biodiversity caused by habitat loss, Vietnam established a system of 30 National Parks and 126 Nature Reserve Areas throughout the country [14-15]. However, relatively few studies have assessed threatened tree species abundance and the associated role of ecological factors [16]. Such ecological studies on threatened tree species are essential in order to accurately assess the effectiveness of biodiversity conservation in protected areas.

We conducted the current study in north-western Vietnam on the south-eastern slopes of the Hoang Lien Son mountain range, a region that has rarely been studied, despite its high biodiversity potential [17-18]. The Ta Xua Nature Reserve includes a strictly protected core zone of near-natural forest; a buffer zone where only traditional forest-use is permitted; and a restoration zone where forest regenerates after shifting cultivation. Our objectives are to assess differences in the abundance of red-listed tree species among three conservation zones and analyze whether they are related to human interference. We want to find out whether the abundance of red-listed tree species in a given altitudinal range declines with intensity of human interference. Our results may provide new insights into the ecological characteristics of some red-listed tree species and provide essential information for evaluating the effectiveness of conservation measures in the research area.

Methods

Study area

The Ta Xua Nature Reserve (21°13′ – 21°26′ N, 104°16′ – 104°46′ E, Fig. 1) was established in 2002 [19]. The topography of the region is characterized by its high, steeply sloping mountains, ranging in altitude from 320 m to 2,765 m a.s.l. with inclinations of between 30° and 40°. The climate is humid-tropical with high levels of precipitation and is influenced by the north-east monsoon. At the

nearest meteorological station (Phu Yen, c. 40 km from Ta Xua Nature Reserve at 175 m a.s.l.), annual precipitation ranges from 1,600 mm to 1,900 mm, and the average temperature is 20°C.

The reserve incorporates a '*core zone*' of 15,211 ha, with a forest cover of 87%. This zone is entirely and strictly protected. All human activities such as logging, hunting, and the gathering of non-timber forest products are prohibited and signs of these activities were rarely observed. The forest types range from evergreen, broad-leaved woodland at lower elevations to coniferous forest mixed with some evergreen, broad-leaved species at the higher mountain peaks [19-20]. The core zone can only be reached by footpaths, some of which were made before the Nature Reserve was established, while others mark out ranger patrol and research project routes or tourist trails.

The '*buffer zone*' of the reserve encompasses 24,674 ha with a forest cover of 44%, which only occurs above 900 m a.s.l. and is managed by the H'Mong people in accordance with forest management regulations established by the forest protection and development law. These regulations allow an official maximum of 25 trees to be felled per year in a forest area of 10,856 ha. However, during field work, some illegal tree felling and signs of such felling were observed. Land below 900 m a.s.l. is mainly agricultural land, with upland rice, maize, and sugarcane cultivation predominating [19-20].

A protected '*restoration zone*' was also established within the reserve, which consists of 2,439 ha enclosed within the core zone and partly borders the buffer zone. In the past, this area was populated and cultivated by the H'Mong using shifting cultivation, but it has been subject to statutory protection since 2002 [19-20].
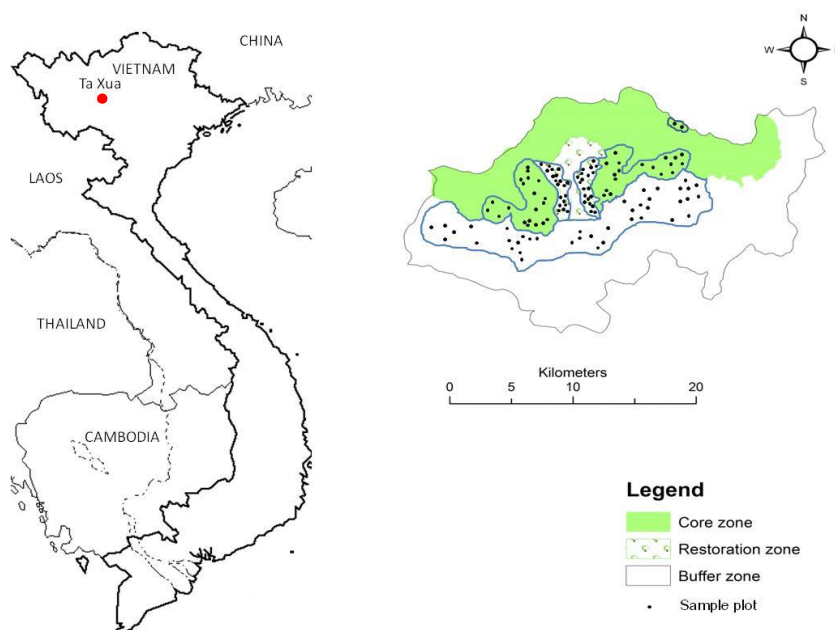

Fig. 1. Vietnam and the geographic position of the Ta Xua Nature Reserve. The actual study area at 1,000 m -1,700 m a.s.l. is indicated by blue lines comprising the core zone, the buffer zone and the restoration zone. Sample plots, 40 per zone, are indicated by black dots.

Site and plot selection
Based on a reconnaissance survey, a provisional forest cover map was established and an elevation range of 1,000 m to 1,700 m a.s.l. was selected for the study, as forest occurred in all three conservation zones. This study area included a 73 ha core zone, 115 ha buffer zone and 22 ha restoration zone. A grid system with 1,400 cells was created and overlaid on the study area plan to randomly select the locations for sample plots. Forty plots of 20 x 20 m were then established in each conservation zone, with the center of each plot located in the center of a selected cell.

Forest inventory

In the sample plots, trees with diameter at breast height (*DBH*) ≥ 6 cm were counted; *DBH* was measured and species were identified at the species level, with help from two botanists from the Vietnam Forestry University (VFU). Specimens of species unidentified in the field were collected for further study at the herbarium of VFU. Individuals that could not be determined to the species level were classified by their genera or families and sorted into specimens. For purposes of the study, red-listed tree species included '*threatened*' species listed in the Red Lists of the IUCN and Vietnam [21-22].

Five hemispherical photographs were taken at five different positions inside each sample plot using a digital camera (Minolta DIMAGE Xt, 185° fish-eye lens) mounted on a self-leveling station (the first position was located at the centre of each sample plot, while the four remaining positions were located within a five meter radius around the first position at ninety degree intervals). The percentage of canopy closure was computed with CAN-EYE V6 software [23] and an average of the five photographs was used per plot. In the center of each plot, a soil sample was collected from a depth of 0 cm to 20 cm using a soil auger for determining soil pH, soil organic matter, and soil texture [24-25]. Litter thickness was measured in cm. Slope inclination and aspect deviation from north were measured using a compass. Elevation, longitude and latitude were recorded using a GPS-locator. The number of footpaths and stumps were counted in each sample plot.

Statistical analysis

A T-test/Mann-Whitney U test and an ANOVA/Kruskal-Wallis H test were used to assess mean comparisons among the three conservation zones (*p* value was ≤ 0.05). The analytical sample-based rarefaction and extrapolation were computed using the Bernoulli product model based on a Mao-Tau estimator and a Chao2 estimator for rarefaction curves and extrapolation curves respectively [26-28]. The processes were interpolated from 40 empirical plots and extrapolated to three times as much as the number of empirical plots in each zone using EstimateS software [29]. This procedure was not applied to the data on red-listed tree species from the restoration zone, because so few empirical plots harbored red-listed tree species that the required sampling threshold of at least 20 samples was not met [30].

Canonical Correspondence Analysis (CCA) was applied to determine whether red-listed tree species abundance was related to the intensity of human interference, as indicated by the variables of footpath density and number of stumps in the core and buffer zones, using PC-ORD version 5.12 [31]. The main matrix contained the density of red-listed tree species that had been recorded more than once within a set of sample plots in the core and buffer zones, while the second matrix contained environmental, forest structural and human disturbance variables measured from the same plots. The data in the main matrix were logarithmically transformed based on the assumption of a normal distribution. In the second matrix, the data of eight independent variables (basal area, canopy closure, litter thickness, number of stumps and footpaths, slope inclination, percentages of clay and organic matter) were combined and relativized by the maximum to ensure equal weighting. Spearman correlation was applied to determine whether a red-listed species significantly correlated with the CCA axes. The CCA were not applied to data from the restoration zone because of the limited number of red-listed tree species found in the few plots surveyed.

Results

Site conditions and forest structural characteristics

Among the three conservation zones, many of the site conditions, such as elevation, were fairly comparable (Table 1). However, forest structural characteristics showed significant differences. The stem density of trees was lowest in the core zone, intermediate in the buffer zone and highest in the restoration zone, while *DBH*, basal area and canopy closure showed an opposite trend. The

differing proportions of trees with *DBH* ≥ 30 cm between the zones were as follows: 19% in core zone, 9% in buffer zone and 1% in the restoration zone. Observed tree species richness decreased from 193 species in the core zone to 173 in the buffer zone and 135 in the restoration zone. Tree species richness, as predicted by the Chao2 estimator, was 254±17 (mean ± standard deviation), 182±5 and 158±9 in the core, buffer and restoration zones, respectively (Table 1). Regarding intensity of human interference, the lowest numbers of stumps and footpaths were found in the core zone, the highest number of footpaths was observed in the buffer zone and the highest number of stumps was recorded in the restoration zone.

Table 1. Site conditions and forest structural characteristics of the three conservation zones. (Means and standard deviations, *n* = 40 plots per zone, small letters indicate significant differences at *p* ≤ 0.05)

	Core zone	Buffer zone	Restoration zone
Total study area (ha)	72.8	115.1	21.6
Mean of elevation (m a.s.l.)	1449.1 ± 62.6[a]	1363.3 ± 86.7[b]	1465.5 ± 91.0[a]
Lowest and highest elevation (m a.s.l)	1326; 1587	1248; 1557	1034; 1593
Slope inclination (degree)	39.5 ± 7.7[a]	35.9 ± 5.4[b]	35.6 ± 5.9[b]
Northern aspect (degree)	47.7 ± 44.8[a]	92.1 ± 56.7[b]	48.2 ± 48.1[a]
Soil pH	4.7 ± 0.4[a]	4.7 ± 0.4[a]	4.8 ± 0.2[a]
Sand (%)	18.6 ± 6.4[a]	21.3 ± 6.6[ab]	22.2 ± 5.2[b]
Silt (%)	43.2 ± 6.4[a]	42.9 ± 7.4[ab]	40.5 ± 5.6[b]
Clay (%)	38.2 ± 7.3[a]	35.8 ± 9.3[a]	37.3 ± 6.2[a]
Organic matter (%)	3.0 ± 1.5[a]	4.3 ± 1.2 [b]	3.4 ± 1.6[a]
Litter thickness (cm)	4.7 ± 2.0[a]	3.4 ± 1.5[b]	3.5 ± 1.1[b]
Tree density (trees ≥ 6 cm; trees/ ha)	925 ± 251[a]	1006 ± 357[a]	1660 ± 387[b]
Diameter (trees ≥ 6 cm; cm)	21.4 ± 3.4[a]	16.6 ± 3.0[b]	12.8 ± 1.4[c]
Basal area (trees ≥ 6 cm; m²/ha)	52.9 ± 21.4[a]	30.4 ± 15.4[b]	24.8 ± 5.9[c]
Canopy closure (%)	88.4 ± 7.2[a]	84.5 ± 9.4[b]	81.3 ± 6.4[c]
Observed tree species richness (sp./40 plots)	193	173	135
*Predicted tree species richness (sp./120 plots)	254±17	182±5	158±9
Stump (no./plot)	0.6 ± 0.8[a]	1.6 ± 1.6 [b]	1.7 ± 1.4[b]
Footpath (no./plot)	0.9 ± 0.6[a]	1.5 ± 0.8[b]	1.1 ± 0.9[ab]

* Tree species richness was extrapolated from 40 empirical plots to three times of 120 pooled plots by the Chao2 estimator.

Red-listed tree species

In total, 18 red-listed tree species were recorded, of which 16 species are listed as being of 'high conservation concern' in the Vietnam Red List, with five listed as 'endangered' and 11 as 'vulnerable' (Appendix 1). These species are therefore considered 'threatened' at the local level. From the total of 18 red-listed species, 16 were found in the core zone, 10 in the buffer zone and five in the restoration zone. The difference between the core and buffer zones became more pronounced when the expected number of red-listed species was estimated by the Chao2 predictor: 21±5 species (mean ± standard deviation) in the core zone and 11±2 species in the buffer zone (Table 2). In relation to the core zone, the Sørensen's and Jaccard's similarity indices were higher in the buffer zone than in the restoration zone, which indicates that the number of red-listed tree species common to the core zone and the buffer zone was higher than that between the core zone and the restoration zone.

Table 2. Observed and predicted red-listed tree species richness in the three conservation zones. The prediction is based on the Mao-Tau and Chao2 estimators (means and standard deviations). Further similarity indices in relation to the core zone are provided.

	Core zone	Buffer zone	Restoration zone
Observed red-listed species richness (sp./40 plots)	16	10	5
Predicted red-listed species richness (sp./120 plots)	21 ± 5	11 ± 2	---
SØrensen's index	---	0.62	0.48
Jaccard's index	---	0.44	0.31

Four red-listed tree species (*Madhuca pasquieri, Cinnadenia paniculata, Aglaia spectabilis*, and *Fokienia hodginsii* (*Fujian Cypress*)) showed the highest frequency and density in the core zone. One species, *Quercus platycalyx,* was particularly abundant in the restoration zone. Some other species were very rare, with only one individual being encountered in 40 plots for each conservation zone (five species in core zone, three species in buffer zone and three species in restoration zone). Of red-listed species that only occurred in a specific zone, seven species (inc. *Castanopsis tessellata, Lithocarpus vestitus, Magnolia braianensis*) were found only in the core zone and two species (*Canarium pimela, Cinnamomum balansae)* were found only in the buffer zone.

Relationships of ecological and human disturbance factors to the abundance of red-listed tree species

The two CCA axes explained 13.1% of the variance of density of red-listed tree species in the core and buffer zones (Fig. 2). The first axis (eigenvalue = 0.4) correlated positively with footpath (r = 0.4) and negatively with basal area (r = -0.4) at $p \leq 0.05$. The density of one species, *Castanopsis cerebrina,* showed a positive correlation with axis 1. Four other species (*Madhuca pasquieri, Fokienia hodginsii, Castanopsis tessellata* and *Lithocarpus vestitus*) with the highest frequency in the core zone showed negative correlations with axis 1. The second axis (eigenvalue = 0.3) related positively with basal area (r = 0.8) and canopy closure (r = 0.7), and negatively with footpath (r = -0.5) at $p \leq 0.05$. The density of *Aglaia spectabilis* showed a positive correlation with axis 2.
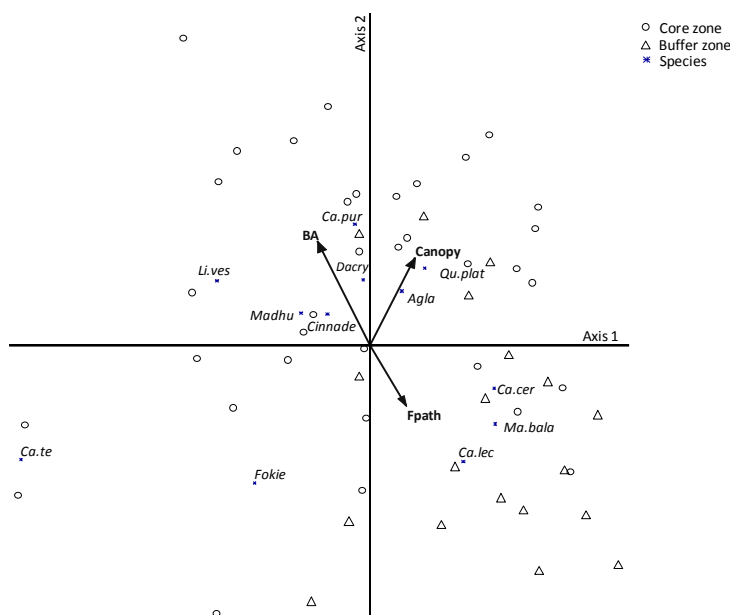
Fig. 2. Canonical correspondence analysis (CCA) shows the correlations between environmental, forest structural, and human disturbance variables and density red-listed tree species which were encountered more than once in the core and buffer zones. The first and the second axes explained 7.3%, and 5.8% of the variance of present data, respectively. Correlation threshold r²= 0.26. (BA = basal area, Fpath = footpath, abbreviation for species code as in Appendix 1).

Discussion

Our objectives were to evaluate differences in the abundance of red-listed tree species between different conservation zones and analyze whether they are related to human interference in the Ta Xua nature reserve in north-western Vietnam. While the study of a single nature reserve with such zonation can be constrained by pseudo-replication [32], our sample plots were selected based on a random procedure. Our study revealed that the richness and abundance of both red-listed species and all tree species in our study area decreased from the core through the buffer to the restoration zones, which indicates a decline in tree species richness and abundance with human interference. However, further studies of other protected areas with similar statutory zoning characteristics would be very welcome in order to draw more general conclusions. Our analysis was based on random sample plots, which, in the case of rare events, may have been constrained by lack of observations in many of the plots. We used 40 randomly allocated plots per zone, and particularly in the restoration zone, only a few species were found in a limited number of plots. While this may reflect current conditions, it does not facilitate detailed statistical analysis. Other methods that may have been employed, such as line distance sampling or adaptive cluster sampling, are believed to be more efficient in the case of rare events [33-34] and are recommended for a better understanding of tree species distribution and abundance in such areas. However, these methods also depend on an informed tree species selection (e.g. rare and clustered species for adaptive cluster sampling), which is often unknown before a survey and for which we think a plot-based random sampling approach would represent an appropriate step. For the comparison of red-listed tree species abundance among different conservation zones, environmental parameters of the studied areas should be as comparable as possible. In our study, many environmental parameters, such as elevation, slope, soil pH, and soil texture, suggest that site conditions were fairly comparable, partly due to the limited size of the study areas. In addition, a sound evaluation depends on precise identification of tree species, and although two expert botanists from the VFU participated in this process, potential errors cannot be excluded, and our data contain some unidentified tree individuals (2.5% in core zone, 1.5% in buffer zone and 1.5% in restoration zone).

Our results indicate that the abundance of all tree species and red-listed tree species declined from the core zone through the buffer zone to the restoration zone in our study area. This is similar to studies from tropical rain forests in Chiapas, Mexico and India - where canopy, basal area, and tree species diversity declined with disturbance intensity [35-38] - while similar results were found for species richness in the Jaú National Park in the Amazon Rainforest [39]. Other studies from central Africa [40] and the Xuan Son National Park in Vietnam [41] respectively found endemic species richness and the abundance of five selected rare tree species to be lower in regenerating forest after shifting cultivation and in selective logged forest.

Some species, such as *Castanopsis purpurella, Castanopsis tessellata,* and *Lithocarpus vestitus,* were exclusively found in the core zone, and others showed their highest densities there (*Madhuca pasquieri, Aglaia spectabilis, Fokienia hodginsii*). In contrast, the buffer and restoration zones contained fewer red-listed tree species, most of which occurred at lower densities. Exceptions included *Castanopsis cerebrina* in the buffer zone and *Quercus platycalyx* in the restoration zone, both of which are considered early successional, light-demanding species [42].

Our data suggest that the abundance of red-listed tree species declined with increasing intensity of human interference on the forest. However, in our canonical correspondence analysis - which included environmental and forest structural parameters and two proxies for human disturbance - the explanation of the two axes was relatively low, at only 13.1% of the variance of density of red-listed tree species in the core and buffer zones. Low percentages of explanation of tree species abundance by environmental parameters are not uncommon in tropical forests. Despite being not

closely comparable, environmental factors explained only 6.2% and 10.1% of the variation between tree species composition in the Amazonian forest and the Ben En National Park in Vietnam studies respectively [43-44]. Similarly low values from a study of rare tree species in the Visayas in the Philippines were also recorded [45]. The high tree species richness of tropical forests and the mechanisms involved in tree species distribution, such as dispersal limitation, may explain the low percentages of explanation of tree species abundance by environmental parameters [46-47].

Our study further suggests that even low intensity forest use can reduce the abundance of red-listed tree species. Some other studies found no or only very few changes in tree species richness under low intensity selective logging [6], and in regenerating forest after shifting cultivation [48]; however, changes in red-listed tree species abundance were not mentioned. Red-listed tree species are probably more vulnerable to disturbance intensity than other species because of individual limitations among populations. Our findings are more in line with the study from Ben En National Park in Vietnam, where red-listed tree species abundance decreased with increasing intensity of human disturbance [44]. In the present study, the high number of red-listed tree species in the core zone illustrates the merits of strict protection measures, while the low numbers of red-listed tree species in the buffer and restoration zones indicate that these species are sensitive to selective logging and shifting cultivation. From a conservation point of view, low selective logging intensity seems to represent a better protection measure for threatened species than shifting cultivation.

Implications for land use and conservation

In our study from the Ta Xua nature reserve, we found the highest abundance of red-listed trees in the core zone, which emphasizes the importance of strictly exclusive statutory protection measures. In the buffer zone, the integration of local people in forest management coupled with regulations governing logging intensity represents a suitable policy for reconciling both conservation and socio-economic development goals, since it most likely serves local demands while ensuring some level of conservation. However, the abundance of red-listed tree species was lower than in the core zone, and considering that illegal logging was frequently observed, we recommend that logging intensity should be more strictly controlled. Finally, while the lowest number of red-listed tree species was recorded in the secondary growth forest of the restoration zone, given the anticipated rate of change in rare species composition, e.g. after 50-60 years of recovery of endemic tree species in shifting cultivation sites in central African rain forest [40], this area may make an important contribution to biodiversity conservation in the future.

Acknowledgements

References

[1] Pimm, S.L. and Brooks, T.M. 2000. *The sixth extinction: How large, where, and when*. Nature and Human Society: The Quest for a Sustainable World. Washington DC: National Academy Press.

[2] Laurance, W.F., Useche, D.C., Rendeiro, J., Kalka, M., Bradshaw, C.J., Sloan, S.P., Laurance, S.G., Campbell, M., Abernethy, K. and Alvarez, P. 2012. Averting biodiversity collapse in tropical forest protected areas. *Nature* 489, 290–294.

[3] Lewis, C. 1996. *Managing conflicts in protected areas*. IUCN.

[4] Gibson, L., Lee, T.M., Koh, L.P., Brook, B.W., Gardner, T.A., Barlow, J., Peres, C.A., Bradshaw, C.J., Laurance, W.F. and Lovejoy, T.E. 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature* 478, 378–381.

[5] Putz, F.E., Zuidema, P.A., Synnott, T., Peña-Claros, M., Pinard, M.A., Sheil, D., Vanclay, J.K., Sist, P., Gourlet-Fleury, S. and Griscom, B. 2012. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conserv. Lett.* 5, 296–303.

[6] Bertault, J.-G. and Sist, P. 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. *For. Ecol. Manag.* 94, 209–218.

[7] Asner, G.P., Broadbent, E.N., Oliveira, P.J., Keller, M., Knapp, D.E. and Silva, J.N. 2006. Condition and fate of logged forests in the Brazilian Amazon. *Proc. Natl. Acad. Sci.* 103(34), 12947–12950.

[8] Kariuki, M., Kooyman, R.M., Smith, R.G.B., Wardell-Johnson, G. and Vanclay, J.K. 2006. Regeneration changes in tree species abundance, diversity and structure in logged and unlogged subtropical rainforest over a 36-year period. *For. Ecol. Manag.* 236, 162–176.

[9] Miller, P.M. and Kauffman, J.B. 1998. Effects of slash and burn agriculture on species abundance and composition of a tropical deciduous forest. *For. Ecol. Manag.* 103, 191–201.

[10] Chazdon, R. L. 2014. *Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation*. Chicago: University of Chicago Press.

[11] Friis, I. and Balslev, H. (Eds.) 2005. Plant diversity and Complexity patterns: *Local, Regional and Global Dimensions*. Regalado Jr, J. C., Hiep, N. T., Loc, P. K., Averyanov, L., Harder, D. K., Friis, I., and Balslev, H. Vol.55, pp 189-197. Biologiske Skrifter, Copenhagen.

[12] Chien, P. D. 2006. *Demography of threatened tree species in Vietnam*. Utrecht University.

[13] *Nghia, N. H. 2000. *Some threatened tree species of Vietnam.* Agricultural Publishing House, Hanoi, Viet Nam.

[14] *Tai, N. M. 1995. *National parks and nature reserve areas in Vietnam.* Agricultural Publishing House, Hanoi, Viet Nam.

[15] *Socialist Republic of Vietnam (SRVN). 2003. Management strategy for the system of nature conservation areas in Vietnam to 2010. Hanoi.

[16] *Forest Techniques and Science Association of Vietnam (FTSA). 2001. *National parks in Vietnam.* Agricultural Publishing House, Hanoi, Viet Nam.

[17] Sobey, R. T. 1998. *Biodiversity Value of Hoang Lien Mountains & Strategies for Conservation: Proceedings of Seminar & Workshop, 7th-9th December 1997, Sa Pa District, Lao Cai Province, Vietnam*. Society for Environmental Exploration

[18] Sterling, E.J. and Hurley, M.M. 2005. Conserving biodiversity in Vietnam: Applying biogeography to conservation research. *Proc.-Calif. Acad. Sci.* 56, 98.

[19] *The People's Committee of Son La Province, 2002. Decision No.3440/2002/QĐ-UB on the constitution of the Ta Xua nature reserve. Sonla.

[20] *Forest Inventory and Planning Institute (FIPI). 2002. Project of Conservation and Development Forest Resources of Ta Xua Nature Reserve. Hanoi.

[21] IUCN. 2014. *The IUCN Red List of Threatened Species. Version 2014.3*. http://www.iucnredlist.org. Last accessed November 21, 2014.

[22] *Ban, NT., Ly, TD., Khoi, KN., 2007. *Vietnam Red List. Part II. Plants.* Science and Techniques Publishing House, Ha Noi.

[23] French National Institute for Agricultural Research (INRA), 2014. Can-Eye V6.3 software, Can Eye user manual. http://www6.paca.inra.fr/can-eye/Documentation-Publications/Documentation. Last accessed March 24, 2014.

[24] Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 37, 29–38.

[25] Gee, G. W. and Bauder, J. W. 1979. Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measurement parameters. *Soil Sci. Soc. Am. J.* 43(5), 1004-1007.

[26] Colwell, R.K., Chao, A., Gotelli, N.J., Lin, S.-Y., Mao, C.X., Chazdon, R.L. and Longino, J.T. 2012. Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. *J. Plant Ecol.* 5, 3–21.

[27] Colwell, R.K., Mao, C.X. and Chang, J. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. *Ecology* 85, 2717–2727.

[28] Chao, A. 1987. Estimating the population size for capture-recapture data with unequal catchability. *Biometrics* 43, 783–791.

[29] Colwell, R. K. 2013. EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. User's Guide and application published at http://purl.oclc.org/estimates. Last accessed June 14, 2014.

[30] Gotelli, N. J. and Colwell, R. K. 2011. Estimating species richness. *Biological diversity: frontiers in measurement and assessment,* 12, 39-54.

[31] Mc Cune, B. and Mefford, M.J. 2006. PC-ORD, multivariate analysis of ecological data. version 5.12. MjM software, Gleneden Beach, Oregon.

[32] Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological monographs*, 54(2), 187-211.

[33] Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. *Distance sampling: Estimating abundance of biological populations*. Chapman and Hall, London.

[34] Philippi.T. 2005. Adaptive cluster sampling for estimation of abundances within local populations of low-abundance plants. *Ecology* 86(5), 1091–1100.

[35] Ramírez-Marcial, N., González-Espinosa, M. and Williams-Linera, G. 2001. Anthropogenic disturbance and tree diversity in montane rain forests in Chiapas, Mexico. *For. Ecol. Manage.* 154(1), 311-326.

[36] Mishra, B., Tripathi, O., Tripathi, R. and Pandey, H. 2004. Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. B*iodivers. Conserv.* 13, 421–436.

[37] Nath, P., Arunachalam, A., Khan, M., Arunachalam, K. and Barbhuiya, A. 2005. Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India. *Biodivers. Conserv.* 14, 2109–2135.

[38] Sagar, R., Raghubanshi, A. S. and Singh, J. S. 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. *For. Ecol. Manage.* 186(1), 61-71.

[39] Ferreira, L.V. and Prance, G.T. 1999. Ecosystem recovery in terra firme forests after cutting and burning: a comparison on species richness, floristic composition and forest structure in the Jaú National Park, Amazonia. *Bot. J. Linn. Soc.* 130, 97–110.

[40] Van Gemerden, B.S., Shu, G.N. and Olff, H. 2003. Recovery of conservation values in Central African rain forest after logging and shifting cultivation. *Biodivers. Conserv.* 12, 1553–1570.

[41] Ngo, T.L. and Hölscher, D. 2014. The fate of five rare tree species after logging in a tropical limestone forest (Xuan Son National Park, northern Vietnam). *Trop. Conserv. Sci.* 7(2), 326-341.

[42] Nguyen N.C., Cao T.C., Vu V.C., Nguyen X.D., Vu V.D., Nguyen K.D., Tran H., Tran T.O., Nguyen B.Q. and Nguyen N.T. 1996. *Vietnam Forest Trees*. Agricultural Publishing House, Hanoi, Viet Nam.

[43] Duivenvoorden J.F. 1995. Tree species composition and rain forest-environment relationships in the middle of Caquetá area, Colombia, NW Amzonia. *Plant Ecol.* 120, 91-113.

[44] Hoang, V., Baas, P., Keßler, P., Slik, J., Steege, H.T. and Raes, N. 2011. Human and environmental influences on plant diversity and composition in Ben En National Park, Vietnam. *J. Trop. For. Sci.* 328–337.

[45] Peque, D. and Hölscher, D. 2014. The abundance of rare tree species in remnant forests across the Visayas, Philippines. *Biodivers. Conserv.* 23, 2183-2200.

[46] Hubbell, S. P. 2006. Neutral theory and the evolution of ecological equivalence. *Ecology*, 87(6), 1387-1398.

[47] Peng, Z., Zhou, S. and Zhang, D. Y. 2012. Dispersal and recruitment limitation contribute differently to community assembly. *Plant Ecol.,* 5(1), 89-96.

[48] McNamara,S., Erskine,P., Lamb, D., Chantalangsy,L. and Boyle, S. 2012. Primary tree species diversity in secondary fallow forests of Laos," *For. Ecol. Manag.*, 281, 93–99.

Note: [*]The initial titles in Vietnamese were translated into English.

Appendix 1. Conservation status, number of individual trees with *DBH* ≥ 6cm, frequency and density of red-listed tree species in three conservation zones. The results from 40 sample plots (20x20m) per each zone.

Scientific name	Species code	Common Vietnamese name[a]	Conservation status[b]		Core zone			Buffer zone			Restoration zone		
			VN red list	IUCN	No. indi.	Freq	n/ha	No. indi.	Freq	n/ha	No. indi.	Freq	n/ha
Aglaia spectabilis (Miq.) S.S. Jain & S.S.R. Bennet	Agla	Gội nếp	VU	LC	12	8	8	1	1	1	1	1	1
Canarium pimela K.D:Koenig	Canar.	Trám đen	VU	nl				1	1	1			
Castanopsis cerebrina (Hickel & A.Camus) Barnett	Ca.cer	Sồi phẳng	EN	nl	4	3	3	13	11	8	9	2	6
Castanopsis lecomtei Hickel & A.Camus	Ca.lec	Cà Ổi Sapa	VU	nl	3	3	2	10	6	6			
Castanopsis purpurella subsp. Purpurella	Ca.pur	Dẻ gai đỏ	VU	nl	3	3	2						
Castanopsis tessellata Hickel & A.Camus	Ca.te	Cà Ổi lá đa	VU	nl	2	2	1						
Cinnadenia paniculata (Hooker f.) Kostermans	Cinnade.	Kháo xanh	VU	LC	12	10	8				1	1	1
Cinnamomum balansae Lecomte	Cinnamo.	Vù hương	VU	EN				1	1	1			
Dacrycarpus imbricatus (Blume) de Laub.	Dacry.	Thông nàng	nl	LC	2	2	1	2	2	1			
Fokienia hodginsii (Dunn) A. Henry & H. H. Thomas	Fokie.	Pơ mu	EN	VU	11	5	7	4	2	3	1	1	1
Goniothalamus macrocalyx Bân	Gon.	Màu cau trắng	VU	VU	1	1	1						
Lithocarpus vestitus (Hickel & A.Camus) A.Camus	Li.ves	Sồi lông nhung	EN	nl	3	3	2						
Madhuca pasquieri (Dubard) H.J.Lam	Madhu.	Sến mật	EN	VU	35	16	22	2	2	1			
Magnolia baillonii Pierre	Ma.bai	Giổi găng	VU	LC	1	1	1						
Magnolia balansae A.DC.	Ma.bala	Giổi lông	VU	DD	1	1	1	2	2	1			
Magnolia braianensis (Gagnep.) Figlar	Ma.bra.	Giổi nhung	EN	DD	1	1	1						
Podocarpus neriifolius D.Don	Pod.	Thông tre lá dài	nl	LC	1	1	1						
Quercus platycalyx Hickel & A.Camus	Qu.plat	Dẻ cau	VU	nl	7	7	4	7	6	4	29	4	18
Total					**99**			**43**			**41**		

No.indi. = Number of individuals; Freq. = Frequency of number of plots appeared red-listed tree species out of 40 sample plots; n/ha = Density of red-listed tree species per hectare

[a] Based on [22,42]; [b] Based on [21,22]; VU = vulnerable; EN = endangered; LC= least concern; DD = data deficient; nl = not listed.