THREATENED TREE SPECIES ACROSS CONSERVATION ZONES IN A NATURE RESERVE OF NORTH-WESTERN VIETNAM

Dao Thi Hoa Hong

(Born in Thanh Oai, Hanoi, Vietnam)

A Dissertation Submitted in Partial Fulfillments for the Academic Degree of Doctor of Philosophy (PhD) of the Faculty of Forest Sciences and Forest Ecology of Georg-August-University, Göttingen

Göttingen, 2017

Reviewers

1. Prof. Dr. Dirk Hölscher

2. Prof. Dr. Christian Ammer

3. Prof. Dr. Holger Kreft

Date of oral defense: 3.3.2017

Abstract

The high diversity of tree species in tropical forests is driven by a large proportion of rare species. Rare species are vulnerable and threatened to extirpation and extinction when their habitats are destroyed. This study addresses the abundance of threatened tree species within three conservation zones with differing levels of protection in the Ta Xua Nature Reserve of north-western Vietnam. The objectives were (1) to assess differences in the abundance of red-listed tree species among the strictly protected core zone, the low intensity traditional forest use buffer zone and the forest restoration zone, and analyze whether they are related to human interference; (2) to analyze the tree community structure in the core zone and the buffer zone, and in case of differences, to identify the impact of important variables, such as timber use, NTFP use, tree diameter, tree rarity, and red-list status, on differences of tree community; and (3) to assess the abundance of an iconic tree species Fujian cypress *(Fokienia hodginsii)* and two other threatened tree species (*Aglaia spectabilis* and *Quercus platycalyx*), and to determine the regeneration status of these three target species.

Firstly, 40 random sample plots were established in each conservation 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. In total, 18 red-listed tree species (IUCN and Vietnamese Red Lists combined) were detected in three conservation zones. 16 red-listed tree species were found in the core zone, 10 in the buffer zone, and five in the restoration zone. 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.

Secondly, the patterns of tree community differences in the strictly protected core zone and the low intensity traditional forest use buffer zone were studied. We found that the forests in the core and buffer zones are rich in tree species (249 observed). Many of these tree species provide non-timber forest products (NTFPs) (48%) or valuable timber (22%). 79 tree species (32%) were rare in at least one of the zones and 18 species (7%) are red-listed. Overall tree density was not different in the two zones, but tree diameter and species richness were lower in the buffer zone. At the *tree level*, logistic regression analysis indicated that *red-listed status*, *tree diameter*, *density of species* and *NTFP use* (in order of reducing importance) were significant associated with the probability of tree absence from the buffer zone. More specifically, *red-listed status, large diameter*, and *low density of conspecifics* increased the probability of tree absence in the buffer zone but not the potential use as a NTFP. However, most NTFP species had different densities in the core and buffer zones, and this correlated with signs of human interference. At the *species level*, the *density of species* was the most important variable, and low density (species rarity) strongly increased the probability of species absence. Our results also indicate that rare and red-listed trees were depleted in the buffer zone. In consideration of conservation goals, the future monitoring of these species at the Ta Xua Nature Reserve and other protected areas is needed, and conservation measures most likely need to be improved.

Finally, the population status of *F. hodginsii* and two other threatened tree species (*Aglaia spectabilis* and *Quercus platycalyx*) was assessed across the three conservation zones. Based on previous simple random sampling, we applied adaptive cluster sampling for trees with a diameter at breast height of at least 6 cm. In addition tree regeneration was assessed. In the core zone, the three target species were moderately rare, in that they were not among the 10% most common species, nor among the 50% rarest species. *F. hodginsii* and *A. spectabilis* were most abundant in the core zone, and much less abundant in the buffer and restoration zones. In contrast, *Q. platycalyx* had its highest density in the restoration zone. Regeneration of all three target species occurred in the core zone; however, there was little or no regeneration of *F. hodginsii* and *A. spectabilis* in the buffer and regeneration zones. Regeneration of *F. hodginsii* and *A. spectabilis* was mostly found in the vicinity of conspecific adult trees. In conclusion, our data do not support conservation concerns regarding *Q. platycalyx* in used and secondary forests, which may influence its status in the next assessment of endangered species. In contrast, adult trees of *F. hodginsii* and *A. spectabilis* were mostly confined to the core zone, and regeneration of these species was absent or very rare in the buffer and restoration zones. For these two species, the core zone was thus the most important refuge, so continued conservation of this zone is important for the preservation of these species.

In conclusion, our results 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. The use of logistic regression models allows evaluation of the conservation effectiveness in a given nature reserve over time and among other nature reserves and national parks, and also facilitates the development of conservation strategies by quantifying the effects of different forest management measures on the presence or absence of trees and species. Monitoring of forest resources with a focus on rare and red-listed species at the Ta Xua Nature Reserve and other protected areas is needed and conservation measures most likely need to be improved.

Table of Contents

Chapter 1: General introduction

1.1 Introduction

Rare tree species often contribute significantly to the high levels of tree species diversity in tropical forests (Hubbell 2013; ter Steege et al. 2013). However, rare tree species are vulnerable and threatened of extirpation or extinction when their habitats are destroyed (Gaston 1994; Laurance 1999; Sodhi et al. 2004; Hubbell 2013). Thus conservation of rare tree species is urgently needed.

Timber logging and non-timber forest product (NTFP) harvesting are two main types of forest use, and these have various impacts on forest biodiversity (Arnold and Pérez 2001; Ticktin 2004; Ndangalasi et al. 2007; Clark and Covey 2012). At low intensity and at a local scale, selective timber logging and harvesting of NTFPs can locally increase floral species richness and may have little impact on the forest tree community (Cannon et al. 1998; Endress et al. 2006, Berry et al. 2010; Putz et al. 2012). However, at high intensity and over a larger scale, both logging and NTFP harvesting may lead to forest degradation and even to the extinction of some species (Arnold and Pérez 2001; Rosser and Mainka 2002; Sodhi et al. 2004; Asner et al. 2006; Gibson et al. 2011; Branch et al. 2013). As a consequence, many valuable timber and NTFP tree species had become very rare or threatened to local extinction. Therefore, the information about abundance of high-value timber species and NTFP tree species in different forest use intensities should be documented for any forest conservation effort.

One main reason of nature protection is to prevent biodiversity loss. However, many species are still declining to unsafe population levels (Hilton-Taylor 2000) and rare species are likely to be more extinction-prone than high abundance species (Davies et al. 2000). Hence, measure of rarity is important to predict species vulnerability and to establish conservation priorities (Fattorini et al. 2013). The International Union for Conservation of Nature (IUCN) Red List of Threatened Species is one approach for assessing and monitoring the status of biodiversity with a focus on species at greatest risk of extinction at the global scale (Baillie et al. 2004). The IUCN Red List provides an assessment of the extinction risk under current circumstances and classifies species into a category of threat (i.e. red-listed species). Although the number of species assessed and listed in each category of the IUCN Red List has increased substantially in recent updates, the conservation status of most of the world's species remains poorly known. Only a very small proportion (2.5%) of the world's described species have been evaluated for the IUCN Red List (Baillie et al. 2004). However, the criteria of the IUCN Red List have inspired the development of national and regional red lists (Rodrigues et al. 2006), which are very useful source of information on species status to identify priority species for conservation. For example, in 1996, the Red List of Threatened Plants of Vietnam had been firstly published. A total of 365 plant species (accounting for 3% of 12000 Vietnamese plant species) were classified as threatened species in different degrees of endangerment. During the assessment process, the Red List of Vietnam has been updated with about 464 plant species (4% of Vietnamese plant species) in the Vietnam Red List 2007 (Nguyen et al. 2007). Rare species is often considered to be particularly vulnerable and of highest conservation concern because these species are most likely to be lost if they are not protected (Lawler et al. 2003). Hence, the information about the abundance of rare and red-listed species is important for assessing the biodiversity status; evaluating efficacy of current conservation measures, and proposing conservation priorities.

Different forest conservation and management measures can affect species composition and diversity in different ways. Therefore, evaluation the efficacy of current forest conservation and management regimes on the tree level and the species level is needed to know whether conservation goals are met or need adjustment. Logistic regression is the most useful statistical technique applied for understanding the influence of several independent variables on a single dichotomous outcome variable (Hosmer et al. 2013). In this study, logistic regression models were applied to identify the impact of important variables, such as timber use, NTFP use, tree diameter, tree rarity, and red-list status, on the difference of tree community structure in the core zone and the buffer zone through predicting the probability of tree and species presence or absence. The use of logistic regression models allows evaluation of the conservation effectiveness in a given nature reserve over time and among other nature reserves and national parks, and also facilitates the development of conservation strategies by quantifying the effects of different forest management measures on the presence or absence of trees and species.

Information about abundance and distribution of rare tree species is important for biodiversity conservation and management (Philippi 2005; Hubbell 2013). However, inventory of rare tree species often meets with problems when applying conventional sampling designs, such as simple random sampling, since the target rare tree species can be absent in many sampling units leading to large variances in the estimated population sizes (Gaston 1994; Cochran, 2007). If a rare or moderately rare species is known or can be expected to occur in clusters, then adaptive cluster sampling (ACS) can be an effective sampling method (Thompson 1990; Philippi 2005). Based on previous simple random sampling, we applied ACS for trees with a diameter at breast height (DBH) of at least 6 cm of the three threatened tree species, *Fokienia hodginsii*, *Aglaia spectabilis* and *Quercus platycalyx* to determine the population status of these species. The results provide quantitative information that may help in assessing the vulnerability degrees of these target tree species and guide or facilitate conservation efforts.

This study was conducted in the Ta Xua Nature Reserve of north-western Vietnam (21°13′ – 21°26′ N, 104°16′ – 104°46′ E), a region that has rarely been studied, although situated in a biodiversity hotspot (Sobey 1998; Sterling and Hurley 2005). The nature reserve comprises a strictly protected core zone of near-natural forest, a buffer zone, where only low intensity traditional forest-use is permitted, and a restoration zone, where forest regenerates after shifting cultivation. In this study, the abundance of *'red-listed tree species'*, *'rare tree species'*, *'high-value timber tree species'* and *'NTFP tree species'* were assessed. The results may provide new insights into the ecological characteristics of these species and give the opportunity to evaluate the conservation efficacy in the given nature reserve over time or across other nature reserves and national parks as well as add to our understanding of the extent to which threatened tree species need protection in core conservation zones and whether they can tolerate in different types of forest use.

1.2 Objectives of the study

The objectives of this study were:

(1) to assess differences in the abundance of red-listed tree species among the strictly protected core zone, the low intensity traditional forest use buffer zone and the forest restoration zone, and analyze whether they are related to human interference.

(2) to analyze the tree community structure in the core zone and the buffer zone, and in case of differences, to identify the impact of important variables, such as timber use, NTFP use, tree diameter, tree rarity, and red-list status, on differences of tree community.

(3) to assess the abundance of an iconic tree species Fujian cypress *(Fokienia hodginsii)* and two other threatened tree species (*Aglaia spectabilis* and *Quercus platycalyx*), and to determine the regeneration status of these three target species.

1.3 Outline of the dissertation

The dissertation consists of six chapters which are briefly presented as follows:

Chapter 1: General introduction

Chapter 2: Materials and methods

Chapter 3: Red-listed tree species abundance in montane forest areas with differing levels of statutory protection in north-western Vietnam. (Published on 29 June 2015 in *Tropical Conservation Science Vol.8 (2): 479-490)*

Chapter 4: Patterns in tree community differences in the core and buffer zones in a nature reserve of north-western Vietnam (Published on 18 October 2016 in *Global Ecology and Conservation 8 (2016) 220-229*)

Chapter 5: Fujian cypress and two other threatened tree species across conservation zones in a nature reserve of north-western Vietnam (Submitted to *Forest Ecosystems* on 2nd January 2017)

Chapter 6: Synthesis

1.4 References Chapter 1

Arnold, J. M., & Pérez, M. R. (2001). Can non-timber forest products match tropical forest conservation and development objectives? *Ecological Economics*, *39*(3), 437–447.

Asner, G. P., Broadbent, E. N., Oliveira, P. J., Keller, M., Knapp, D. E., & Silva, J. N. (2006). Condition and fate of logged forests in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *103*(34), 12947–12950.

Baillie, J., Hilton-Taylor, C., & Stuart, S. N. (2004). *2004 IUCN red list of threatened species: a global species assessment*. IUCN.

Berry, N. J., Phillips, O. L., Lewis, S. L., Hill, J. K., Edwards, D. P., Tawatao, N. B., … Maryati, M. (2010). The high value of logged tropical forests: lessons from northern Borneo. *Biodiversity and Conservation*, *19*(4), 985–997.

Branch, T. A., Lobo, A. S., & Purcell, S. W. (2013). Opportunistic exploitation: an overlooked pathway to extinction. *Trends in Ecology & Evolution*, *28*(7), 409–413.

Cannon, C. H., Peart, D. R., & Leighton, M. (1998). Tree species diversity in commercially logged Bornean rainforest. *Science*, *281*(5381), 1366–1368.

Clark, J. A., & Covey, K. R. (2012). Tree species richness and the logging of natural forests: A meta-analysis. *Forest Ecology and Management*, *276*, 146–153.

Cochran, W. G. (2007). *Sampling techniques*. John Wiley & Sons.

Davies, K. F., Margules, C. R., & Lawrence, J. F. (2000). Which traits of species predict population declines in experimental forest fragments? *Ecology*, *81*(5), 1450–1461.

Endress, B. A., Gorchov, D. L., & Berry, E. J. (2006). Sustainability of a non-timber forest product: effects of alternative leaf harvest practices over 6 years on yield and demography of the palm Chamaedorea radicalis. *Forest Ecology and Management*, *234*(1), 181–191.

Fattorini, S., Di Giulio, A., & Dapporto, L. (2013). Measuring insect rarity: practical issues, pragmatic approaches. *Journal of Insect Biodiversity*, *1*(10), 1–21.

Gaston, K. J. (1994). *Rarity*. Chapman & Hall. Retrieved from http://books.google.de/books?id=KQkUAQAAIAAJ

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., … Lovejoy, T. E. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, *478*(7369), 378–381.

Hilton-Taylor, C. (2000). *2000 IUCN red list of threatened species*. IUCN.

Hosmer Jr, D. W., Lemeshow, S., & Sturdivant, R. X. (2013). *Applied logistic regression* (Vol. 398). John Wiley & Sons.

Hubbell, S. P. (2013). Tropical rain forest conservation and the twin challenges of diversity and rarity. *Ecology and Evolution*, *3*(10), 3263–3274.

Laurance, W. F. (1999). Reflections on the tropical deforestation crisis. *Biological Conservation*, *91*(2), 109–117.

Lawler, J. J., White, D., Sifneos, J. C., & Master, L. L. (2003). Rare species and the use of indicator groups for conservation planning. *Conservation Biology*, *17*(3), 875–882.

Ndangalasi, H. J., Bitariho, R., & Dovie, D. B. (2007). Harvesting of non-timber forest products and implications for conservation in two montane forests of East Africa. *Biological Conservation*, *134*(2), 242–250.

Nguyen, T.B., Tran ,D.L., Nguyen, K.K., (2007) Vietnam red list. Part II: Plants. Science and Techniques Publishing House, Hanoi.

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

Putz, F. E., Zuidema, P. A., Synnott, T., Peña-Claros, M., Pinard, M. A., Sheil, D., … Griscom, B. (2012). Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. *Conservation Letters*, *5*(4), 296–303.

Rodrigues, A. S., Pilgrim, J. D., Lamoreux, J. F., Hoffmann, M., & Brooks, T. M. (2006). The value of the IUCN Red List for conservation. *Trends in Ecology & Evolution*, *21*(2), 71–76.

Rosser, A. M., & Mainka, S. A. (2002). Overexploitation and species extinctions. *Conservation Biology*, 584–586.

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. Retrieved from http://books.google.de/books?id=frwhtwAACAAJ

Sodhi, N. S., Koh, L. P., Brook, B. W., & Ng, P. K. (2004). Southeast Asian biodiversity: an impending disaster. *Trends in Ecology & Evolution*, *19*(12), 654–660.

Sterling, E. J., & Hurley, M. M. (2005). Conserving biodiversity in Vietnam: Applying biogeography to conservation research. *PROCEEDINGS-CALIFORNIA ACADEMY OF SCIENCES*, *56*, 98.

ter Steege, H. Ter, Pitman, N. C., Sabatier, D., Baraloto, C., Salomão, R. P., Guevara, J. E., … Molino, J.-F. (2013). Hyperdominance in the Amazonian tree flora. *Science*, *342*(6156), 1243092.

Thompson, S. K. (1990). Adaptive cluster sampling. *Journal of the American Statistical Association*, *85*(412), 1050–1059.

Ticktin, T. (2004). The ecological implications of harvesting non-timber forest products. *Journal of Applied Ecology*, *41*(1), 11–21.

Chapter 2: Materials and Methods

2.1 Study area

The study was conducted in the Ta Xua Nature Reserve (21°13’ – 21°26’ N, 104°16’ – 104°46’ E, Fig.2.1), a protected area in north-western Vietnam within a biodiversity hotspot (Sobey 1998; Sterling and Hurley 2005). The nature reserve includes a strictly protected core zone of near-natural forest; a buffer zone where only low intensity traditional forest use by the H’Mong people is permitted; and a restoration zone where forest regenerates after shifting cultivation. The topography of the region is characterized by its high, steeply sloping mountains ranging in altitude from 320 m to 2765 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 1600 mm to 1900 mm, and the average temperature is 20°C.

The reserve incorporates a *‘core zone’* of 15211 ha, with a forest cover of 87%. Human activities such as logging, hunting, and gathering of NTFPs are prohibited. During our field work, signs of these activities were rarely observed. The forest types range from evergreen and broad-leaved rainforest at lower elevations to coniferous forest mixed with some evergreen and broad-leaved species at higher elevations. The core zone can only be reached by footpaths, some of which were made before the nature reserve was established, and others were marked out ranger patrols and research project routes or tourist trails (FIPI 2002).

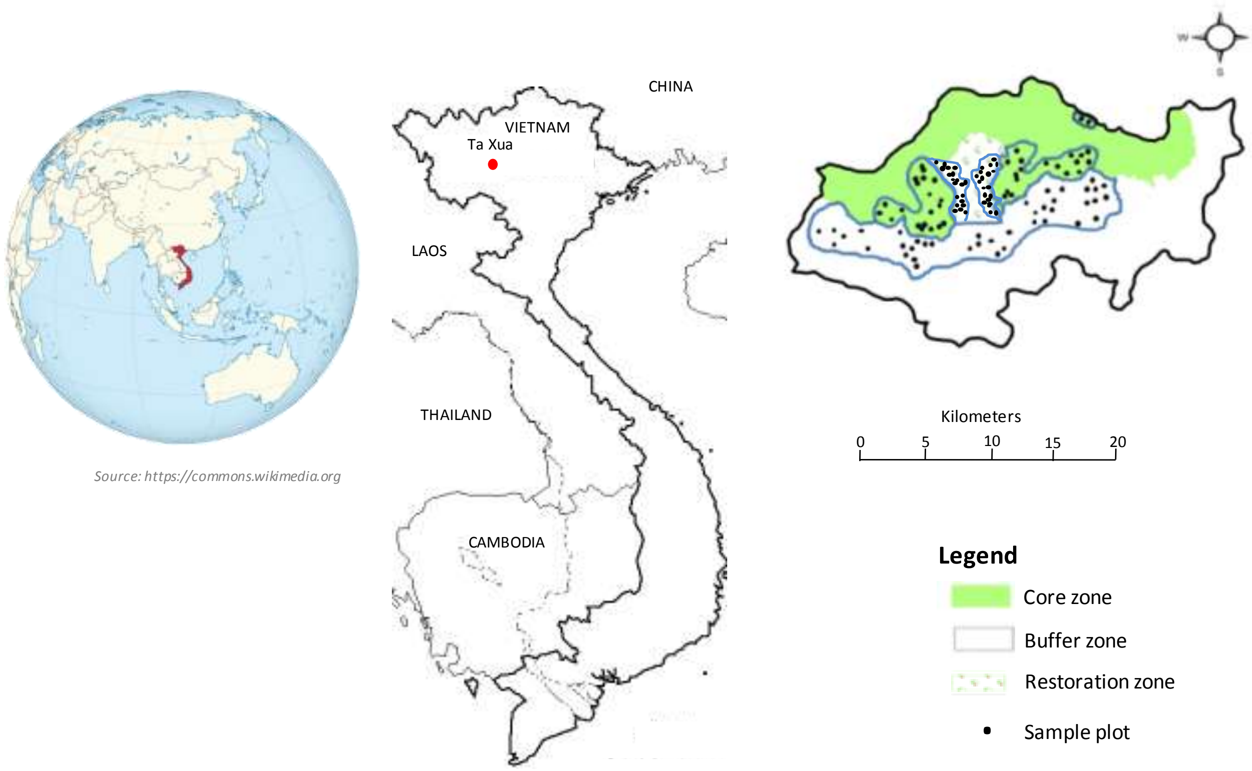

Fig. 2.1. Vietnam and location of the Ta Xua Nature Reserve. The study area is enclosed by blue lines (1000-1700 m a.s.l.). Sample plots are indicated by black dots

The *'buffer zone'* of the reserve encompasses 24674 ha with a forest cover of 44%. The forest only occurs above 900 m a.s.l. and is used by the H'Mong people in accordance with forest management regulations established by the law of forest protection and development (Law No.29/2004/QH11 2004). These regulations allow a maximum of 25 trees to be felled per year in a forest area of 10856 ha and gathering of NTFPs to fulfill demand without detailed specific quantity regulation. 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 (FIPI 2002).

A protected *'restoration zone'* was also established within the reserve, which consists of 2439 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 (FIPI 2002).

The Ta Xua Nature Reserve is famous for the natural distribution of *Fokienia hodginsii* (Dunn) A. Henry & H. H. Thomas which is of high value of timber and genetic conservation. In addition, several valued endemic species such as *Cinnamomum balansae* Lecomte*,* *Goniothalamus macrocalyx* Bân*,* and *Madhuca pasquieri* (Dubard) H.J.Lam have been recorded in this area.

2.2 Study design

2.2.1 Random sampling method

Based on a reconnaissance survey, a provisional forest cover map was established. An elevation range of 1000 to 1700 m a.s.l. was selected for the study, as forest in this elevation range occurred in all three conservation zones. The study area included 73 ha in the core zone, 115 ha in the buffer zone and 22 ha in restoration zone. A grid system with 1400 cells was created and overlaid on a map of the study area to randomly select locations for sample plots. Forty plots of 400m^2 (20 × 20 m) were established in each conservation zone with the center of each plot located in the center of a selected cell.

2.2.2 Adaptive cluster sampling method

Adaptive cluster sampling (ACS) is an inventory method with potential strength in detecting rare species that can be expected to cluster geographic distribution (Thompson 1990; Philippi 2005). ACS initially uses random sample plots, and then successively adds neighboring plots that satisfy a certain condition. If any of the added plots also satisfy the condition, then its neighbors are also added, leading to a cluster of plots (Thompson 1990).

In this study, we applied ACS to determine the population status of three threatened tree species, *Fokienia hodginsii*, *Aglaia spectabilis* and *Quercus platycalyx*. The 40 random sample plots of 400 m^2 (20 × 20 m) per conservation zone were the initial plots. Thus, if an initial random plot contained at least one target tree with a diameter at breast height (DBH) of at least 6 cm ($tree_{\geq 6cm}$), then four neighboring plots were added. If an added plot also had at least one target $tree_{\geq 6cm}$, then it was added to the sample and its neighbors are recursively. The addition of plots ended when no more added plots contain the target species (Fig.2.2). This procedure was applied separately for each of the three target species.

For the inventory of tree regeneration, in the center of each initial random plots and additional plots, a subplot of 25 m^2 (5 × 5 m) was laid to assess regeneration of all tree species and target tree species with DBH < 6 cm ($tree_{<6cm}$).

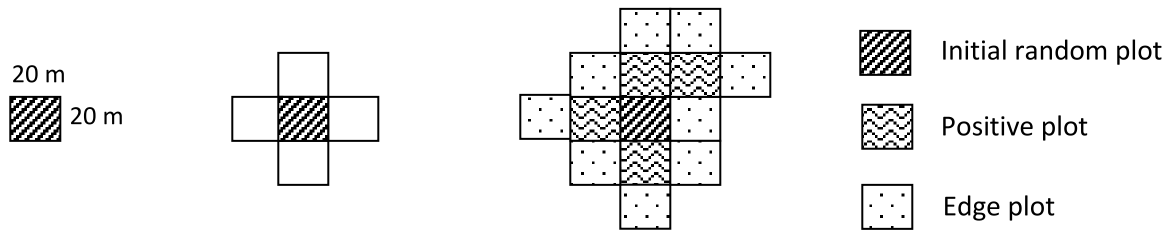

Fig. 2.2. Initial sample plot, neighboring plots are added to initial sample plot that satisfies the condition of at least one target tree$_{\geq 6cm}$, and a cluster of sample plots includes the initial plot, added positive plots and edge plots.

2.3 Data collection

2.3.1 Random sample plots

All standing trees with DBH of at least 6 cm in the random sample plots were counted. DBH was measured and tree species were identified at the species level with support from two botanists from the Vietnam National University of Forestry (VNUF). Specimens of unidentified species in the field were collected for further study at the herbarium of the VNUF. Individuals that could not be determined to the species level were classified by genus or family and sorted into morphospecies. For the purpose of the study, a *'threatened tree species'* was species listed in the Red Lists of IUCN and Vietnam (Nguyen et al. 2007; IUCN 2014). A locally *'rare tree species'* was classified when the density of a species was one or fewer individual per hectare (Pitman et al. 1999). The tree species providing NTFPs (*'NTFP tree species'*) were directly identified by two H'Mong persons who are experienced in NTFP collection in the region and who participated in data collection. In addition, specimens of

NTFP tree species were collected for further ethnobotanical survey with the assistance of H'Mong elders and traditional doctors. Occurring tree species were assigned to *'valuable timber species'* based on standard textbooks of Vietnam forest trees and Vietnam economic forest trees (Tran and Nguyen 1993; Nguyen et al. 1996), with the criteria of large size at maturity, stem straightness, hard and durable wood, fine-textured wood, wood dimensional stability, easy to work with, and use for many purposes.

Additional information was also collected from the random sample plots. 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 5 m radius around the first position at 90° intervals. The percentage of canopy closure was computed with CAN-EYE V6 software (INRA 2014) and an average of the five photographs was used per plot. In the center of each plot, a soil sample (0-20 cm deep) was collected using a soil auger for determining soil pH, soil organic matter, and soil texture (Walkley and Black 1934; Gee and Bauder 1979). Slope inclination and aspect deviation from north were measured using a compass. Elevation, longitude, and latitude were recorded using a GPS-locator. The numbers of footpaths and tree stumps were counted in each sample plot as indicators of human disturbance.

2.3.2 Adaptive added plots

In added positive plots and edge plots, all target and non-target trees$_{\geq 6\ cm}$ were counted and DBH was measured. Trees$_{\geq 6\ cm}$ in plots of 400 m^2 and regenerating trees$_{<6\ cm}$ in subplots of 25 m^2 were identified at the species level, which was supported by two botanists from VNUF. Specimens of unidentified non-target species in the field were collected for further study at the herbarium of VNUF. Individuals of non-target tree species that could not be determined to the species level were classified by genus or family and sorted into morphospecies. Some information of species distribution, ecological characteristics and conservation status of three species studied using ACS is as follows:

F. hodginsii (Fujian cypress) is native to Vietnam, China, and Laos. This species usually occurs above 900 m a.s.l. and grows on acidic and well-drained soils. It is a slow-growing, long-lived, large tree and is considered a late successional species (Nguyen et al. 1996; Le and Le 2000). The female cones are subglobose and 15-25 × 12-22 mm in size. The seeds are ovoid, 4-5 mm long, and have two wings that are very unequal in size and shape. The larger wing is ca. 5-6 mm long, and the smaller one is ca. 1.5 mm long, or a mere strip near the seed apex (Farjon 2010). Timber of *F. hodginsii* is a precious and much-valued product due to its fine, straight grain and distinct aroma. Aromatic essential oil from this species ("Siam-wood essential oil" or "Pemou oil") has a high sesquiterpene content, and reportedly can kill bacteria, purify and disinfect the air, repel mosquitoes and insects, and is used in aromatherapy to improve mental clarity and emotional balance (Lesueur et al. 2006; Paluch 2009). The population of *F. hodginsii* has declined severely, and this species is listed as 'endangered' in the Vietnam Red

List (Nguyen et al. 2007) and 'vulnerable' in the IUCN Red List (IUCN 2014). Because of its great longevity (at least 1500 years) and sensitivity to moisture, researchers have recently used *F. hodginsii* for dendro-climatic studies (Sano et al. 2008; Buckley et al. 2016).

A. spectabilis has a wide distribution, and occurs in Southeast Asia, China, and India. This tree species is usually found in near natural or slightly disturbed forests and grows on deep, clay and well-drained soil. It is a long-lived and large tree. Seeds are dispersed mainly by animals (especially civets and squirrels), birds and dehiscence (Nguyen et al. 1996). Its high quality wood is used for doors, window frames, and furniture. The natural population is seriously fragmented due to habitat destruction and over-exploitation. *A. spectabilis* is classified ‘vulnerable' in the Vietnam Red List (Nguyen et al. 2007).

Q. platycalyx is native to Vietnam and China, and occurs in secondary forests (Nguyen et al. 1996). It is a light-demanding and fast-growing tree species. Nuts and burrs are mainly dispersed by animals (especially squirrels, mice, wild boars, and bears) and gravity. Its high-quality wood is used for construction and furniture. This species is threatened by selective logging for its timber. *Q. platycalyx* is classified as 'vulnerable' in the Vietnam Red List (Nguyen et al. 2007).

2.4 References Chapter 2

Buckley, B. M., Stahle, D. K., Luu, H. T., Wang, S.Y. S., Nguyen, T. Q. T., Thomas, P., Le, C.N., Ton, T.M., Bui, T.H., Nguyen, V. T. (2016). Central Vietnam climate over the past five centuries from cypress tree rings. *Climate Dynamics*, 1–17. https://doi.org/10.1007/s00382-016-3297-y

Farjon A. (2010) A Handbook of the World's Conifers. Brill, Leiden.

Forest Inventory and Planning Institute (FIPI) (2002). Project of conservation and development forest resources of Ta Xua Nature Reserve. Vietnam.

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. (Accessed 24 March 2014).

Gee, G., & Bauder, J. (1979). Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measurement parameters. *Soil Science Society of America Journal*, *43*(5), 1004–1007.

IUCN (2014). *The IUCN Red List of Threatened Species. Version 2014.3.* http://www.iucnredlist.org.

Law No.29/2004/QH 11, 2004. Protection and development of forest, the National Assembly of the Socialist Republic of Vietnam

Le, M.C., & Le, T.H. (2000). *Forest plants*. Agricultural Publishing House, Hanoi.

Lesueur, D., Ban, N. K., Bighelli, A., Muselli, A., & Casanova, J. (2006). Analysis of the root oil of Fokienia hodginsii (Dunn) Henry et Thomas (Cupressaceae) by GC, GC–MS and 13C-NMR. *Flavour and Fragrance Journal*, *21*(1), 171–174.

Manimaran, A., & Cruz, M. M. J. J. (n.d.). 5. Plant Oils to Combat Mosquitoes.

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., & Nguyen, N.T. (1996). *Vietnam Forest Trees*. Agricultural Publishing House, Ha Noi.

Nguyen, T.B., Tran ,D.L., Nguyen, K.K., (2007) Vietnam red list. Part II: Plants. Science and Techniques Publishing House, Hanoi.

Paluch, G. E. (2009). Characterization of botanical terpene activity in arthropods. Dissertation, Iowa State University, USA

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

Pitman, N. C., Terborgh, J., Silman, M. R., & Nuñez V, P. (1999). Tree species distributions in an upper Amazonian forest. *Ecology*, *80*(8), 2651–2661.

Sano, M., Buckley, B. M., & Sweda, T. (2008). Tree-ring based hydroclimate reconstruction over northern Vietnam from Fokienia hodginsii: eighteenth century mega-drought and tropical Pacific influence. *Climate Dynamics*, *33*(2), 331. https://doi.org/10.1007/s00382-008-0454-y

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. Retrieved from http://books.google.de/books?id=frwhtwAACAAJ

Sterling, E. J., & Hurley, M. M. (2005). Conserving biodiversity in Vietnam: Applying biogeography to conservation research. *PROCEEDINGS-CALIFORNIA ACADEMY OF SCIENCES*, *56*, 98.

Thompson, S. K. (1990). Adaptive cluster sampling. *Journal of the American Statistical Association*, *85*(412), 1050–1059.

Tran, H., & Nguyen, B. Q. (1993). *Vietnam economic forest trees*. Hanoi: Agricultural Publishing House.

Walkley, A., & 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 Science*, *37*(1), 29–38.

Chapter 3

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, Germany

[2] Faculty of Silviculture, Vietnam National University of Forestry, Hanoi, Vietnam

[*] Correspondence to: Thi Hoa Hong Dao, Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany. E-mail: tdao@gwdg.de; Telephone: +49 176 9585 4889

Published in **Tropical Conservation Science** Vol.8 (2): 479-490, 2015

Abstract Chapter 3

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

3.1 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 464 plant 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.

3.2 Methods

3.2.1 Study area

The Ta Xua Nature Reserve (21°13′ – 21°26′ N, 104°16′ – 104°46′ E, Fig. 3.1) 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 2765 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 1600 mm to 1900 mm, and the average temperature is 20°C.

The reserve incorporates a '*core zone*' of 15211 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 rainforest 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 patrols and research project routes or tourist trails.

The '*buffer zone*' of the reserve encompasses 24674 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 10856 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 2439 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].

3.2.2 Site and plot selection

Based on a reconnaissance survey, a provisional forest cover map was established and an elevation range of 1000 m to 1700 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 1400 cells was created and overlaid on the study area plan to randomly select the locations for sample plots. Forty plots of 20 × 20 m were then established in each conservation zone, with the center of each plot located in the center of a selected cell.

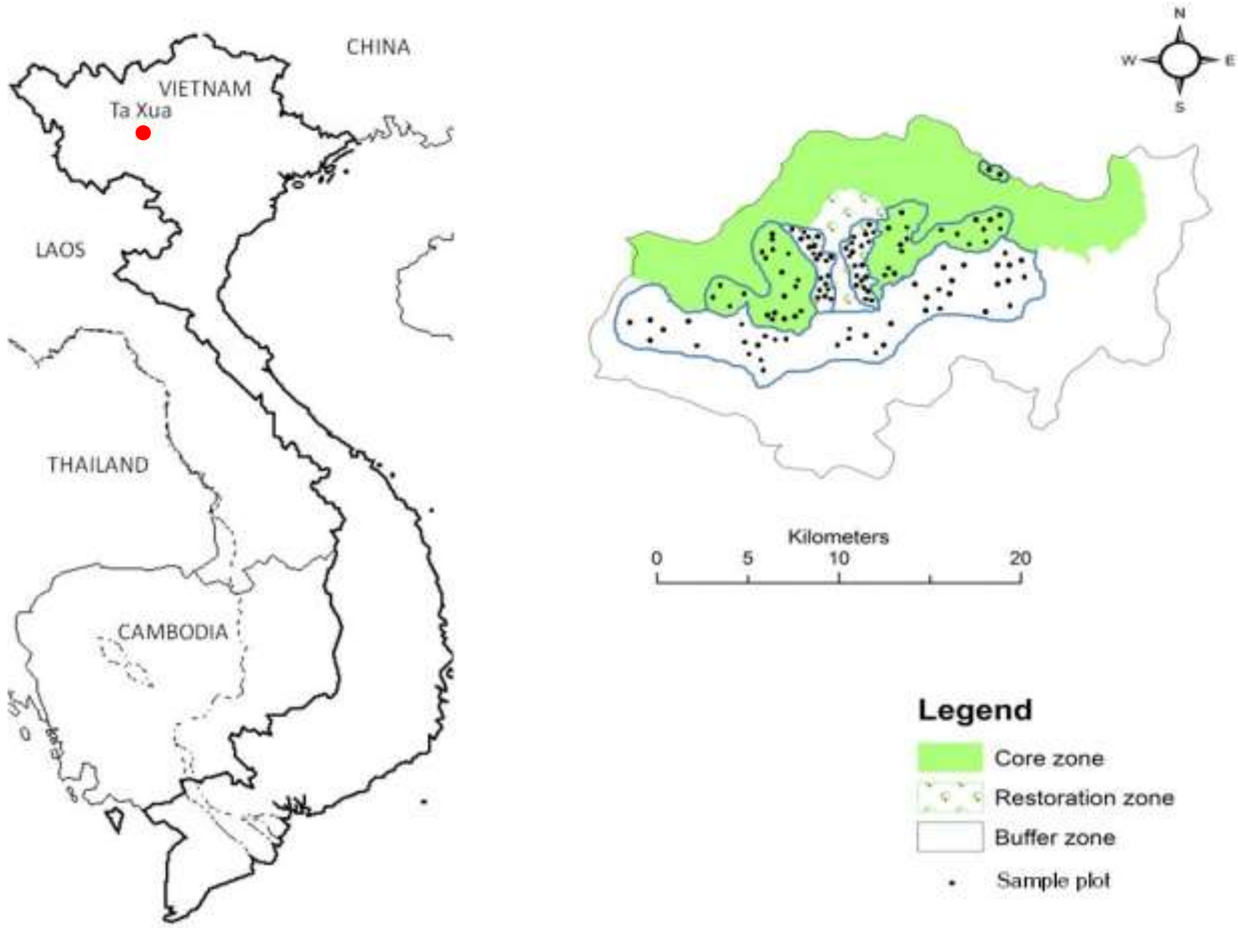

Fig. 3.1. Vietnam and the geographic position of the Ta Xua Nature Reserve. The actual study area at 1000 m -1700 m a.s.l. is indicated by blue lines comprising the core zone, the buffer zone and the restoration zone. Sample plots, 40 per zone, are indicated by black dots.

3.2.3 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 National University of Forestry (VNUF). Specimens of species unidentified in the field were collected for further study at the herbarium of VNUF. Individuals that could not be determined to the species level were classified by their genera or families and sorted into morphospecies. 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.

3.2.4 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.

3.3 Results

3.3.1 Site conditions and forest structural characteristics

Among the three conservation zones, many of the site conditions, such as soil pH and slope inclination, were fairly comparable (Table 3.1). 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 3.1 and Fig. 3.2). 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 3.1. Site conditions and forest structural characteristics of the three conservation zones. (Means and standard deviations, n = 40 plots per zone, different superscripts small letters indicate significant differences at $p \leq 0.05$)

	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; m^2/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.

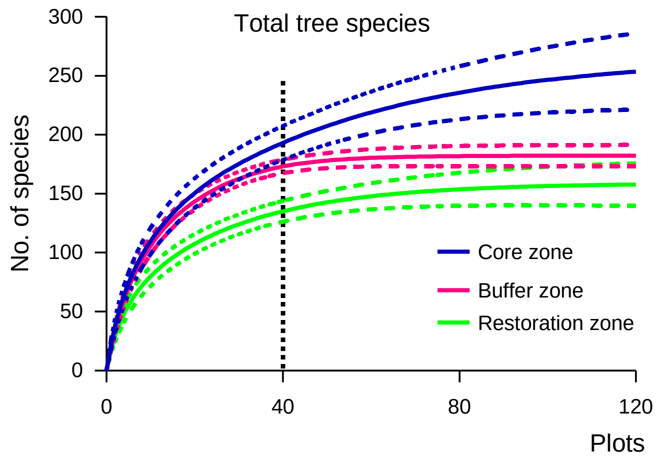

Fig. 3.2. Sample-based rarefaction and extrapolation of tree species accumulation curves (solid lines) and 95% lower and upper unconditional confidence intervals (dash lines). Rarefaction from 0 to 40 plots, extrapolation from 40 to 120 pooled plots of all encountered tree species in three conservation zones.

3.3.2 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 3.2). 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 3.2. 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), (Fig. 3.3). 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.

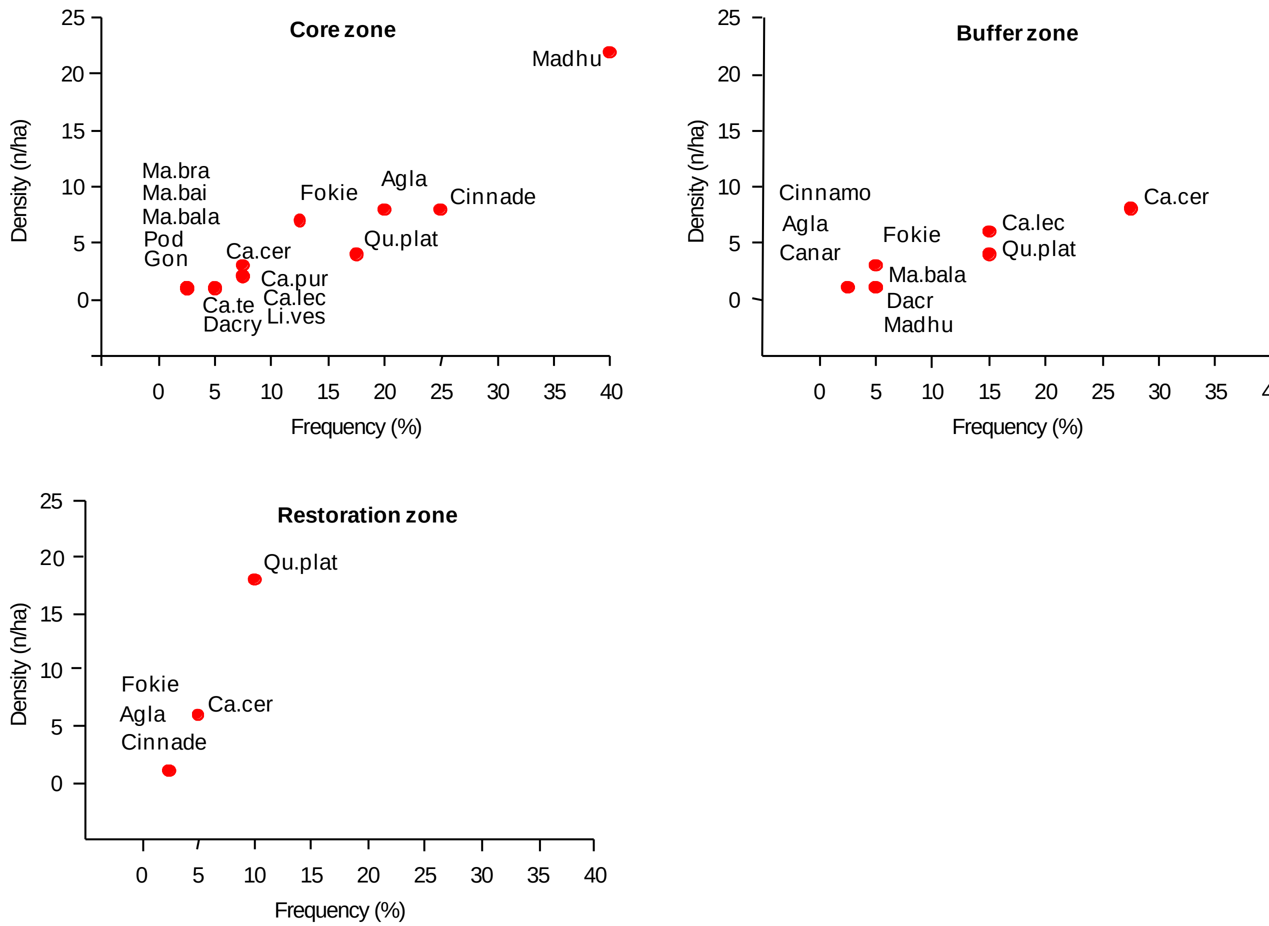

Fig. 3.3. Frequency and density of red-listed tree species across 40 sample plots in each conservation zone (abbreviation for species code as in Appendix 1)

3.3.3 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. 3.4). 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.

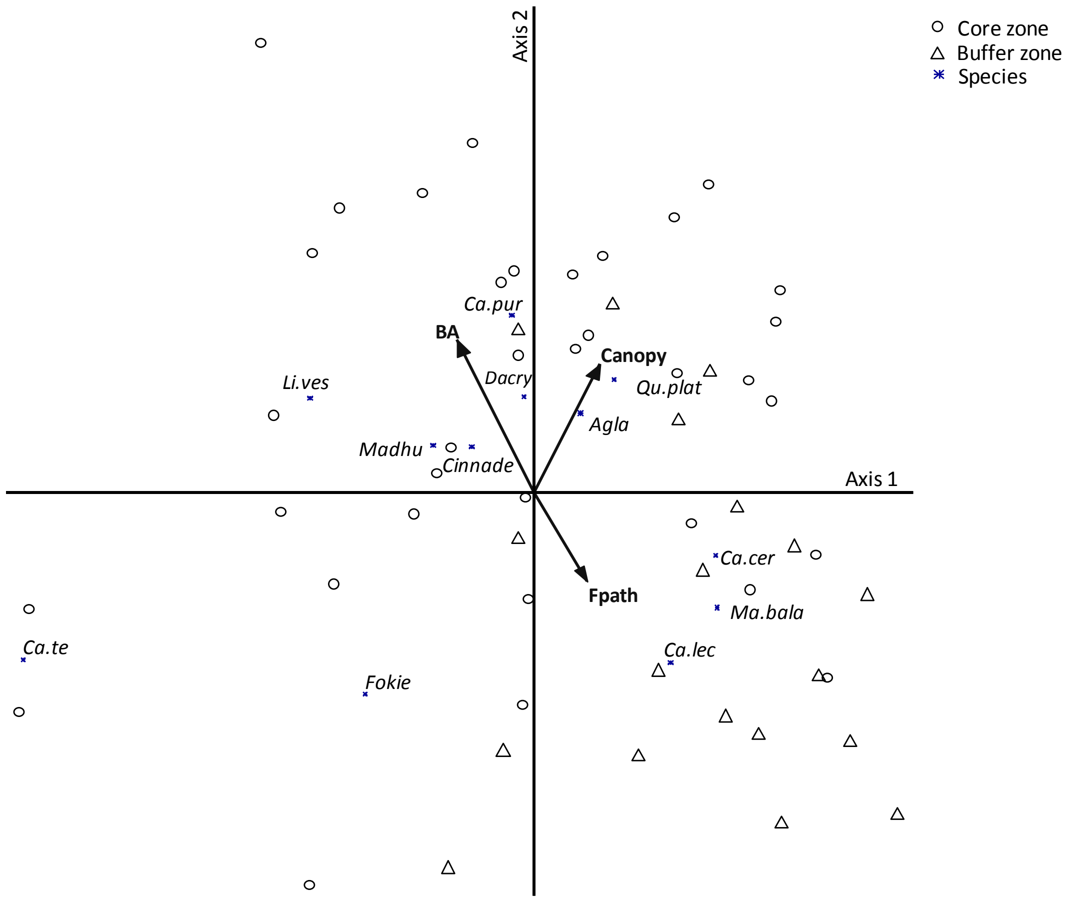

Fig. 3.4. Canonical correspondence analysis (CCA) shows the correlations between environmental, forest structural, and human disturbance variables and density red-listed tree species which were encountered more than once in the core and buffer zones. The first and the second axes explained 7.3%, and 5.8% of the variance of present data, respectively. Correlation threshold r^2= 0.26. (BA = basal area, Fpath = footpath, abbreviation for species code as in Appendix 1)

3.4 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 VNUF 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.

3.5 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

This study was supported by the Vietnamese Government, the German Academic Exchange Service (DAAD), and the Rufford Small Grants Foundation; the publication was supported by an Open Access Grant Program of the German Research Foundation (DFG) and the Open Access Publication Funds of Göttingen University. We thank Nguyen Q.D., Luong V.P., Dang V.L., Dao V.P., Nguyen M.T., Pham K.C., Vang A.S., Vang A.C. for their assistance during different phases of fieldwork; two botanists, Phung V.P., Phan V.D. for tree identification; Tran T.H. and Nguyen T.H. for their help in soil sample analysis; Ngo T.L., Nguyen V.T., Phan T.N., Le T.K. for their comments on our research; and managers and local people in the Ta Xua Nature Reverse for helping us conduct this study. We thank the editor and reviewers for constructive comments that improved the manuscript.

3.6 References Chapter 3

[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] Ramı́rez-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 tiles in Vietnamese were translated into English.*

3.7 Appendix Chapter 3

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 (20 × 20m) 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 phảng	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.

Chapter 4

Patterns of tree community differences in the core and buffer zones of a nature reserve in north-western Vietnam

Thi Hoa Hong Dao[1,2*], Joachim Saborowski[3,4], Dirk Hölscher[1]

[1] Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Germany

[2] Forest Inventory and Planning, Faculty of Silviculture, Vietnam National University of Forestry, Hanoi, Vietnam

[3] Ecoinformatics, Biometrics and Forest Growth, Georg-August-Universität Göttingen, Germany

[4] Ecosystem Modelling, Georg-August-Universität Göttingen, Germany

[*] Correspondence to: Thi Hoa Hong Dao, Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany. E-mail: tdao@gwdg.de; Telephone: +49 176 9585 4889

Published in **Global Ecology and Conservation** 8 (2016) 220–229, doi:10.1016/j.gecco.2016.09.011

Abstract Chapter 4

In tropical forest conservation, areas with full statutory protection are often surrounded by buffer zones. Information on the patterns of tree community structure differences in these zones is helpful to evaluate the conservation efficacy. Our study was implemented within a biodiversity hotspot, in the Ta Xua Nature Reserve of north-western Vietnam, which has a statutorily protected core zone and a buffer zone, where local H'Mong people are permitted low intensity forest use. The forests are rich in tree species (249 observed). Many of these tree species provide non-timber forest products (NTFPs) (48%) or valuable timber (22%), and 18 species are red-listed. Overall tree density was not different in the two zones, but tree diameter and species richness were lower in the buffer zone. At the tree level, logistic regression analysis indicated that red-list status, large diameter, and low density of conspecifics increased the probability of tree absence from the buffer zone but not the potential use as a NTFP. However, most NTFP species had different densities in the core and buffer zones, and this correlated with signs of human interference. At the species level, the density of species was the most important variable, and rarity strongly increased the probability of species absence. Our results also indicate that rare and red-listed trees were depleted in the buffer zone. In consideration of conservation goals, the future monitoring of these species at the Ta Xua Nature Reserve and other protected areas is needed, and conservation measures most likely need to be improved.

Keywords: conservation; diversity; logistic model; non-timber forest products; rarity; timber

4.1 Introduction

Tropical forest conversion and degradation have caused severe losses in biodiversity (Sodhi et al. 2009; Gibson et al. 2011). Thus conservation of tropical forests is urgently needed. Tropical forests are also capable of providing renewable resources, such as timber, non-timber forest products (NTFPs), and other ecosystem services. Forest stewardship intends to unify and further develop both the conservation and production functions of forests (Messier et al. 2015). One approach to tropical forest stewardship and conservation is the establishment of strictly protected core zones, which safeguard remaining habitats and species (Bruner et al. 2001; Joppa and Pfaff 2010), and surrounding buffer zones, where low impact forest use intensity is presumed. This approach can enhance the conservation value of protected areas and at the same time provide some forest products (DeFries et al. 2005; Chape et al. 2005).

Timber logging and NTFP harvesting are main types of forest use, and these have various impacts on forest biodiversity (Arnold and Pérez 2001; Ticktin 2004; Ndangalasi et al. 2007; Clark and Covey 2012). At low intensity and at a local scale, selective timber logging and harvesting of NTFPs can locally increase floral species richness and may have little impact on the forest tree community (Cannon et al. 1998; Endress et al. 2006, Berry et al. 2010; Putz et al. 2012). However, at high intensity and over a larger scale, both logging and NTFP harvesting may lead to forest degradation and species loss (Arnold and Pérez 2001; Rosser and Mainka, 2002; Sodhi et al. 2004; Asner et al. 2006; Gibson et al. 2011; Branch et al., 2013). In particular rare tree species often contribute significantly to the high levels of tree species diversity in tropical forests (Hubbell 2013; ter Steege et al. 2013), but such species are also prone to high risks of extirpation (Mouillot et al. 2013) or extinction when their habitats are destroyed (Gaston 1994; Laurance 1999; Sodhi et al. 2004; Hubbell 2013). Therefore, the patterns of tree community changes between the core and buffer zones related to tree uses, dimensions, and rarity must be assessed in order to evaluate whether conservation goals are met or need adjustment.

In this context, tropical forests in rural and today remote areas are of utmost importance (Tyukavina et al. 2016). Local human communities traditionally use tropical forests, while also external interests including biodiversity conservation and logging of timber and harvesting of NTFPs are enforcing. The present study was conducted in the Ta Xua Nature Reserve, a protected area in north-western Vietnam within a biodiversity hotspot (Sobey 1998; Sterling and Hurley 2005). This nature reserve has a strictly protected core zone of near-natural forest and a buffer zone, where only low intensity traditional forest use by the H'Mong people is permitted. The main goals of this study were to analyze tree community structure in the core zone and the buffer zone, and in case of differences, to identify the impact of important variables, such as timber use, NTFP use, tree diameter, tree rarity, and red-list status, on differences of tree community between the core zone and buffer zone. The expected results will contribute to further develop forest stewardship concepts by pointing to significant influencing factors based on a statistically sound approach.

4.2 Materials and methods

4.2.1 Study area

The Ta Xua Nature Reserve (21°13’ – 21°26’ N, 104°16’ – 104°46’ E, Fig. 4.1) was established in 2002. The topography of the region is characterized by high, steeply sloping mountains, ranging in altitude from 320 m to 2765 m a.s.l. with inclinations of between 30° and 40°. The climate is humid-tropical 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.), the annual precipitation ranges from 1600 mm to 1900 mm, and the average temperature is 20 °C.

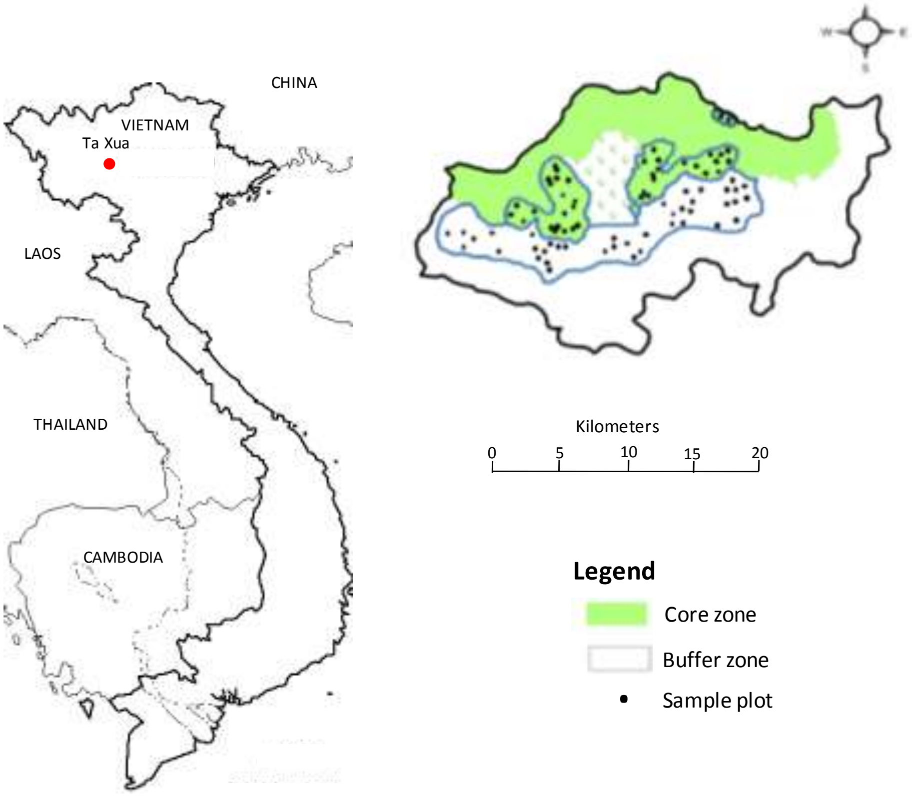

Fig. 4.1. Vietnam and location of the Ta Xua Nature Reserve (left). The study area is enclosed by blue lines (right; 1000-1700 m a.s.l.). Sample plots (40 in the core zone, 40 in the buffer zone) are indicated by black dots

The reserve incorporates a core zone of 15211 ha, with a forest cover of 87%. Human activities such as logging, hunting, and the gathering of NTFPs are prohibited. During our field work, signs of these activities were rarely observed. The forest types range from evergreen and broad-leaved rainforest at lower elevations to coniferous forest mixed with some evergreen and broad-leaved species at higher elevations. The core zone can only be reached by footpaths, some of which were made before the nature reserve was established, and others were marked out ranger patrols and research project routes or tourist trails (FIPI 2002) (Fig. 4.2).

The buffer zone of the reserve encompasses 24674 ha with a forest cover of 44%. The forest only occurs above 900 m a.s.l. and is used by the H'Mong people in accordance with forest management regulations established by the law of forest protection and development (Law No.29/2004/QH11, 2004). These regulations allow a maximum of 25 trees to be felled per year in a forest area of 10856 ha and gathering of NTFPs to fulfill demand without detailed specific quantity regulation. 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 (FIPI 2002).

Fig. 4.2. The landscape of the Ta Xua Nature Reserve (A) and trees in the forest of its core zone (B: *Madhuca pasquieri* & C: *Podocarpus neriifolius*).

4.2.2 Site and plot selection

Based on a reconnaissance survey, a provisional forest cover map was established. An elevation range of 1000 to 1700 m a.s.l. was selected for the study, as forest in this elevation range occurred in the core and buffer zones. The study area included 73 ha in the core zone and 115 ha in the buffer zone. A grid system with 1400 cells was created and overlaid on a map of the study area to randomly select locations for sample plots. Forty plots of 20 × 20 m were established in each conservation zone.

4.2.3 Data collection

All standing trees with diameter at breast height (DBH) of at least 6 cm in the sample plots were counted. DBH was measured and tree species were identified at the species level with support from two botanists from the Vietnam National University of Forestry (VNUF). Specimens of unidentified species in the field were collected for further study at the herbarium of the VNUF. Individuals that could not be determined to the species level were classified by genus or family and sorted into morphospecies. The tree species providing NTFPs were directly identified by two H'Mong persons who are experienced in NTFP collection in the region and who participated in data collection. In addition, specimens were collected for further ethnobotanical survey with the assistance of H'Mong elders and traditional doctors. Occurring tree species were assigned to valuable timber species based on standard textbooks of Vietnam forest trees and Vietnam economic forest trees (Tran and Nguyen 1993; Nguyen et al. 1996), with the criteria of large size at maturity, stem straightness, hard and durable wood, fine-textured wood, wood dimensional stability, easy to work with, and use for many purposes. A tree species was classified as locally rare when the density of species was 1 or fewer individual per hectare (Pitman et al. 1999), and as red-listed when the tree species was listed in the Vietnam Red List and/or the IUCN Red List (Nguyen et al. 2007; IUCN 2014).

Additional information was also collected from the study plots. 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 center of each sample plot, while the four remaining positions were located within a 5 m radius around the first position at 90° intervals. The percentage of canopy closure was computed with CAN-EYE V6 software (INRA 2014) and an average of the five photographs was used per plot. In the center of each plot, a soil sample (0-20 cm deep) was collected using a soil auger for determining soil pH, soil organic matter, and soil texture (Walkley and Black 1934; Gee and Bauder 1979). Slope inclination and aspect deviation from north were measured using a compass. Elevation, longitude, and latitude were recorded using a GPS-locator. The numbers of footpaths and tree stumps were counted in each sample plot as indicators of human disturbance. Thus, sample plots were randomly chosen; the tree inventory, field classification of tree uses and the assessments of human disturbance signs were done at the same visit.

4.2.4 Statistical analysis

A *t*-test was used to test the differences of means of the two conservation zones (significant if $p \leq 0.05$) if the data satisfy the criteria of normal distribution and homogeneity of variance. When these requirements were not met, the nonparametric Mann-Whitney *U*-test was applied. The predicted tree species richness in the core zone and buffer zone were estimated using the Bernoulli product model, based on the Mao-Tau and Chao2 estimators (Chao 1987), by interpolation from 40 empirical plots and extrapolation to three-times the number of empirical plots in each zone (Colwell et al. 2004; Colwell et al. 2012) using EstimateS software (Colwell 2013).

The probabilities of tree and species absence in the buffer zone were modeled by logistic regression analysis. Predictor variables that were statistically significant in the Wald *z*-test were selected for the logistic models. Stepwise logistic regression was used to select variables for inclusion in the regression models. In comparison of the different models, the model with the lowest Akaike Information Criterion (AIC) was selected. Odds ratios (ORs) and 95% confidence intervals (CIs) were used to compare the influence of different exposure variables. The probabilities of tree absence and species absence were calculated by transforming back to the original scale ($p = 1/[1+e^{-\text{logit}(p)}]$), (Hosmer et al. 2013).

A multiple logistic regression model with four significant predictor variables was used to predict *tree* absence probability: *tree DBH*, *density of species*, *NTFP use*, and *red-listed status*. For each tree in the core zone, absence of a similar tree was recorded if there was no tree in the buffer zone with an identical NTFP, valuable timber and red-listed parameters and belonging to the same species and DBH class (the width of DBH classes was 10 cm). For predicting the probability of *species* absence, the presence or absence of the same species in the buffer zone was recorded. Here, only one predictor variable, *density of species*, was statistically significant according to the *z*-test. This variable was transformed to several forms such as inverse function (1/density of species) and different powers of (1/density of species) to identify the best model for predicting the probability of species absence.

The relationships of forest structure and human interference variables with abundance of NTFP tree species in the core zone and buffer zone were analyzed using detrended correspondence analysis (DCA). The main matrix contained the names and densities of NTFP tree species within a set of sample plots in the core and buffer zones, and a second matrix included the forest structural and human interference variables from the same plots. Densities of the main matrix were log-transformed and standardized to achieve approximately standard normal distributions, and data in the second matrix were expressed relative to their maxima to ensure equal weighting before running DCA. Spearman correlation analysis was used to test whether density of each NTFP tree species correlated significantly with the DCA axes scores. Data analyses were conducted using Statistica (StatSoft 2014), PC-ORD software version 5.12 (McCune and Mefford 2006), and RStudio (RStudio Team 2015).

4.3 Results

4.3.1 Site conditions and forest stand structure

The site conditions at randomly chosen plots in the core zone and buffer zone were the similar in soil variables such as pH (average 4.7 in both) and only slightly different in slope inclination (39.5° vs. 35.9°, in the core and buffer zones respectively). However, these two zones differed significantly in numerous forest structural characteristics. Tree diameter, basal area, and canopy closure were significantly higher in the core zone, where also significantly fewer tree stumps and footpaths were observed (Table 4.1). All of these differences reflect the influences of human interference.

Table 4.1. Site conditions and forest structural characteristics of the core zone and buffer zone. Values indicate means ± standard deviations from 40 sample plots in each zone. Different superscript small letters indicate significant differences between zones ($p \leq 0.05$)

	Core zone	**Buffer zone**
Total study area (ha)	72.8	115.1
Elevation (m a.s.l.)	1449.1 ± 62.6^{a}	1363.3 ± 86.7^{b}
Slope inclination (degree)	39.5 ± 7.7^{a}	35.9 ± 5.4^{b}
Soil pH (0-20 cm depth)	4.7 ± 0.4^{a}	4.7 ± 0.4^{a}
Tree density (trees ≥ 6 cm; trees/ ha)	925 ± 251^{a}	1006 ± 357^{a}
DBH (trees ≥ 6 cm; cm)	21.4 ± 3.4^{a}	16.6 ± 3.0^{b}
Basal area (trees ≥ 6 cm; m^2/ha)	52.9 ± 21.4^{a}	30.4 ± 15.4^{b}
Canopy closure (%)	88.4 ± 7.2^{a}	84.5 ± 5.9^{b}
*Species diversity ($e^{H'}$)	18.4 ± 4.9^{a}	14.9 ± 4.9^{b}
Stumps (no./plot)	0.6 ± 0.8^{a}	1.6 ± 1.6^{b}
Footpaths (no./plot)	0.9 ± 0.6^{a}	1.5 ± 0.8^{b}

* Exponential of Shannon entropy (Jost, 2006)

4.3.2 Tree species classification

3090 trees (249 species) with DBH of at least 6 cm in the two zones were detected (Fig. 4.3). A total of 48% of all tree species were used for NTFPs and 22% were valuable timber species. Among these, 14% were multiple-use species in that they provided both NTFPs and valuable timber (Fig. 4.3; Appendices 4.1 & 4.2). A total of 110 species (44%) were neither NTFPs nor valuable timber species. 79 tree species (32%) were rare in at least one of the zones

(Appendix 4.3). Eighteen species (7%) were listed as threatened species on the red list of the IUCN and/or the red list of Vietnam (Appendix 4.4).

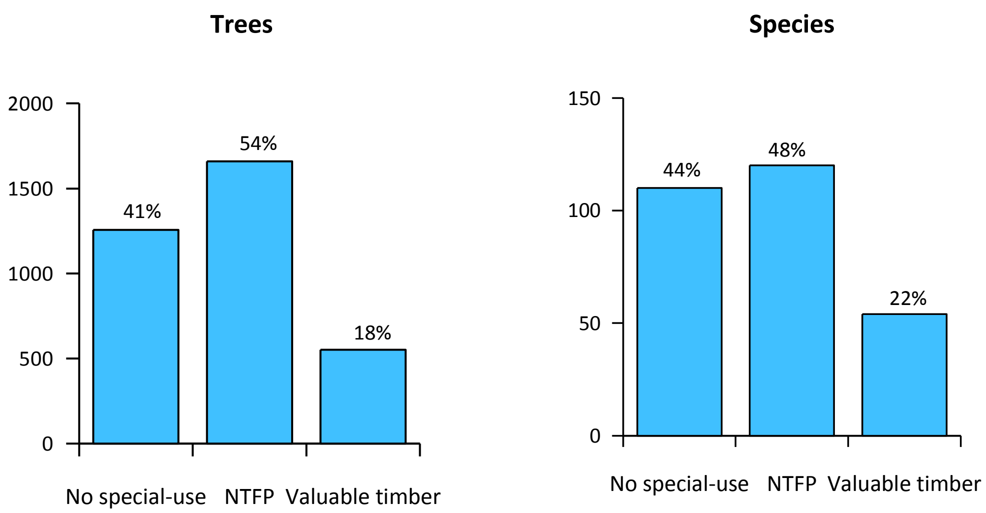

Fig. 4.3. Use of encountered trees (3090) and tree species (249) in the core zone and buffer zone. A total of 12% of trees and 14% of tree species were used as both non-timber forest products (NTFPs) and valuable timber

4.3.3 Differences in tree communities

The overall tree density in the core zone and buffer zone did not differ significantly (Table 4.2). However the density of large diameter trees (DBH ≥ 30 cm) significantly reduced and the density of small diameter trees (DBH < 30 cm) increased in the buffer zone. Trees providing NTFPs were significantly more numerous in the buffer zone, whereas trees providing valuable timber were more numerous in the core zone. Rare and red-listed trees had lower densities in the buffer zone.

Table 4.2. Characteristics of trees with DBH of at least 6 cm in the core zone and buffer zone. Values indicate means ± stand deviations of 40 sample plots in each zone. Different superscript small letters indicate significant differences between zones (*p*≤0.05)

		Core zone	Buffer zone	Difference (%)
Density	All (trees/plot)	37 ± 10^{a}	40.2 ± 14^{a}	9
	*Not rare (trees/plot)	35.6 ± 10^{a}	39.6 ± 14.2^{a}	11
	** Rare (trees/plot)	1.4 ± 1.3^{a}	0.6 ± 0.8^{b}	-56
Diameter	DBH < 30cm (trees/plot)	29.7 ± 9.2^{a}	36.6 ± 14.4^{a}	23
	DBH ≥ 30cm (trees/plot)	7.2 ± 2.6^{a}	3.5 ± 3^{b}	-51
Use	No special (trees/plot)	17.4 ± 6.8^{a}	14.2 ± 7^{b}	-18
	NTFP (trees/plot)	11.1 ± 4.7^{a}	21 ± 11.4^{b}	89
	Valuable timber (trees/plot)	2.3 ± 1.8^{a}	1.9 ± 2.8^{b}	-16
	Multiple-use (trees/plot)	6.2 ± 3.7^{a}	3.1 ± 2.1^{b}	-50
Red-listed	Red-listed (trees/plot)	2.5 ± 1.9^{a}	1.1 ± 1.5^{b}	-57

*Number of individual trees in a species with density of more than 1 trees/ha
**Number of individual trees in a species with density of 1 or fewer individual tree/ha

Comparison of tree species in the two zones indicated that the buffer zone had the estimated species richness 28% lower (Table 4.3). The buffer zone also had 53% fewer tree species with DBH ≥ 30 cm, 7% fewer valuable timber species, 10% fewer NTFP species, and 35% fewer multiple-use species. Rare and red-listed tree species also reduced by 56% and 38%, respectively, in the buffer zone.

Eighty-five species provided only NTFPs. Among these, forty-two of these species had higher density in the buffer zone, 37 had lower density in the buffer zone, and the 6 other species had similar density in each zone.

Table 4.3. Characteristics of tree species in the core zone and buffer zone. Estimated tree species richness from 40 plots to 120 pooled plots employed the Chao2 estimator

		Core zone	Buffer zone	Core zone only	Buffer zone only	Difference (%)
Diversity	Found (species/40 plots)	193	173	76	56	-10
	Estimated (species/120 plots)	254±17	182±5	127±16	61±3	-28
	*Not rare (species/40 plots)	136	148	22	34	9
	**Rare (species/40 plots)	57	25	54	22	-56
Diameter	DBH < 30cm (species/40 plots)	163	159	70	64	-2
	DBH ≥ 30cm (species/40 plots)	30	14	28	12	-53
Use	No special (species/40 plots)	79	78	33	32	-1
	NTFP (species/40 plots)	68	61	24	17	-10
	Valuable timber (species/40 plots)	15	14	5	4	-7
	Multiple-use (species/40 plots)	31	20	15	4	-35
Red-listed	Red-listed (species/40 plots)	16	10	8	2	-38

*Species with density of more than 1 trees/ha

**Species with density of 1 or fewer individual tree/ha

4.3.4 Logistic regression models for predicting probabilities of tree and species absence

A multiple logistic regression analysis was used to predict the probability of *tree* absence in the buffer zone (Table 4.4). The results indicate that *red-listed status* (OR = 2.94, 95% CIs = 1.81- 4.78) and *large DBH* (OR = 1.01, 95% CIs = 1.00 - 1.02) increased the probability of tree absence in the buffer zone. In contrast, *high density* (OR = 0.99, 95% CIs = 0.98 -1.00) and *NTFP use* (OR = 0.62, 95% CIs = 0.49 - 0.76) reduced the probability of tree absence in the buffer zone.

Table 4.4. Probability of *tree* absence in the buffer zone by a multiple logistic regression model: logit(*p*) = 1.078×Red-listed + 0.011×DBH - 0.0096×density - 0.483×NTFP; AIC = 1984.1; likelihood ratio test: *p*< 0.001; CIs: confidence intervals

Predictor variable	Parameter estimate	Standard errors	p (z test)	Odds ratios	95% CIs	Type of variable
Red-listed	1.078	0.2477	<0.0001	2.94	1.81 - 4.78	0/1
DBH (cm)	0.011	0.0035	0.0017	1.01	1.00 - 1.02	continuous
Density of species (n/ha)	-0.0096	0.0032	0.0025	0.99	0.98 – 1.0	continuous
NTFP	-0.483	0.109	<0.0001	0.62	0.49 - 0.76	0/1

Logistic regression analysis was used to predict the probability of *species* absence in the buffer zone (Table 4.5). The results indicate that the probability of species absence was predicted by *density of species per hectare*, but not by other analyzed factors (*DBH*, *NTFP use*, *valuable timber*, *red-listed status*). In particular, low density was strongly associated with increased probability of species absence (Table 4.5 and Fig. 4.4).

Table 4.5. Prediction of the probability of *species* absence in the buffer zone by three logistic regression models

Predictor variable	Model	p (z test)	AIC value
Density of species (n/ha)	logit (p) = -0.157×density	0.002	243.48
1/density of species	logit(p) = -1.545 +1.455× (1/density)	<0.0001	230.12
$(1/\text{density of species})^{0.25}$	logit(p) = -4.261 + 4.397× $(1/\text{density})^{0.25}$	<0.0001	227.12
Mean species diameter (cm)	---	0.61	---
NTFP	---	0.77	---
Valuable timber	---	0.91	---
Red-listed	---	0.37	---

Comparison of different logistic models for density of species indicated that the (1/density of species per ha) and (1/density of species per ha)$^{0.25}$ models had lower AIC values than the (density of species /ha) model, and that the (1/density of species per ha)$^{0.25}$ model had the lowest AIC value indicating the highest level of prediction accuracy.

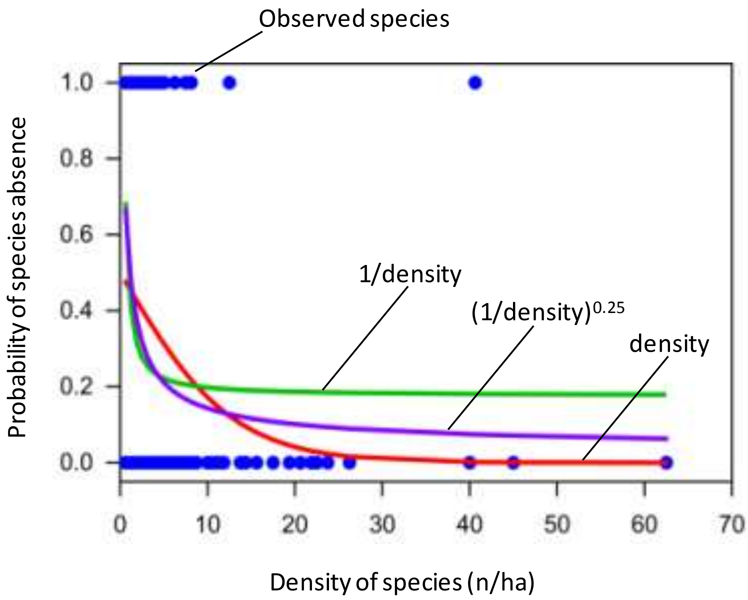

Fig. 4.4. Probability of species absence based on three logistic regression models of density of species (density of species per hectare; 1/ density of species; and [1/ density of species]0.25). The (1/ density of species)0.25 model (purple line) had the lowest Akaike Information Criterion (AIC) value, indicating the best prediction accuracy (see Table 4.5)

4.3.5 DCA for analyzing tree densities of NTFP species

Correlations of densities of NTFP tree species with forest structure and human interference variables were analyzed using DCA (Fig. 4.5). The first DCA axis correlated negatively with species richness (r = -0.4) and positively with the number of footpaths (r = 0.3), and the second DCA axis correlated negatively with the number of stumps (r = -0.4) and positively with tree DBH (r = 0.7), ($p \leq 0.05$). The different directions of the vectors of these four variables suggest contrasting influences of forest structure variables and human disturbance variables on the abundance of NTFP species.

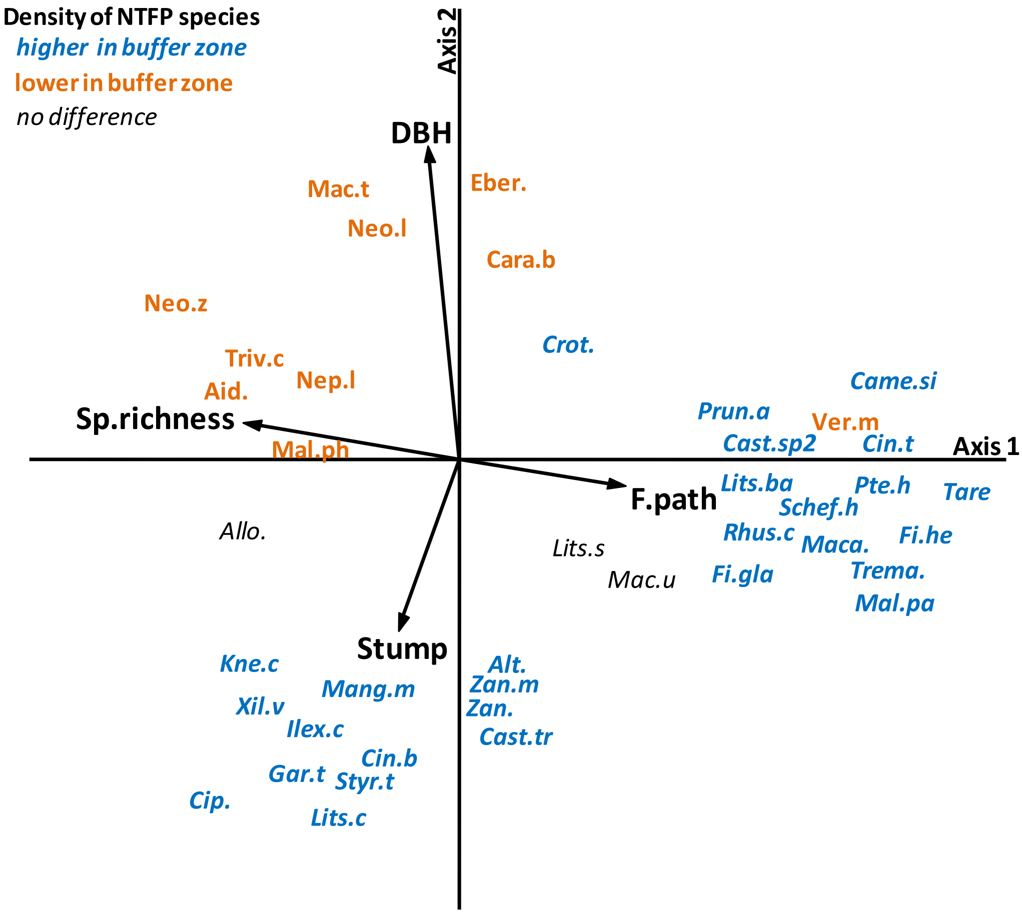

Fig. 4.5. Detrended correspondence analysis of the density of 85 NTFP tree species in the core zone and buffer zone according to forest structure and human interference indicators. Eigenvalues: 0.42 (axis 1) and 0.50 (axis 2); correlation threshold: r2=0.4. A total of 41 NTFP tree species correlated significantly with two DCA axes. Abbreviations: DBH: diameter at breast height, Sp. richness: species richness, F.path: footpath. Abbreviations for species are given in Appendix 4.1.

NTFP tree species that had high densities in the buffer zone positively correlated with two human interference variables: number of footpaths and number of stumps. It indicated that densities of these species are likely to increase with increasing numbers of footpaths and stumps. On the other hand, NTFP tree species that had low densities in the buffer zone negatively correlated with these human interference variables. It means that densities of these species tend to decrease with increasing human interference. In other words, these results indicated that human interference had divergent effects on the abundance of NTFP tree species.

4.4 Discussion

Our study of differences in tree community between the core zone and buffer zone in the Ta Xua Nature Reserve indicated that overall tree density was not different, but other tree community characteristics such as tree diameter and species richness differed significantly. *Red-listed status*, *tree DBH*, *density of species*, and *NTFP use* (in order of reducing importance) were significantly associated with the probability of *tree* absence in the buffer zone. More specifically, *red-listed status*, *large diameter*, and *low density* increased the probability of tree absence in the buffer zone, and *NTFP use* reduced the probability of tree absence in the buffer zone. The results of the DCA indicated that human interference correlated positively with some NTFP species, but negatively with other NTFP species. In predicting the probability of *species* absence, a logistic model indicated that *density of species* was the most important variable, and low density (species rarity) strongly enhanced the probability of species absence.

Timber logging was evident in the buffer zone, as indicated by a tree community structure that differed from the core zone and by the large number of stumps. It was also obvious that some valuable timber tree species such as *Fokienia hodginsii* (Fujian cypress) were sought for logging. However, the multivariate logistic models indicated that *valuable timber* was not a significant variable at the tree level or species level. This may be because of the relatively small proportion of tree species in this category or because loggers did not search for species regarded valuable timber. *Tree DBH* in contrast was a significant variable, suggesting that loggers mainly focused on large diameter trees. The H'Mong people, as indicated by their knowledge of NTFPs, know their tree species, so it seems reasonable that the loggers are not H'Mong. In fact, the H'Mong people claimed that illegal loggers came from outside. Thus, in this case, the management plan for conservation of the buffer zone seems sound, but better enforcement is needed. If not, it is possible that logging may spread into the core zone. Our findings are e.g. consistent with a study in Kibale National Park in Uganda which found that trees with large diameters were strongly depleted in disturbed forests (Osazuwa-Peters et al. 2015).

It is likely that NTFP use by local people changed the density of tree species, but it did not lead to species extirpation. Some NTFP species, such as *Mallotus paniculatus*, *Macaranga denticulata*, *Litsea cubeba*, *Styrax tonkinensis*, and *Ficus glandulifera*, had higher densities in the buffer zone and positively correlated with human interference. On the other hand, several other species, such as *Trivalvaria costata, Eberhardtia tonkinensis*, *Neolitsea zeylanica*, *Nephelium lappaceum*, and *Machilus thunbergii*, were less abundant in the buffer zone and negatively correlated with human interference. These results illustrate that the traditional methods of the H’Mong people in harvesting and using NTFPs had divergent effects on the abundance of NTFP tree species. Similarly, *Mallotus* and *Macaranga* species were strongly associated with disturbance and can be used as indicators for forest disturbance in Kalimantan, Indonesia (Slik et al. 2003), whereas *Neolitsea zeylanica* disappeared due to disturbance in Uttara Kannada, in southern India (Daniels et al. 1995). However, our findings differ from those of a study in the Western Ghats of India, which found that contemporary practices of NTFP harvesting were exploitive and harmed NTFP resources due to high intensity and destructive harvesting (Muraleedharan et al. 2005). Our results indicated that NTFP use by local H'Mong people did not lead to tree species depletion.

Of rare and red-listed tree species, our results showed that most of these tree species were present in the core zone, and their numbers were significantly lower in the buffer zone. More specifically, *red-listed status* and *low density* (rarity) were significantly associated with the probability of tree absence in the buffer zone. In fact, a tree species may be rare because of many different reasons, such as small geographic range, narrow habitat tolerance, or small population size (Rabinowitz 1981). Demographic and environmental stochasticity coupled with anthropogenic disturbance can lead to population decline (Gaston 1998); this may partly explain why many rare tree species were present in the core zone but not in the buffer zone. Moreover, rare species often have restricted distributions. In the buffer zone, where anthropogenic disturbance happens with higher frequency, rare tree species are more likely to experience stressful conditions and this, coupled with the increased vulnerability due to low density, leads to reduce the number of rare tree species in such zone. Some rare tree species that have large diameters and/or provide valuable products become critically endangered when they coincidentally become targets of selective logging.

Consequently, a large number of rare tree species were not present in the buffer zone. On the other hand, there was a relatively high abundance of rare tree species in the core zone, and these species contributed significantly to the high level of species diversity in this area. This reflects a typical diversity status of tropical rainforests, in which diversity is due to a large proportion of rare species (Hubbell 2013). Our findings also support the conclusion that a strictly protected core conservation zone is valuable because it provides a refuge for rare and red-listed tree species.

4.5 Considerations for forest management and conservation

Timber use likely changed forest structure and species composition, whereas use of NTFPs by the local people in general raised less of concern. Red-listed status, large tree DBH, and rarity were strongly related to tree community depletion in the buffer zone. The use of logistic regression models allows evaluation of the conservation effectiveness in a given nature reserve over time and among other nature reserves and national parks, and also facilitates the development of conservation strategies by quantifying the effects of different forest management measures on the presence or absence of trees and species. Monitoring of forest resources with a focus on rare and red-listed species is needed to confirm whether the current forest status in the buffer zone is declining or stable, and thereby can be used to fine-tune forest use regulations.

Acknowledgements

This study was supported by the Vietnamese Government, the German Academic Exchange Service (DAAD), the Rufford Small Grants Foundation, and the International Tropical Timber

Organization; the publication was supported by an Open Access Grant Program of the German Research Foundation (DFG) and the Open Access Publication Funds of Göttingen University. We thank Nguyen Q.D., Luong V.P., Luong V.T., Dang V.L., Dao V.P., Nguyen M.T., Pham K.C., Vang A.S., Vang A.C. for their assistance during different phases of the fieldwork; two botanists, Phung V.P. and Phan V.D., for tree identification; Tran T.H. and Nguyen T.H. for their help in soil sample analysis; Professor Holger Kreft, Phan T.N., Le T.K., for their comments on our research; and the managers and local people in the Ta Xua Nature Reverse for helping us conduct this study.

Conflict of Interest: The authors declare no conflicts of interest.

4.6 References Chapter 4

Arnold, J.M, Pérez, M.R., 2001. Can non-timber forest products match tropical forest conservation and development objectives? Ecol. Econ. 39, 437–447. http://dx.doi.org/10.1016/S0921-8009(01)00236-1.

Asner, G.P., Broadbent, E.N., Oliveira, P.J., Keller, M., Knapp, D.E., Silva, J.N., 2006. Condition and fate of logged forests in the Brazilian Amazon. Proc. Natl. Acad. Sci. 103, 12947–12950. http://dx.doi.org/10.1073/pnas.0604093103.

Berry, N.J., Phillips, O.L., Lewis, S.L., Hill, J.K., Edwards, D.P., Tawatao, N.B., Ahmad, N., Magintan, D., Khen, C.V., Maryati, M., 2010. The high value of logged tropical forests: lessons from northern Borneo. Biodivers. Conserv. 19, 985–997. http://dx.doi.org/10.1007/s10531-010-9779-z.

Branch, T.A., Lobo, A.S., Purcell, S.W., 2013. Opportunistic exploitation: an overlooked pathway to extinction. Trends Ecol. Evol. 28, 409–413. http://dx.doi.org/10.1016/j.tree.2013.03.003.

Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.AB., 2001. Effectiveness of parks in protecting tropical biodiversity. Science 291, 125–128. http://dx.doi.org/10.1126/science.291.5501.125.

Cannon, C.H., Peart, D.R., Leighton, M., 1998. Tree species diversity in commercially logged Bornean rainforest. Science 281, 1366–1368. http://dx.doi.org/10.1126/science.281.5381.1366.

Chao, A., 1987. Estimating the population size for capture-recapture data with unequal catchability. Biometrics 783–791. http://dx.doi.org/10.2307/2531532.

Chape, S., Harrison, J., Spalding, M., Lysenko, I., 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philos. Trans. R. Soc. B 360, 443–455. http://dx.doi.org/10.1098/rstb.2004.1592.

Clark, J.A., Covey, K.R., 2012. Tree species richness and the logging of natural forests: A meta-analysis. For. Ecol. Manag. 276, 146–153. http://dx.doi.org/10.1016/j.foreco.2012.04.001.

Colwell, R.K., 2013. EstimateS, Version 9.10: Statistical estimation of species richness and shared species from samples. (Software and User's Guide). Freeware published at http://viceroy.eeb.uconn.edu/estimates.

Colwell, R.K., Chao, A., Gotelli, N.J., Lin, S.Y., Mao, C.X., Chazdon, R.L., 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. http://dx.doi.org/10.1093/jpe/rtr044.

Colwell, R.K., Mao, C.X., Chang, J., 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85, 2717–2727. http://dx.doi.org/10.1890/03-0557.

Daniels, R., Gadgil, M., Joshi, N., 1995. Impact of human extraction on tropical humid forests in the Western Ghats Uttara Kannada, South India. J. Appl. Ecol. 866–874. http://dx.doi.org/10.2307/2404826.

DeFries, R., Hansen, A., Newton, A.C., Hansen, M.C., 2005. Increasing isolation of protected areas in tropical forests over the past twenty years. Ecol. Appl. 15, 19–26. http://dx.doi.org/10.1890/03-5258.

Endress, B.A., Gorchov, D.L., Berry, E.J., 2006. Sustainability of a non-timber forest product: effects of alternative leaf harvest practices over 6 years on yield and demography of the palm Chamaedorea radicalis. For. Ecol. Manag. 234, 181–191. http://dx.doi.org/10.1016/j.foreco.2006.07.020.

Forest Inventory Planning Institute (FIPI), 2002. Project of conservation and development forest resources of Ta Xua Nature Reserve. Hanoi.

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. (Accessed 24 March 2014).

Gaston, K.J., 1998. Ecology: rarity as double jeopardy. Nature 394, 229–230. http://dx.doi.org/10.1038/28288.

Gaston, K.J., 1994. In: Rarity, Population and Community Biology Series, vol. 13, Springer, Falmouth, UK, Chapman and Hall.

Gee, G., Bauder, J., 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, 1004–1007. http://dx.doi.org/10.2136/sssaj1979.03615995004300050038x.

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., Lovejoy, T.E., 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. Nature 478, 378–381. http://dx.doi.org/10.1038/nature10425.

Hosmer, J.D.W., Lemeshow, S., Sturdivant, R.X., 2013. Applied Logistic Regression. John Wiley & Sons.

Hubbell, S.P., 2013. Tropical rain forest conservation and the twin challenges of diversity and rarity. Ecol. Evol. 3, 3263–3274. http://dx.doi.org/10.1002/ece3.705.

IUCN, 2014. The IUCN Red List of Threatened Species. Version 2014.3. http://www.iucnredlist.org. (Accessed 21 November 2014).

Joppa, L.N., Pfaff, A., 2010. Global protected area impacts. Proc. R. Soc. Lond. B Biol. Sci. http://dx.doi.org/10.1098/rspb.2010.1713 rspb20101713.

Jost, L., 2006. Entropy and diversity. Oikos 113, 363–375. http://dx.doi.org/10.1111/j.2006.0030-1299.14714.x.

Laurance, W.F., 1999. Reflections on the tropical deforestation crisis. Biol. Conserv. 91, 109–117. http://dx.doi.org/10.1016/S0006-3207(99)00088-9.

Law No.29/2004/QH11, 2004. Protection and Development of Forest, the National Assembly of the Socialist Republic of Vietnam.

McCune, B., Mefford, M.J., 2006. PC-ORD, Multivariate Analysis of Ecological Data, Version 5.12. MjM Software. Gleneden Beach, Oregon.

Messier, C., Puettmann, K., Chazdon, R., Andersson, K., Angers, V., Brotons, L., Filotas, E., Tittler, R., Parrott, L., Levin, S., 2015. From management to stewardship: viewing forests as complex adaptive systems in an uncertain world. Conserv. Lett. 8, 368–377. http://dx.doi.org/10.1111/conl.12156.

Mouillot, D., Bellwood, D.R., Baraloto, C., Chave, J., Galzin, R., Harmelin-Vivien, M., Kulbicki, M., Lavergne, S., Lavorel, S., Mouquet, N., 2013. Rare species support vulnerable functions in high-diversity ecosystems. PLoS Biol. 11, e1001569. http://dx.doi.org/10.1371/journal.pbio.1001569.

Muraleedharan, P., Sasidharan, N., Kumar, B., Sreenivasan, M., Seethalakshmi, K., 2005. Non-timber forest products in the Western Ghats of India: floristic attributes, extraction and regeneration. J. Trop. For. Sci. 243–257.

Ndangalasi, H.J., Bitariho, R., Dovie, D.B., 2007. Harvesting of non-timber forest products and implications for conservation in two montane forests of East Africa. Biol. Conserv. 134, 242–250. http://dx.doi.org/10.1016/j.biocon.2006.06.020.

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., Nguyen, N.T., 1996. Vietnam Forest Trees. Agricultural Publishing House, Ha Noi.

Nguyen, T.B., Tran, D.L., Nguyen, K.K., 2007. Vietnam Red List. Part II. Plants. Science and Techniques Publishing House, Ha Noi.

Osazuwa-Peters, O.L., Chapman, C.A., Zanne, A.E., 2015. Selective logging: does the imprint remain on tree structure and composition after 45 years? Conserv. Physiol. 3 (1), cov012. http://dx.doi.org/10.1093/conphys/cov012.

Pitman, N.C., Terborgh, J., Silman, M.R., Nuñez, V.P., 1999. Tree species distributions in an upper Amazonian forest. Ecology 80, 2651–2661. http://dx.doi.org/10.1890/0012-9658(1999)080[2651:TSDIAU]2.0.CO;2.

Putz, F.E., Zuidema, P.A., Synnott, T., Peña-Claros, M., Pinard, M.A., Sheil, D., Vanclay, J.K., Sist, P., Gourlet-Fleury, S., Griscom, B., 2012. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conserv. Lett. 5, 296–303. http://dx.doi.org/10.1111/j.1755-263X.2012.00242.x.

Rabinowitz, D., 1981. Seven forms of rarity. In: Synge, H. (Ed.), The Biological Aspects of Rare Plan Conservation, Wiley, New York.

Rosser, A.M., Mainka, S.A., 2002. Overexploitation and species extinctions. Conserv. Biol. 16 (3), 584–586.

RStudio Team, 2015. RStudio: Integrated Development Environment for R.RStudio, Inc., Boston, MA. URL http://www.rstudio.com/.

Slik, J.F., Keßler, P.J., van Welzen, P.C., 2003. Macaranga and Mallotus species (Euphorbiaceae) as indicators for disturbance in the mixed lowland dipterocarp forest of East Kalimantan (Indonesia). Ecol. Indic. 2, 311–324. http://dx.doi.org/10.1016/S1470-160X(02)00057-2.

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

Sodhi, N.S., Koh, L.P., Brook, B.W., Ng, P.K., 2004. Southeast Asian biodiversity: an impending disaster. Trends Ecol. Evol. 19, 654–660. http://dx.doi.org/10.1016/j.tree.2004.09.006.

Sodhi, N.S., Lee, T.M., Koh, L.P., Brook, B.W., 2009. A meta-analysis of the impact of anthropogenic forest disturbance on Southeast Asia's biotas. Biotropica 41, 103–109. http://dx.doi.org/10.1111/j.1744-7429.2008.00460.x.

StatSoft, Inc., 2014. STATISTICA (data analysis software system), version 12. www.statsoft.com.

Sterling, E.J., Hurley, M.M., 2005. Conserving biodiversity in Vietnam: Applying biogeography to conservation research. Proc. Calif. Acad. Sci. 56, 98–118.

ter Steege, H.T., Pitman, N.C.A., Sabatier, D., Baraloto, C., Salomão, R.P., Guevara, J.E., Phillips, O.L., Castilho, C.V., Magnusson, W.E., Molino, J.F., 2013.

Hyperdominance in the Amazonian tree flora. Science 342, 1243092. http://dx.doi.org/10.1126/science.1243092.

Ticktin, T., 2004. The ecological implications of harvesting non-timber forest products. J. Appl. Ecol. 41, 11–21. http://dx.doi.org/10.1111/j.1365-2664.2004.00859.x.

Tran, H., Nguyen, B.Q., 1993. Vietnam Economic Forest Trees. Agricultural Publishing House, Hanoi.

Tyukavina, A., Hansen, M., Potapov, P., Krylov, A., Goetz, S., 2016. Pan-tropical hinterland forests: mapping minimally disturbed forests. Glob. Ecol. Biogeogr. 25, 151–163. http://dx.doi.org/10.1111/geb.12394.

Walkley, A., 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.

4.7 Appendix Chapter 4

Appendix 4.1 Traditional uses of non-timber forest products (NTFPs). Tree species names, number of trees with DBH of at least 6 cm in the core zone (C.z) and buffer zone (B.z), utilization categories, and specific use of 120 NTFP species in the Ta Xua Nature Reserve (40 sample plots per zone). Utilization categories: 1, medicine; 2, food; 3, fiber; 4, fodder; 5, fish paralysis (coma); 6, incense. Detailed utilization is based on indigenous knowledge. Species correlated significantly with DCA axes (Fig. 4.5) are indicated in bold in the species code column

Scientific name	Species code	Vietnamese name	No. of trees		Utilization						Detailed utilization
			C.z	B.z	1	2	3	4	5	6	
Acer campbellii subsp. wilsonii (Rehder) P.C.DeJong	Ace.w	Thích 3 thùy	5	0		x					Fruits are edible.
Acronychia pedunculata (L.) Miq.	Acr.	Bưởi bung	8	0	x	x					Decoction of roots and leaves is used to treat colds, cough, indigestion, and rheumatism. Crushed leaves are used to treat swelling pain. The water of boiled leaves is used to treat flu and pimples. Fruits are edible and used to treat anorexia and flatulence.
Actinodaphne cochinchinensis Meisn	Act.c	Mò vối thuốc	1	2	x						Decoction of leaves is used to treat measles, dysentery, abdominal pain, and rheumatism. Crushed bark and leaves are used to treat scabies, injuries, and swelling pain.
Aglaia odorata Lour.	Agla.	Gội ngâu	7	0	x	x					Roots are used to induce vomiting. Leaves are used to treat scabies. Scented flowers are used to preserve tea.
Aidia pycnantha (Drake) Tirveng	**Aid.**	Mãi táp lông	6	2	x						Medicine
Alangium chinense (Lour.) Harms	Ala.c	Thôi ba	2	1	x			x			Roots are used to treat rheumatism. The liquid of chewed leaves and the paste residue is used to treat snakebite. Root bark is used to treat bone pain, joint pain, and swelling pain. Fruits are combined with other species to treat kidney disease.

											Leaves are used as food for animals.
Allospondias lakonensis (Pierre) Stapf	**Allo.**	Dâu da xoan	4	4	x	x					Bark is used to treat cough. Crushed leaves are used to treat pain and swollen knees. Seeds are used to treat indigestion. Fruits are edible and have a sour and sweet taste.
Altingia siamensis Craib	**Alt.**	Tô hạp điện biên	17	91						x	Resin is used to make incense.
Antidesma ghaesembilla Gaertn.	Ant.g	Chòi mòi	1	0	x	x					Flowers are used to treat rheumatism. Bark is used to treat diarrhea. Crushed leaves are used to treat headaches and pimples. A decoction of branches is used to treat irregular menstruation. Fruits are edible,have a sour taste, and are used to treat cough and pneumonia.
Aphanamixis polystachya (Wall.) R.Parker	**Aph.**	Gội trắng	1	9	x						Decoction of bark is used to treat the spleen, liver disease, tumors, and abdominal pain. Seed oil is used as an ointment during massage for rheumatism.
Archidendron clypearia (Jack) I.C.Nielsen	Arc.c	Mán đỉa	0	2	x						Water of boiled leaves is used to treat scabies.
Archidendron lucidum (Benth.) I.C.Nielsen	Arc.l	Mán đỉa trâu	1	5	x						Branches and leaves are used to treat emphysema and rheumatism.
Artocarpus tonkinensis A.Chev. ex Gagnep.	Art.	Chay rừng	0	1	x	x					Fruits are used to treat lung disease, bleeding cough, nose-bleeding, sore throat, stomach ache, and anorexia. Roots are used to treat arthritis, back pain, menorrhagia, and to strengthen teeth. Root bark and the sour and sweet fruits are edible.
Betula alnoides Buch.-Ham. ex D.Don	**Betu.a**	Cáng lò	1	4	x						Bark and leaves are used to treat venomous snake bites. Bark is used to treat common colds, stomach ache, dysentery, and rheumatism.
Bischofia javanica Blume	Bis.	Nhội	1	0	x	x					Shoots and young leaves are used to treat diarrhea, pimples, itches, and vaginitis. The water of boiled shoots and young leaves is used to treat toothache, gingivitis, and sore throat. Fruits, shoots, and young leaves are edible.

Camellia chrysantha (Hu) Tuyama	Came.ch	Chè hoa vàng	2	0	x	x		Leaves are used to make tea and treat dysentery.
Camellia sinensis (L.) Kuntze	**Came.si**	Chè rừng	4	15	x	x		Leaves are used to make tea and treat indigestion.
Canarium pimela K.D.Koenig	Canar.	Trám đen	0	1	x	x		Fruits are edible, have a fleshy and buttery taste, and are used to treat for detoxification alcohol, eating toxic fishes and larynx disease. Fruits and seeds are used to treat dental caries. Roots are used to treat rheumatism and backache. Leaves are used to treat flu, upper respiratory infection, pneumonia, and scabies.
Carallia brachiata (Lour.) Merr.	**Cara.b**	Trúc tiết	11	8	x	x		Bark is used to treat scabies, spreading ulcers, mouth ulcers, and sore throat. Fruits are edible.
Castanopsis chinensis (Spreng.) Hance	Cast.c	Dẻ gai trung quốc	1	1		x		Nuts are rich in starch and edible.
Castanopsis indica (Roxb. ex Lindl.) A.DC.	**Cast.i**	Dẻ gai ấn độ	18	20		x		Nuts are rich in starch and edible.
Castanopsis lecomtei Hickel & A.Camus	Ca.lec	Cà ổi sapa	3	0		x		Nuts are rich in starch and edible.
Castanopsis purpurella (Miq.) N.P.Balakr.	Ca.pur	Dẻ gai đỏ	3	0		x		Nuts are rich in starch, edible, and used to make distilled alcohol.
Castanopsis sp2.	**Cast.sp2**	Dẻ gai	0	15		x		Nuts are edible.
Castanopsis sp3.	Cast.sp3	Dẻ gai lá nhỏ	1	0		x		Nuts are edible.
Castanopsis tonkinensis Seemen	**Cast.to**	Dẻ gai bắc bộ	35	17		x		Nuts are edible.
Castanopsis tribuloides (Sm.) A.DC.	**Cast.tr**	Dẻ sp	1	10		x		Nuts are edible.
Choerospondias axillaris (Roxb.) B.L.Burtt & A.W.Hill	Choe.	Xoan nhừ	8	9	x	x	x	Fruits are used to treat weak/damaged spleen, indigestion, and hemorrhagic injuries. Bark and root bark are used to treat burns and pimples. Roots and leaves are used to treat indigestion. Fruits are edible, havea sour and sweet taste, and are used to make wine. Fiber from bark is used to braidropes.
Cinnamomum balansae Lecomte	Cinnamo.	Vù hương	0	1	x			Oil from leaves, bark, trunk, and roots are used to treat flu,

									indigestion, cough, and rheumatism.
Cinnamomum bejolghota (Buch.-Ham.) Sweet	**Cin.b**	Re bầu	3	14	x				Bark, branches, leaves, and roots contain aromatic oils. Bark is used to treat flatulence and liver damage. Bark and leaves are used to treat hemorrhagic injuries, bone fractures, and snake bites.
Cinnamomum curvifolium (Lam.) Nees	**Cin.c**	Re lá cong	4	0	x				Bark is used to treat palpitation.
Cinnamomum iners Reinw. ex Blume	Cin.i	Re hương	16	12	x				Oil from bark and leaves is used for massages in treating rheumatism.
Cinnamomum tonkinense (Lecomte) A.Chev.	**Cin.t**	Re xanh	0	3	x				Shoots are used to treat kidney disease, back pain, flu, and bone pain.
Cipadessa baccifera (Roth) Miq.	**Cip.**	Cà muối	0	4	x				Decoction of leaves is used to treat rheumatism and in baths for treating scabies
Cleistanthusmonoicus (Lour.) Müll.Arg	Clei.	Đỏm trơn	1	2	x	x			Root bark and leaves are used to treat bone pain and rheumatism. Fruit is edible and cleans the tongue.
Commersonia bartramia (L.) Merr.	Com.	Hu đen	0	2			x		Bark provides fiber for knitting mats.
Croton poilanei Gagnep	**Crot.**	Bã đậu lá dài	100	107	x		x		Bark is used to treat eye diseases and orally for treating abdominal pain. Leaves are used to treat allergies. Fiber from the bark is used for weaving and making braided ropes.
Eberhardtia tonkinensis Lecomte	**Eber.**	Mắc niễng	72	22		x			Seeds are edible.
Elaeocarpus grandiflorus Sm.	Ela.g	Côm đắng	1	0		x			Fruits are edible.
Endospermum chinense Benth.	Endo.	Vạng trứng	2	0	x				Leaves are used to treat bone fractures, injuries, arthritis, joint pain, back pain, and paralysis of arms and legs.
Ficus fistulosa Reinw. ex Blume	Fi.fi	Sung rừng	6	7		x			Fruits are edible.
Ficus glandulifera (Wall. ex Miq.) King	**Fi.gla**	Vỏ mản	4	63			x		Bark provides fiber.
Ficus heterophylla L.f.	**Fi.he**	Vú bò	0	11		x		x	Fruits are edible. Leaves are used as a food for cattle.

Ficus hirta Vahl	Fi.hi	Ngõa lông	0	8	x			Resin is used to treat flatulence and constipation. Leaves and fruits are used to treat bruises.
Fokienia hodginsii (Dunn) A.Henry & H H.Thomas	Fokie.	Pơ mu	11	4			x	Oil is used for making incense
Garcinia cowa Roxb. ex Choisy	Gar.c	Tai chua	1	0	x	x		Seeds are used as an anti-emetic. Resin and leaves are used as an antiseptic. Fruits are edible, have a sour taste, and are used to treat fever.
Garcinia multiflora Champ. ex Benth.	Gar.m	Dọc	2	0	x	x		Seed oil is used to treat pimples. Bark and fruits are used to treat emphysema and are astringent and analgesic. Young leaves and fruits are edible.
Garcinia oblongifolia Champ. ex Benth.	Gar.ob	Bứa lá thuôn	2	1	x	x		Decoction of bark is used to treat stomach ache, indigestion, gastroenteritis, gingivitis, and cough-bleeding. Crushed bark is used to treat burns, pimples, eczema, allergy, and removal of bullets from the body. Resin is used to treat burns. Young leaves and fruits are edible.
Garcinia oliveri Pierre	Gar.o	Bứa lá dày	1	0	x	x		Combination of fruits with other species *(Garcinia villersiana)* is used to treat sprains. Fruit is edible and has a sour taste.
Garcinia xanthochymus Hook.f. ex T.Anderson	**Gar.t**	Nụ	2	5	x			Leaves are used to treat edema, flatulence, and abdominal pain.
Gmelina arborea Roxb.	Gme.	Lõi thọ	3	0	x			Juice of leaves is used to treat gonorrhea, cough, and ulcers. Branches are used to treat snake bites and scorpion stings. A decoction of roots is used to treat indigestion, fever, and edema.
Goniothalamus macrocalyx Bân	Gon.	Màu cau trắng	1	0	x			Bark, fruits, and leaves are used to make a tea for anti-cancer treatment.
Helicia robusta (Roxb.) R.Br. ex Blume	Hel.r	Mạ sưa răng cưa	2	0	x			Leaves, bark, branches, roots, and fruits are used as a poultice.
Heliciopsis lobata (Merr.) Sleumer	Heli.l	Răng cưa	0	3	x			Leaves, branches, and bark are used to treat rheumatism and in preparing a water bath for women after childbirth to provide refreshment and analgesia.

Heteropanax fragrans (Roxb.) Seem.	Hete.	Đại khải	0	2	x		Root bark and roots are used for detoxification, to treat emphysema, and to provide analgesia and hemostatic effects. Branches are used to treat burns, sunstroke, headache, rheumatism, arthritis, hemorrhages, and snake bites.
Hydnocarpus anthelminthica Pierre ex Gagnep.	Hyd.a	Đại phong tử	3	5	x		In combination with other species is used to treat ulcers due to leprosy and some skin diseases.
Ilex cymosa Blume	**Ilex.c**	Nhựa ruồi	7	10	x		Roots are used to prevent fever. Leaves are used to treat sprains.
Ilex rotunda Thunb.	**Ilex.**	Vỏ rụt	4		x		Leaves and bark are used to treat flu, tonsillitis, sore throat, gastroenteritis, rheumatism, and dengue fever. Crushed leaves and bark are used to treat bruises, burns, pimples, and hemorrhagic injuries.
Juglans regia L.	**Jug.**	Óc chó	0	4	x	x	Seeds are edible and used to treat kidney disease, back pain, wounds, and asthma. Leaves are used to treat tuberculosis and skin diseases.
Kibatalia laurifolia (Ridl.) Woodson	Kib.	Ớt sừng	0	3	x		Root, trunk, and leaves are used as diuretics and to provide hemostasis.
Knema conferta (King) Warb.	**Kne.c**	Máu chó lá bé	1	2	x		Seeds are used to treat scabies and skin diseases.
Lithocarpus vestitus (Hickel & A.Camus) A.Camus	**Lit.v**	Sồi lông nhung	3	0		x	Fruits are edible.
Litsea balansae Lecomte	**Lits.ba**	Mò roi	4	18	x		Oil is used to treat common colds.
Litsea cubeba (Lour.) Pers.	**Lits.c**	Màng tang	2	81	x	x	Roots are used to treat headache, stomach ache, rheumatism, bruises, irregular menses, and flatulence. Fruits are used to treat indigestion and stomach ache. Leaves are used to treat pimples, mastitis, and snake bites. Young leaves are edible.
Litsea rotundifolia Hemsl.	Lits.r	Bời lời lá tròn	2	0	x		Oil, leaves, and roots are used to treat arthritis, injuries, back pain, dysmenorrhea, digestive problems, flatulence, headache, and colds

Litsea sp1.	**Lits.s**	Bời lời xanh	4	4	x			Crushed bark and leaves are used as a poultice to treat swelling, burns, and wounds. A decoction of bark is used to treat diarrhea and dysentery.
Litsea umbellata (Lour.) Merr.	Lits.u	Mò lông	1	1	x			Boiled leaves are used to treat bruises and pimples.
Macaranga denticulata (Blume) Müll.Arg.	**Maca.**	Lá nến	3	34	x		x	Boiled leaves are given to women after childbirth to provide refreshment. Leaves are used to treat pimples. Bark has fiber.
Machilus bonii Lecomte	**Mac.b**	Kháo vàng	10	0	x			Bark is used to treat burns and toothaches.
Machilus thunbergii Siebold & Zucc.	**Mac.t**	Re vòng	9	0	x			Bark is used to treat stretched ligaments' and emphysema.
Machilus velutina Champ. ex Benth.	Mac.v	Kháo lông	5	4	x			Bark and oil are used to treat common colds.
Macropanax undulatus (Wall. ex G.Don) Seem.	**Mac.u**	Đại đinh dúng	14	14	x			Bark is used to treat diabetes, edema, rheumatism, and indigestion.
Madhuca pasquieri (Dubard) H.J.Lam	**Mad.**	Sến mật	35	2	x	x		Seeds are edible and used to treat rheumatism and cardiac diseases.
Magnolia baillonii Pierre	Ma.bai	Giổi găng	1	0	x			Bitter bark is used as an antipyretic.
Magnolia balansae A.DC.	**Ma.bala**	Giổi lông	1	2		x		Seeds are used as spices.
Magnolia braianensis (Gagnep.) Figlar	Ma.bra	Giổi nhung	1	0	x			Seeds and bark are used to treat colic and fever.
Magnolia coco (Lour.) DC.	Mag.c	Hoa trứng gà	1	0	x	x		Scented flowers are used to preserve teas. Other parts of the tree are used to treat rheumatism. Women are given boiled leaves to promote recovery after childbirth.
Magnolia mediocris (Dandy) Figlar	**Mag.m**	Giổi xanh	3	0	x	x		Seeds are used as spices. Seeds and bark are used to treat colic and fever.
Mallotus metcalfianus Croizat	Mal.	Ba bét đỏ	0	1			x	Bark has fiber.
Mallotus paniculatus (Lam.) Müll.Arg.	**Mal.pa**	Ba soi	5	45	x		x	Roots and fruits are used to treat swelling and bruises. Fiber from the bark is used for braiding ropes.

Mallotus philippensis (Lam.) Müll.Arg.	**Mal.ph**	Cánh kiến	3	1	x			Roots are used to treat dysentery and sore throat. Bark is used to treat epilepsy and diarrhea. Hairs from the fruit are used to kill tapeworms, treat edema, syphilis, skin diseases, and as a contraceptive.
Mangifera minutifolia Evrard	**Mang.m**	Xoan rừng	4	5		x		Young leaves and fruits are edible.
Manglietia fordiana (Oliv.) Hu	**Mang.f**	Vàng tâm	25	9	x			Fruits, bark, and root bark are used to treat constipation and dry cough.
Melia azedarach L.	Meli.	Xoan quả to	1	0	x			Fruits are used to treat stomach ache, abdominal pain due to flatulence and tapeworms, hepatitis, dysmenorrhea, cardiac diseases, and fever. Bark is used to treat scabies and itches.
Neocinnamomum lecomtei H. Liu	**Neo.l**	Re mới	4	0	x			Bark is used to treat stomach ache.
Neolitsea zeylanica (Nees & T. Nees) Merr.	**Neo.z**	Kháo lá dài	16	7	x		x	Roots are used to treat pimples on the fingers. Crushed mature leaves and bark are used to make incense.
Nephelium cuspidatum Blume	**Nep.c**	Vải thiều rừng	17	7		x		Fruits are edible and have a sour and sweet taste.
Nephelium lappaceum L.	**Nep.l**	Vải rừng	10	5	x	x		Young fruit and fruit rind are used to treat diarrhea, dysentery, fever, malaria, and kill tapeworms. Fruits are edible.
Paulownia fortunei (Seem.) Hemsl.	**Pau.**	Hông	0	2	x			Roots are used to treat rheumatism.Root bark is used to treat sore muscles. Bark is used to treat bruises. Flowers and leaves are used to treat poisoning, boils, burns, and swelling. Fruits are used to treat bronchitis.
Persea odoratissima (Nees) Kosterm.	**Perse.**	Rè vàng	7	3			x	Bark is used to make incense.
Podocarpus neriifolius D.Don	Pod.	Thông tre lá dài	1	0	x	x		Bark and a decoction of leaves are used to treat arthritis and joint pain. Seeds are edible and have a fragrant flavor.
Polyalthia cerasoides (Roxb.) Bedd.	Poly.c	Nhọc lá nhỏ	1	0	x			Consumption of the water of boiled roots is used to treat hives.
Prunus arborea (Blume) Kalkman	**Prun.a**	Xoan đào	4	25	x			Bathing in the water of boiled leaves is used to treatscabies.

Pterospermum heterophyllum Hance	**Pte.h**	Lòng mang	0	3	x					Roots are used to treat rheumatism, back pain, hemiplegia, swollen wounds, and fatigue after childbirth.
Pterygota alata (Roxb.) R.Br.	**Pter.a**	Sảng cánh	1	2	x		x			The mucus of seeds is soaked and used as an anesthetic, and to promote sleep. Bark has fiber.
Quercus platycalyx Hickel & A.Camus	Que.p	Dẻ cau	7	7		x				Fruits are edible.
Rhamnoneuron balansae (Drake) Gilg	Rham.	Gió dấy	1	0	x		x			Leaves, bark, and branches are used to treat malaria and cough. Bark has fiber.
Rhus chinensis Mill.	**Rhus.c**	Muối	1	2	x	x				Roots, leaves and fruits are used to treat flu, bee stings, skin rashes, itches, snake bites, and pimples. Fruits are edible.
Schefflera heptaphylla (L.) Frodin	**Schef.h**	Chân chim tám lá	3	20	x	x				Bark, roots, and leaves are used to treat back pain, tendonitis, and swelling. Young leaves are used as a vegetable.
Schima superba Gardner & Champ.	Schima.	Vối thuốc lông	10	0					X	Crushed bark is used for fish paralyzed (coma), and sometimes combined with *Derris elliptica* to increase efficacy.
Sterculia lanceolata Cav.	Ster.l	Sảng nhung	2	0	x	x				Bark is used to treat swelling and pimples. Leaves are used to treat bruises. Seeds are edible.
Streblus asper Lour.	Streb.	Ruối rừng	0	1	x	x	x	x		Leaves are used to treat hemorrhage and dysentery. Crushed young leaves are used to treat bleeding wounds. Resin is used to treat headache. Bark is used to treat tooth decay, colic, fever, diarrhea, cough, bone fractures, and dog bites. A decoction of branches and roots is used to treat diabetes and urinary retention. Fruits are edible and have a fragrant and sweet taste. Fiber from bark is used to weave bags. Leaves are used as a food for cattle.
Styrax tonkinensis Craib ex Hartwich	**Styr.t**	Bồ đề	2	63	x					The stem is incised to harvest resin that is used to treat cough, colic, and provide sedation.
Symplocos cochinchinensis (Lour.) S. Moore	Sym.c	Dung nam bộ	4	1	x					Shoots are used to treat burns. Bark is used to treat fever, dysentery, diarrhea, and common colds.
Syzygium chloranthum (Duthie) Merr. & L.M.Perry	Syz.c	Roi rừng	3	0		x				Fruits are edible.

Syzygium hancei Merr. & L.M.Perry	Syz.h	Trâm vỏ dày	1	0	x				Bark is used as an antiseptic to treat dysentery and diarrhea, and to eliminate helminthes.
Syzygium polyanthum (Wight) Walp.	Syz.p	Sắn thuyền	1	0	x	x			Crushed leaves are used to treat suppurating wounds, burns, infectious wounds, bone fractures, and skin necrosis. Bark is used to treat dysentery. Young leaves are edible.
Syzygium zeylanicum (L.) DC.	**Syz.z**	Trâm tía	14	4	x	x			Bark, leaves, and roots are used to treat rheumatism and syphilis. Fruits are edible and have a good flavor.
Tarenna attenuata (Voigt) Hutch.	**Tare.**	Cà phê rừng	0	30	x				Crushed roots are used to treat wounds in children. Other parts of the tree are used to treat arthritis, bruises, and bone fractures.
Tetradium glabrifolium (Champ. ex Benth.) T.G. Hartley	Tetra.	Thôi chanh tía	3	7	x				Root bark is used to treat rheumatism. Leaves are used to treat snake bites.
Trema orientalis (L.) Blume	**Trema.**	Hu đay	0	16	x	x	x	x	Roots and leaves are used to treat hemorrhagic injuries. Shoots and young leaves are consumed as vegetables. Bark provides fiber. Leaves are use as food for cattle.
Triadica cochinchinensis Lour.	Tria.c	Sồi tía	3	2	x				Roots and leaves are used to treat snake bites, constipation, and abscesses.
Trivalvaria costata (Hook.f. & Thomson) I.M.Turner	**Triv.c**	Nhọc lá bóng	38	10	x				Roots are used to treat gastritis, spleen diseases, and indigestion.
Vernicia montana Lour.	**Ver.m**	Trẩu	3	2	x	x			Bark is used to treat toothache and tooth decay. Seeds are used to treat pimples and impetigo. Oil seed is edible.
Wendlandia glabrata DC.	Wen.g	Hoắc quang trắng	2	0	x				Bark is used to treat arthritis, fatigue after childbirth, indigestion, and diabetes.
Wrightia pubescens R.Br.	Wrig.p	Thừng mực lông	1	0	x				Roots, bark, and leaves are used to treat tuberculosis, rheumatism, back pain, itches, pimples, and bronchitis.
Xanthophyllum hainanense Hu	Xan.h	Chanh rừng	2	2		x			Leaves are edible. Branches are used to make energy drinks.
Xylopia vielana Pierre	**Xil.v**	Dền	2	4	x	x			Bark is used as a blood tonic for women after childbirth, and to

								treat depression, asthenia, malaria, and irregular menstruation. Leaves are used to treat indigestion and rheumatism. Fruits are edible.
Zanthoxylum armatum DC.	**Zan.**	Hồi gai	0	2	x			Roots, branches, fruits, seeds, bark, and leaves are used to treat toothache, stomach ache, digestive disorders, helminth infections, flu, headache, cough, asthma, rheumatism, snake bites, and skin diseases.
Zanthoxylum myriacanthum Wall. ex Hook. f.	**Zan.m**	Mắc khén	1	5	x	x		Roots and leaves are used to treat rheumatism, bleeding injuries, bone fractures, pimples, itches, and burns. Fruits are used as a spice.

Appendix 4.2 Valuable timber species. Tree species names, number of trees with DBH of at least 6 cm in the core zone (C.z) and buffer zone (B.z), and wood characteristics of the 54 valuable timber species in the Ta Xua Nature Reserve (40 plots per zone)

Scientific name	Vietnamese name	No. of trees		Tree size and wood characteristics[a]
		C.z	B.z	
Acer laurinum Hassk.	Thích 10 nhị	6	14	A large tree. Wood is hard, straight, fine-textured and easy to work.
Acer oblongum Wall. ex DC.	Thích lá nguyên	10	9	A large tree. Wood is of good qualityand used in construction.
Aglaia spectabilis (Miq.) S.S.Jain & S.Bennet	Gội nếp	12	1	A large tree. Wood is hard, durable and easy to work.
**Aphanamixis polystachya* (Wall.) R.Parker	Gội trắng	1	9	A large tree. Wood is fine-textured and durable.
**Betula alnoides* Buch.-Ham. ex D.Don	Cáng lò	1	4	A large tree. Wood is hard.
**Bischofia javanica* Blume	Nhội	1	0	A large tree. Wood is heavy, durable and easy to work.
**Canarium pimela* K.D.Koenig	Trám đen	0	1	A medium to large sized tree. Wood is soft, light and quite good quality.
Castanopsis cerebrina (Hickel &A.Camus) Barnett	Sồi phảng	4	13	A large tree. Wood is hard and of good quality.
Castanopsis echinocarpa Miq.	Dẻ gai thô	14	6	A large tree. Wood is hard, smooth-textured, easy to work, and resistant to rot.
**Castanopsis hystrix* Hook. f. & Thomson ex A. DC.	Dẻ gai đỏ	3	0	A large tree. Wood is coarse-textured, easy to work and resistant to rot.
**Castanopsis indica* (Roxb. ex Lindl.) A.DC.	Dẻ gai ấn độ	18	20	A large tree. Wood is hard, good quality and resistant to termites and insects.
**Castanopsis lecomtei* Hickel & A.Camus	Cà ổi sapa	3	0	A medium sized tree. Wood is used for many purposes.
Castanopsis tessellata Hickel & A. Camus	Cà ổi lá đa	2	0	A large tree. Wood is hard, fine-textured, straight and durable.
**Castanopsis tonkinensis* Seemen	Dẻ gai bắc bộ	35	17	A medium to large sized tree. Wood is white. The sapwood is used for construction.
Chaetocarpus castanocarpus (Roxb.) Thwaites	Da nâu	0	2	A large tree. Wood is fine, white and hard.

**Choerospondias axillaris* (Roxb.) B.L.Burtt & A.W.Hill	Xoan nhừ	8	9	A medium sized tree. Wood is fine-textured, easy to work.
Cinnadenia paniculata (Hook. f.) Kosterm	Kháo xanh	12	0	A medium to large sized tree. Wood is hard, heavy, durable and easy to work.
**Cinnamomum balansae* Lecomte	Vù hương	0	1	A large tree. Wood is heavy, durable and easy to work.
**Cinnamomum curvifolium* (Lam.) Nees	Re lá cong	4	0	A medium sized tree. Wood is straight and fine structure.
**Cinnamomum iners* Reinw. ex Blume	Re hương	16	12	A medium sized tree. Wood is of good quality, straight and has a good smell.
Dacrycarpus imbricatus (Blume) de Laub.	Thông nàng	2	2	A large tree. Wood is light, straight, fine, and easy to work.
**Fokienia hodginsii* (Dunn) A.Henry & H H.Thomas	Pơ mu	11	4	A large tree. Wood is light, fine, durable and aromatic
**Gmelina arborea* Roxb.	Lõi thọ	3	0	A large tree. Wood rarely splits or warps, easy to work and resistant to termites.
**Ilex rotunda* Thunb.	Vỏ rụt	4	0	A medium to large sized tree. Wood is slightly soft, heavy and easy to work.
**Juglans regia* L.	Óc chó	0	4	A large tree. Wood is straight, rarely splits.
Lithocarpus ducampii (Hickel & A.Camus) A.Camus	Dẻ đỏ	3	11	A large tree. Wood is pinkish, hard, fine veins and valuable.
**Lithocarpus vestitus* (Hickel & A.Camus) A.Camus	Sồi lông nhung	3	0	A medium to large sized tree. Wood is hard, heavy, rough-textured and rot resistant.
**Machilus bonii* Lecomte	Kháo vàng	10		A medium to large sized tree. Wood is soft and straight.
**Madhuca pasquieri* (Dubard) H.J.Lam	Sến mật	35	2	A large tree. Wood is hard, heavy, durable and very good quality.
**Magnolia baillonii* Pierre	Giổi găng	1	0	A large tree. Wood is hard, fine-textured, durable and valuable.
**Magnolia balansae* A.DC.	Giổi lông	1	2	A medium sized tree. Wood is fine-textured, rarely splits or warps, resistant to termites and insects.
**Magnolia braianensis* (Gagnep.) Figlar	Giổi nhung	1	0	A large tree. Wood is straight, fine-textured, durable, resistant to termites
**Magnolia mediocris* (Dandy) Figlar	Giổi xanh	3	0	A large tree. Wood is hard, fine-textured, easy to work, and resistant to termites.
Magnolia sumatrana var. glauca (Blume) Figlar &Noot.	Mỡ	0	7	A large tree. Wood is soft, straight, durable and easy to work.

Magnolia foveolata (Merr. ex Dandy) Figlar	Giổi lá bạc	11	1	A large tree. Wood is hard, fine and durable.
**Manglietia fordiana* (Oliv.) Hu	Vàng tâm	25	9	A medium to large sized tree. Wood is fine-textured, aromatic and resistant to termites and insects.
**Melia azedarach* L.	Xoan quả to	1	0	A medium to large sized tree. Wood is soft, easy to work and resistant to termites.
Mischocarpus pentapetalus (Roxb.) Radlk.	Trường kẹn	4	4	A large tree. Wood is straight, heavy, fine and durable.
**Nephelium cuspidatum* Blume	Vải thiều rừng	17	7	A medium sized tree. Wood is hard, fine-textured and durable.
**Paulownia fortunei* (Seem.) Hemsl.	Hông	0	2	A medium to large sized tree. Wood is fine-textured, light, and soft, does not split and is a good insulator.
Pavieasia anamensis (Pierre) Pierre	Trường mật	0	2	A large tree. Wood is heavy, straight, fine-textured and durable.
**Persea odoratissima* (Nees) Kosterm.	Rè vàng	7	3	A medium to large sized tree. Wood is hard, durable, easy to work and resistant to termites
Phoebe macrocarpa C.Y.Wu	Kháo lá to	9	1	A medium sized tree. Wood is white, hard and fine.
**Podocarpus neriifolius* D.Don	Thông tre lá dài	1	0	A medium to large sized tree. Wood is straight, fine-textured, and easy to work.
**Pterygota alata* (Roxb.) R.Br.	Sảng cánh	1	2	A large tree. Wood is smooth-textured, easy to work, and durable.
Quercus acutissima Carruth.	Sồi nhọn	1	0	A medium sized tree. Wood is of good quality and moderately valuable.
**Quercus platycalyx* Hickel & A.Camus	Dẻ cau	7	7	A medium sized tree. Wood is hard and straight, used in construction.
Quercus chevalieri Hickel & A.Camus	Sồi Sapa		10	A large tree. Wood is of quite good quality and used for many purposes.
**Schima superba* Gardner & Champ.	Vối thuốc lông	10	0	A large tree. Wood is fine-textured, easy to work, and resistant to termites.
**Syzygium hancei* Merr. & L.M.Perry	Trâm vỏ dày	1	0	A medium sized tree. Wood is hard, heavy and resistant to termites.
Syzygium levinei (Merr.) Merr.	Trâm	3	0	A medium sized tree. Wood is smooth, hard and durable.
**Syzygium zeylanicum* (L.) DC.	Trâm tía	14	4	A medium sized tree. Wood is hard, fine-textured and durable.

Tapiscia sinensis Oliv	Trương hôi	1	0	A large tree. Wood is of good qualityand used in construction.
[*]*Tetradium glabrifolium* (Champ. ex Benth.) T.G. Hartley	Thôi chanh tía	3	7	A medium sized tree. Wood is light and resistant to termites and insects.

[a] Based on standard textbooks (Tran and Nguyen 1993; Nguyen et al. 1996)
[*]Species are multiple-use

Appendix 4.3 Rare tree species. Tree species names, number of trees with DBH of at least 6 cm in the core zone and/or buffer zone of 79 rare species in the Ta Xua Nature Reserve (40 plots per zone).

Scientific name	Vietnamese name	No. of trees	
		Core zone	Buffer zone
Species are rare in the core zone and buffer zone			
Castanopsis chinensis (Spreng.) Hance	Dẻ gai trung quốc	1	1
Glochidion zeylanicum (Gaertn.) A.Juss.	Áng nước	1	1
Litsea umbellata (Lour.) Merr.	Mò lông	1	1
Species are rare and only found in the core zone			
Acer tonkinense Lecomte	Thích lá to	1	0
Antidesma ghaesembilla Gaertn.	Chòi mòi	1	0
Antidesma velutinum Tul.	Chòi mòi lông	1	0
Ardisia sp.	Trọng đũa lá nhỏ	1	0
Bischofia javanica Blume	Nhội	1	0
Camellia crassiphylla Ninh & Hakoda	Chè lá dày	1	0
Camellia forrestii (Diels) Cohen-Stuart	Chè	1	0
Camellia sp	Chè sp	1	0
Carallia brachiata (Lour.) Merr.	Răng cá	1	0
Castanopsis sp3.	Dẻ gai lá nhỏ	1	0
Cinnamomum glaucescens (Nees) Hand.-Mazz.	Re chum	1	0
Elaeocarpus grandiflorus Sm.	Côm đắng	1	0
Flacourtia indica (Burm.f.) Merr.	Mùng quân	1	0
Garcinia cowa Roxb. ex Choisy	Tai chua	1	0
Garcinia oliveri Pierre	Bứa lá dày	1	0
Goniothalamus macrocalyx Bân	Màu cau trắng	1	0
Knema furfuracea (Hook. f. & Thomson) Warb	Máu chó lá lớn	1	0
Litsea baviensis Lecomte	Bời lời Ba vì	1	0
Machilus parviflora Meisn.	Kháo hoa thưa	1	0
Machilus sp	Kháo lá bạc	1	0
Magnolia coco (Lour.) DC.	Hoa trứng gà	1	0
Melia azedarach L.	Xoan quả to	1	0
Magnolia baillonii Pierre	Giổi găng	1	0
Magnolia braianensis (Gagnep.) Figlar	Giổi nhung	1	0
Podocarpus neriifolius D.Don	Thông tre lá dài	1	0
Polyalthia cerasoides (Roxb.) Bedd.	Nhọc lá nhỏ	1	0
Prunus zippeliana Miq.	Da bò	1	0
Pterospermum acerifolium (L.) Willd.	Lòng mang thường	1	0
Rhamnoneuron balansae (Drake) Gilg	Gió dấy	1	0
Sp1	Dâu núi	1	0
Syzygium balsameum (Wight) Wall. ex Walp.	Trâm hôi	1	0
Syzygium glaucum (King) Chantaran. & J.Parn.	Trâm đỏ	1	0
Syzygium hancei Merr. & L.M.Perry	Trâm vỏ dày	1	0
Syzygium polyanthum (Wight) Walp.	Sắn thuyền	1	0

Syzygium sterrophyllum Merr. & L.M.Perry	Trâm sắng	1	0
Tapiscia sinensis Oliv.	Trường hôi	1	0
Wrightia pubescens R.Br.	Thừng mực lông	1	0
Species are rare and only found in the buffer zone			
Artocarpus tonkinensis A.Chev. ex Gagnep.	Chay rừng	0	1
Canarium pimela K.D.Koenig	Trám đen	0	1
Cinnamomum balansae Lecomte	Vù hương	0	1
Cleistanthus oblongifolius (Roxb.) Müll.Arg.	Cọc rào	0	1
Mallotus metcalfianus Croizat	Ba bét đỏ	0	1
Pavetta graciliflora Wall. ex Ridl.	Xương gà	0	1
Phyllanthus elegans Wall. ex Müll.Arg.	Ngót rừng	0	1
Sterculia sp.	Chôm sp	0	1
Streblus asper Lour.	Ruối rừng	0	1
Wendlandia sp1.	Hoắc quang tía	0	1
Wrightia laevis Hook.f.	Thừng mực mỡ	0	1
Species are rare in the core zone but not rare in the buffer zone			
Actinodaphne cochinchinensis Meisn.	Mò vối thuốc	1	2
Aphanamixis polystachya (Wall.) R.Parker	Gội trắng	1	9
Archidendron lucidum (Benth.) I.C.Nielsen	Mán đỉa trâu	1	5
Sp2	Bạc tán xanh	1	2
Betula alnoides Buch.-Ham. ex D.Don	Cáng lò	1	4
Cleistanthus monoicus (Lour.) Müll.Arg	Đỏm trơn	1	2
Castanopsis tribuloides (Sm.) A.DC.	Dẻ sp	1	9
Cryptocarya concinna Hance	Nanh chuột	1	12
Eurya ciliata Merr.	Chè lông	1	4
Heritiera augustata Pierre	Vôi cui	1	2
Knema conferta (King) Warb.	Máu chó lá bé	1	2
Lithocarpus sp1.	Sồi	1	6
Machilus salicina Hance	Kháo lá bé	1	4
Magnolia balansae A.DC.	Giổi lông	1	2
Rhus chinensis Mill.	Muối	1	2
Pterygota alata (Roxb.) R.Br.	Sảng cánh	1	2
Zanthoxylum myriacanthum Wall. ex Hook. f.	Mắc khén	1	5
Species are rare in the buffer zone but not rare in the core zone			
Aglaia spectabilis (Miq.) S.S.Jain & S.Bennet	Gội nếp	12	1
Alangium chinense (Lour.) Harms	Thôi ba	2	1
Cryptocarya impressa Miq.	Mò quả tròn	8	1
Elaeocarpus hainanensis Oliv.	Côm lá đào	3	1
Elaeocarpus japonicus Siebold	Côm nhật	4	1
Garcinia oblongifolia Champ. ex Benth.	Bứa lá thuôn	2	1
Mallotus philippensis (Lam.) Müll.Arg.	Cánh kiến	3	1
Magnolia foveolata (Merr. ex Dandy) Figlar	Giổi lá bạc	11	1
Phoebe macrocarpa C.Y. Wu	Kháo lá to	9	1
Quercus myrsinifolia Blume	Dẻ lá tre	5	1
Symplocos cochinchinensis (Lour.) S. Moore	Dung nam bộ	4	1

Rare tree species when density of a species was 1 or fewer individual/ha (Pitman et al. 1999)

Appendix 4.4 Red-listed tree species. Tree species names, number of trees with DBH of at least 6 cm in the core zone (C.z) and/or buffer zone (B.z), and conservation status in the Vietnam and IUCN Red Lists of 18 red-listed tree species in the Ta Xua Nature Reserve (40 plots per zone)

Scientific name	Vietnamese name	No. of trees		Conservation status[a]	
		C.z.	B.z	Vietnam	IUCN
Aglaia spectabilis (Miq.) S.S. Jain & S.S.R. Bennet	Gội nếp	12	1	VU	LC
Canarium pimela K.D:Koenig	Trám đen	0	1	VU	nl
Castanopsis cerebrina (Hickel & A.Camus) Barnett	Sồi phẳng	4	13	EN	nl
Castanopsis lecomtei Hickel & A.Camus	Cà ổi Sapa	3	10	VU	nl
Castanopsis purpurella subsp. Purpurella	Dẻ gai đỏ	3	0	VU	nl
Castanopsis tessellata Hickel & A.Camus	Cà ổi lá đa	2	0	VU	nl
Cinnadenia paniculata (Hooker f.) Kostermans	Kháo xanh	12	0	VU	nl
Cinnamomum balansae Lecomte	Vù hương	0	1	VU	EN
Dacrycarpus imbricatus (Blume) de Laub.	Thông nàng	2	2	nl	LC
Fokienia hodginsii (Dunn) A. Henry & H. H. Thomas	Pơ mu	11	4	EN	VU
Goniothalamus macrocalyx Bân	Màu cau trắng	1	0	VU	VU
Lithocarpus vestitus (Hickel & A.Camus) A.Camus	Sồi lông nhung	3	0	EN	nl
Madhuca pasquieri (Dubard) H.J.Lam	Sến mật	35	2	EN	VU
Magnolia baillonii Pierre	Giổi găng	1	0	VU	LC
Magnolia balansae A.DC.	Giổi lông	1	2	VU	DD
Magnolia braianensis (Gagnep.) Figlar	Giổi nhung	1	0	EN	DD
Podocarpus neriifolius D.Don	Thông tre lá dài	1	0	nl	LC
Quercus platycalyx Hickel & A.Camus	Dẻ cau	7	7	VU	nl

[a] Based on the Vietnam and the IUCN Red Lists (Nguyen et al. 2007; IUCN 2014). VU = vulnerable; EN = endangered; LC= least concern; DD = data deficient; nl = not listed

Chapter 5

Fujian cypress and two other threatened tree species across conservation zones in a nature reserve of north-western Vietnam

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

[1] Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Germany

[2] Forest Inventory and Planning, Faculty of Silviculture, Vietnam National University of Forestry, Hanoi, Vietnam

[*] Correspondence to: Thi Hoa Hong Dao, Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen, Büsgenweg 1, 37077 Göttingen, Germany. E-mail: tdao@gwdg.de; Telephone: +49 176 9585 4889

Submitted to *Forest Ecosystems* on 2nd January 2017

Abstract Chapter 5

Background

Fujian cypress (*Fokienia hodginsii*) is a highly valued but today endangered tree species. The Ta Xua Nature Reserve in Vietnam is one of its main conservation centers. This nature reserve consists of a fully protected core zone, a buffer zone in which low intensity forest use is permitted, and a forest restoration zone in which forest regenerates after shifting cultivation.

Methods

The community and population status of *F. hodginsii* and two other threatened tree species (*Aglaia spectabilis* and *Quercus platycalyx*) were assessed across the three conservation zones. Based on previous simple random sampling, we applied adaptive cluster sampling for trees with a diameter at breast height of at least 6 cm. In addition tree regeneration was assessed.

Results

Overall, tree species richness was greatest in the core zone, intermediate in the buffer zone, and lowest in the restoration zone. In the core zone, the three target species were moderately rare, in that they were not among the 10% most common species, nor among the 50% rarest species. *F. hodginsii* and *A. spectabilis* were most abundant in the core zone, and much less abundant in the buffer and restoration zones. In contrast, *Q. platycalyx* had its highest density in the restoration zone. Regeneration of all three target species occurred in the core zone; however, there was little or no regeneration of *F. hodginsii* and *A. spectabilis* in the buffer and regeneration zones. Regeneration of *F. hodginsii* and *A. spectabilis* was mostly found in the vicinity of conspecific adult trees.

Conclusions

Our data do not support conservation concerns regarding *Q. platycalyx* in used and secondary forests. In contrast, adult trees of *F. hodginsii* and *A. spectabilis* were mostly confined to the core zone, and regeneration of these species was absent or very rare in the buffer and restoration zones. For these two species, the core zone was thus the most important refuge, so continued conservation of this zone is important for the preservation of these species.

Keywords: Abundance; Adaptive cluster sampling; Conservation; Rarity; Secondary forest; Tropical forest

5.1 Introduction

The high diversity of tree species in tropical forests is driven by a large proportion of rare species (Hubbell 2013; ter Steege et al. 2013). Rare species are vulnerable and threatened to extirpation and extinction when their habitats are destroyed (Gaston 1994; Laurance 1999; Sodhi et al. 2004; Hubbell 2013). In recent decades, extensive conversion and degradation have significantly affected tropical forests (Dirzo and Raven 2003; Sodhi et al. 2009; Gibson et al. 2011). Southeast Asia has high rates of deforestation, and this has endangered many plant and animal species and led to local extinctions (Sodhi et al. 2004). Selective logging may convert a common forest tree species into a rare one, and cause local extirpation or even extinction of rare and high-value species (Fearnside 1997; Laurance 1999). Thus, there is a need for conservation in tropical forests and one focus should be on rare and threatened species (Philippi 2005; Hubbell 2013).

One main forest conservation strategy is the establishment of strictly protected core zones to safeguard remaining habitats and species (Bruner et al. 2001; Joppa and Pfaff 2010), and surrounding low-use buffer zones, which enhance the conservation value of the protected area and provide forest products (DeFries et al. 2005; Chape et al. 2005). Primary forests are considered irreplaceable for maintaining tropical biodiversity (Gibson et al. 2011), and strictly protected core zones can be refuges for rare and red-listed tree species. However, protected areas can create 'conservation islands' in a sea of 'degraded habitats' (Williams et al. 2000). In the buffer zones, where logging is permitted, the method and intensity of logging can impact species composition variously. Low-intensity selective logging may have a low detrimental effect on biodiversity (Gibson et al. 2011); however intensive selective logging can reduce species diversity and exacerbate species loss (Sodhi et al. 2010). Hence, studies of tree communities in different forest conservation zones are essential to evaluate the efficacy of different conservation practices.

Vietnam has a high biodiversity probably because of its tropical climate and complex terrain (Facelli and Pickett 1991; Thai 1998). However, wars and over-exploitation severely degraded the natural forests of Vietnam. Consequently, many species in Vietnam are classified as endangered (Nguyen 2000). In particular, the Vietnam Red List considers 464 plant species as being endangered to different degrees (Nguyen et al. 2007).

Fokienia hodginsii (Dunn) A. Henry & H.H. Thomas (Fujian cypress) is an iconic tree species in the family Cupressaceae. In Vietnam, timber of this species is much valued for its use in construction, art works, and furniture because of its characteristic aroma and exceptional wood density. Local people use its timber in construction through necessity, and rich people use it as the timber of choice. *F. hodginsii* timber is also exported to Europe and elsewhere in Asia (Osborn 2004). Therefore, intensive logging of *F. hodginsii* has led to a severe decline in its population. This species is now rare, and mainly occurs in certain protected areas, and there are few individuals and a limited range of distribution (Thomas and Yang 2013). *F. hodginsii* is listed as 'endangered' in the Vietnam Red List (Nguyen et al. 2007) and as 'vulnerable' in the IUCN Red List (IUCN 2014). Two other threatened tree species in Vietnam are *Aglaia spectabilis (*Miq.) S.S. Jain & S.S.R. Bennet and *Quercus platycalyx* Hickel & A. Camus. The timber of these species is also high quality, so its products are highly valued. Consequently, populations of *A. spectabilis* and *Q. platycalyx* are also seriously fragmented due to habitat destruction and over-exploitation, and both species are listed as 'vulnerable' in the Vietnam Red List (Nguyen et al. 2007).

The Ta Xua Nature Reserve is one of the main conservation centers of *F. hodginsii* in north-western Vietnam. Inventories, based on random sampling, indicated that the abundance of red-listed tree species has declined due to human interventions (Dao and Hölscher 2015). Together with red-list status, large diameter and species rarity were associated with increasing the probability of tree absence in the buffer zone (Dao et al. 2016). However, rare and moderately rare species may not be well represented in random sampling, because these species may be absent in many sampling units, leading to large variances in the estimated population sizes (Cochran 1977; Gaston 1994). If a rare or moderately rare species is known or can be expected to occur in clusters, then adaptive cluster sampling (ACS) can be an effective sampling method (Thompson 1990; Philippi 2005).

Based on our previous results, we applied ACS to determine the population status of *F. hodginsii*, *A. spectabilis*, and *Q. platycalyx* in the Ta Xua Nature Reserve. This nature reserve consists of a fully protected core zone, a buffer zone in which low intensity forest use is permitted, and a forest restoration zone in which forest regenerates after shifting cultivation. The objectives of this study were to assess tree communities and the abundance of *F. hodginsii*, *A. spectabilis* and *Q. platycalyx,* and to determine the regeneration status of the three target species in the three conservation zones. The results will provide quantitative information that may help in assessing the vulnerability degrees of these tree species and guide or facilitate conservation efforts. More generally, our results will add to our understanding of the extent to which threatened tree species need protection in core conservation zones, and whether they can tolerate different types of forest use.

5.2 Methods

5.2.1 Study area

The Ta Xua Nature Reserve (21°13′ – 21°26′ N, 104°16′ – 104°46′ E, Fig. 5.1) was established in 2002. This region has high, steeply sloping mountains, an altitude of 320 m to 2765 m a.s.l., and inclinations of 30° to 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 1600 mm to 1900 mm, and the average temperature is 20°C.

The reserve has a core zone of 15211 ha and a forest cover of 87%. This zone is entirely and strictly protected. All human activities, such as logging, hunting, and gathering of non-timber forest products, are prohibited. During our field work, signs of these activities were only rarely observed in the core zone. The forest types range from evergreen and broad-leaved rainforest at lower elevations to coniferous forest mixed with some evergreen and broad-leaved species at the higher mountain peaks (FIPI 2002). The core zone can only be reached by footpaths; some were made before the nature reserve was established, and the others are from ranger patrols, research project routes, or tourist trails.

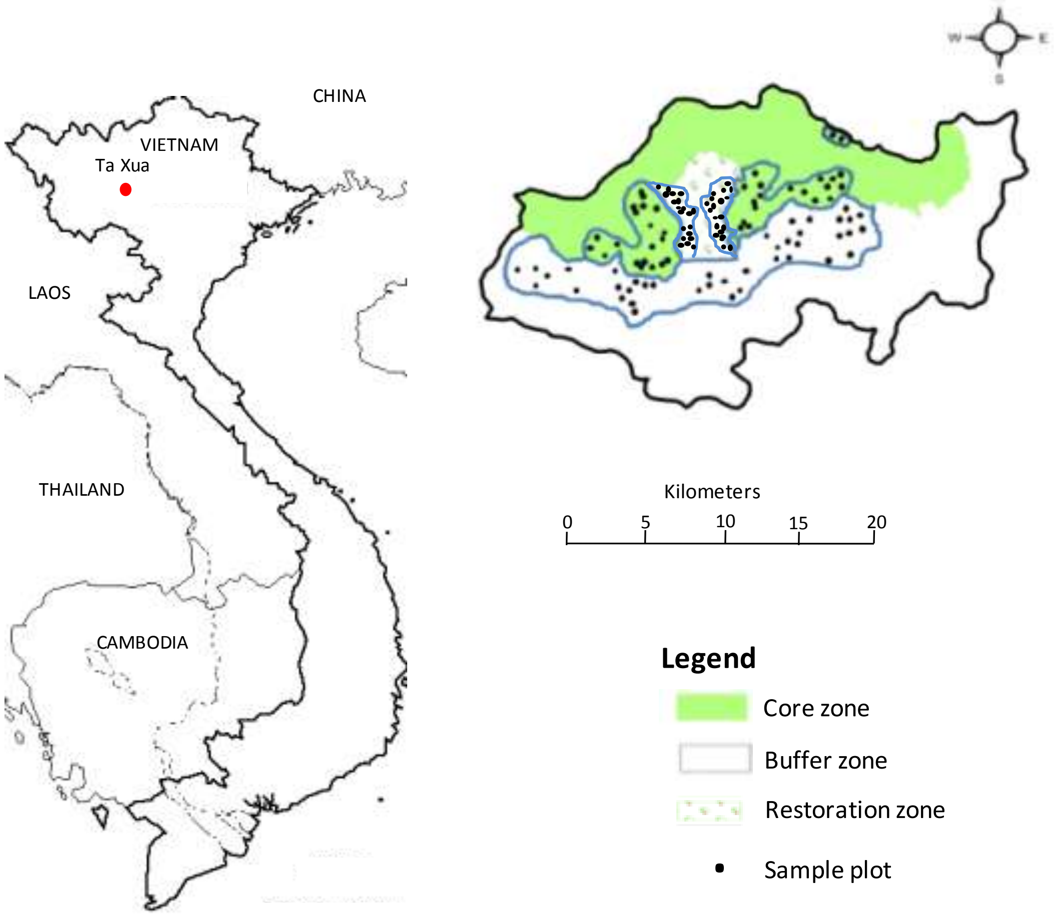

Fig. 5.1. Location of the Ta Xua Nature Reserve in north-western Vietnam (left), and detail of the study area, which is enclosed by blue lines (right; 1000-1700 m a.s.l.). Black dots indicate initial random sample plots (40 plots per zone).

The buffer zone encompasses 24674 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 that were established by the law of forest protection and development (Law No.29/2004/QH11 2004). Based on these regulations, a maximum of 25 trees can be felled per year in a forest area of 10856 ha. However, during field work, some illegal tree felling and signs of such were observed. Land below 900 m a.s.l. is mainly agricultural land, with upland rice, maize, and sugarcane predominating (FIPI 2002).

A protected restoration zone was also established within the reserve, which consists of 2439 ha enclosed within the core zone and partly borders the buffer zone. In the past, the H'Mong people lived there and practiced shifting cultivation, but this area has been subject to statutory protection since 2002 (FIPI 2002).

5.2.2 Target tree species

Three tree species, *F. hodginsii*, *A. spectabilis*, and *Q. platycalyx* (Fig. 5.2), were examined in this study because their timber is highly favored and very expensive. Therefore, they are sought for logging. Over the years, these species have become endangered and rare. Their populations are diminished, and they are considered of conservation concern according to the IUCN and Vietnam Red Lists (Nguyen et al. 2007; IUCN 2014). Simple random sampling indicated these species were moderately rare in the core zone of the Ta Xua Nature Reserve (Dao and Hölscher 2015).

F. hodginsii (Fujian cypress) is native to Vietnam, China, and Laos. This species usually occurs above 900 m a.s.l. and grows on acidic and well-drained soils. It is a slow-growing, long-lived, large tree and is considered a late successional species (Nguyen et al. 1996; Le and Le 2000). The female cones are 15-25 × 12-22 mm in size. The seeds are ovoid, 4-5 mm long, and have two wings that are unequal in size and shape. The larger wing is ca. 5-6 mm long, and the smaller one is ca. 1.5 mm long, or a mere strip near the seed apex (Farjon 2010). Timber of *F. hodginsii* is a precious and much-valued product due to its fine, straight grain and distinct aroma. Aromatic essential oil from this species ("Siam-wood essential oil" or "Pemou oil") has a high sesquiterpene content, and reportedly can kill bacteria, purify and disinfect the air, repel mosquitoes and insects, and is used in aromatherapy to improve mental clarity and emotional balance (Lesueur et al. 2006; Paluch 2009). The population of *F. hodginsii* has declined severely, and this species is listed as 'endangered' in the Vietnam Red List (Nguyen et al. 2007) and 'vulnerable' in the IUCN Red List (IUCN 2014). Because of its great longevity (at least 1500 years) and sensitivity to moisture, researchers have recently used *F. hodginsii* for dendro-climatic studies (Sano et al. 2008; Buckley et al. 2016).

A. spectabilis has a wide distribution, and occurs in Southeast Asia, China, and India. This tree species is usually found in near natural or slightly disturbed forests and grows on deep, clay and well-drained soil. It is a long-lived and large tree. Seeds are dispersed mainly by animals (especially civets and squirrels), birds and dehiscence (Nguyen et al. 1996). Its high quality wood is used for doors, window frames, and furniture. The natural population is fragmented due to habitat destruction and over-exploitation. *A. spectabilis* is classified ‘vulnerable' in the Vietnam Red List (Nguyen et al. 2007).

Q. platycalyx is native to Vietnam and China, and occurs in secondary forests (Nguyen et al. 1996). It is a light-demanding and fast-growing tree species. Nuts and burrs are mainly dispersed by animals (especially squirrels, mice, wild boars, and bears) and gravity. Its high-quality wood is used for construction and furniture. This species is threatened by selective logging for its timber. *Q. platycalyx* is classified as 'vulnerable' in the Vietnam Red List (Nguyen et al. 2007).

Fig. 5.2. Mature tree, female cones, and seeds of *F. hodginsii* (left); mature tree, leaves, fruits and seeds of *A. spectabilis* (center); and mature tree, leaves, and nuts of *Q. platycalyx* (right). Photos are from Vuong Duy Hung, Dao Thi Hoa Hong, Truong Tat Do, and Trinh Ngoc Bon.

5.2.3 Sampling design

A provisional forest cover map was established based on a reconnaissance survey. Land at an elevation of 1000 m to 1700 m a.s.l. was selected for the study, as forest occurred in all three conservation zones within this range. The study area consisted of 73 ha in the core zone, 115 ha in the buffer zone and 22 ha in the restoration zone. A grid system with 1400 cells was created and overlaid on the study area plan to randomly select the locations for sample plots. Forty plots of 20 × 20 m were then established in each conservation zone, with the center of each plot located in the center of a selected cell.

ACS initially uses random sample plots, and then successively adds neighboring plots that satisfy a certain condition (in our case, containing a tree of the target species). If any of the added plots also satisfy the condition, then its neighbors are also added, leading to a cluster of plots (Thompson 1990). The 40 random sample plots of 400 m^2 (20 × 20 m) per conservation zone were the initial plots. Thus, if an initial random plot contained at least one target tree with a diameter at breast height (DBH) of at least 6 cm ($tree_{\geq 6cm}$), then four neighboring plots were added. If an added plot also had at least one target $tree_{\geq 6cm}$, then it was added to the sample and its neighbors are recursively. The addition of plots ended when no more added plots contain the target species. This procedure was applied separately for each of the three target species.

For the inventory of tree regeneration, in the center of each initial random plot and additional plot, a subplot of 25 m^2 (5 × 5 m) was laid to assess regeneration of all tree species and target tree species with DBH less than 6 cm ($tree_{<6cm}$).

5.2.4 Data collection

In the initial and adaptively added plots, each target and non-target $tree_{\geq 6\ cm}$ was counted, and its DBH was measured. All $trees_{\geq 6cm}$ in the 400 m^2 plots, and regenerating $trees_{<6cm}$ in subplots of 25 m^2 were identified at the species level, with assistance from two botanists of the Vietnam National University of Forestry (VNUF). Field specimens of unidentified non-target species were collected for identification using the herbarium of the VNUF. Non-target trees that could not be identified to the species level were classified by genus or family, and sorted into morphospecies.

Some information about site conditions, forest canopy closure, and human interference in the initial random sample plots was also collected. The three conservation zones had similar basic characteristics of site condition such as soil pH and slope inclination (Table 5.1). The two signs of human disturbance, number of footpaths and number of stumps, were rarest in the core zone; the greatest number of footpaths was in the buffer zone and the greatest number of stumps was in the restoration zone (Dao and Hölscher 2015).

5.2.5 Statistical analysis

A *t*-test or Mann-Whitney *U*-test and an ANOVA or Kruskal-Wallis *H* test were used to determine the significance of differences in the means of the three conservation zones (significant if $p \leq 0.05$). The predicted species richness of $\text{trees}_{\geq 6cm}$ and $\text{trees}_{<6cm}$ in the core zone, buffer zone, and restoration zone were estimated using the Bernoulli product model, based on the Mao-Tau and Chao2 estimators (Chao 1987), by interpolation from 40 empirical plots for $\text{trees}_{\geq 6cm}$ and 40 subplots for $\text{trees}_{<6cm}$ and extrapolation to three-times the number of empirical plots (or subplots) in each zone (Colwell et al. 2004; Colwell et al. 2012) using EstimateS software (Colwell 2013). The mean densities of the three target species from ACS were calculated using the modified and unbiased Hansen-Hurwitz estimator (Thompson and Seber 1996).

5.3 Results

5.3.1 Forest structure and overall tree species abundance

The species richness ($trees_{\geq 6cm}$) was 193 species in the core zone, 173 in the buffer zone, and 135 in the restoration zone (Table 5.1). These differences were more distinct when predicted by the Chao2 estimator: 254 ± 17 species (mean ± standard deviation) in the core zone, 182 ± 5 species in the buffer zone, and 158 ± 9 species in the restoration zone. Tree diameters, basal area, and canopy closure were highest in the core zone, intermediate in the buffer zone, and lowest in the restoration zone.

Table 5.1. Site conditions and forest structural characteristics of the three conservation zones. Numbers are means and standard deviations, with 40 plots per zone. Different superscript letters indicate significant differences ($p \leq 0.05$).

	Core zone	**Buffer zone**	**Restoration zone**
Total study area (ha)	72.8	115.1	21.6
Elevation (m a.s.l.)	1449.1 ± 62.6[a]	1363.3 ± 86.7[b]	1465.5 ± 91.0[a]
Slope inclination (degrees)	39.5 ± 7.7[a]	35.9 ± 5.4[b]	35.6 ± 5.9[b]
Soil pH	4.7 ± 0.4[a]	4.7 ± 0.4[a]	4.8 ± 0.2[a]
Tree density ($trees_{\geq 6cm}$; trees/ha)	925 ± 251[a]	1006 ± 357[a]	1660 ± 387[b]
DBH ($trees_{\geq 6cm}$; cm)	21.4 ± 3.4[a]	16.6 ± 3.0[b]	12.8 ± 1.4[c]
Basal area ($trees_{\geq 6\ cm}$; m^2/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 species richness ($trees_{\geq 6cm}$, sp./40 plots)	193	173	135
*Predicted species richness ($trees_{\geq 6cm}$, sp./120 plots)	254±17	182±5	158±9
Stumps (no./plot)	0.6 ± 0.8[a]	1.6 ± 1.6 [b]	1.7 ± 1.4[b]
Footpaths (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 120 pooled plots by Chao2 estimator

A total of 10% of tree species in the core zone, 11% of tree species buffer zone, and 6% of tree species in the restoration zone were the most common species; they accounted for 50% of all individual trees in each of these areas (Fig. 5.3, Appendix 5.1). The rarest half of tree species constituted 10% of individual trees in the core zone and buffer zone, and 5% of all individual trees in the restoration zone.

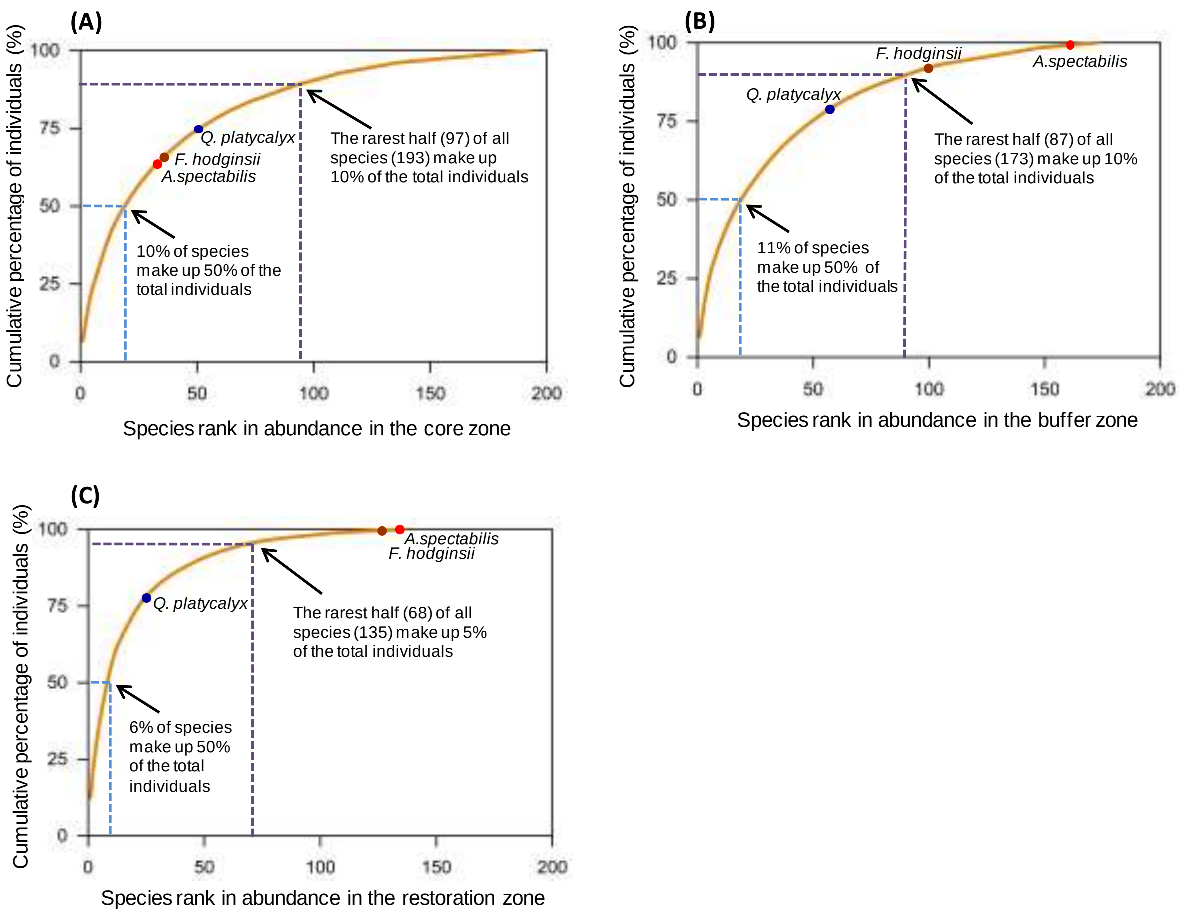

Fig. 5.3. Cumulative abundance of tree species (trees$_{\geq 6cm}$) in 40 random plots (20 × 20 m) in the core zone (A, 193 species), buffer zone (B, 173 species), and restoration zone (C, 133 species). The ordinate represents the cumulative percentage of individuals, and the abscissa represents the abundance rank of species, from most common (left) to rarest (right). The rank abundance of the three target species is indicated.

5.3.2 Abundance of the three target species

In the core zone, the three target species were moderately rare, in that they were not among the 10% most common species, nor among the 50% rarest species (Fig. 5.3A). Five of the 40 initial random plots contained *F. hodginsii*, and 44 plots were added adaptively. Among these 49 plots, 18 plots had at least one tree$_{\geq 6cm}$ ("positive plots"), and there was a total of 47 trees. The 31 remaining plots were empty edge plots. The average density of this species was 4.9 trees/ha (Table 5.2). Eight of the 40 initial random plots in the core zone contained *A. spectabilis*, and 90 plots were added adaptively. Among the 98 plots, 45 plots were positive plots, and there was a total of 74 trees. The 53 remaining plots were empty edge plots. The average density of this species was 5.1 trees/ha. Seven of the 40 initial random plots in the core zone contained *Q. platycalyx*, and 44 plots were added adaptively. Among the 51 plots, 13 plots were positive, and there was a total of 13 trees (one tree per plot). The other 38 plots were empty edge plots. The average density of this species was 4.4 trees/ha. These results indicate that *F. hodginsii* and *A. spectabilis* occur in clusters in the core zone, making ACS an effective inventory method. However, *Q. platycalyx* seems to have a scattered distribution.

In the buffer zone and restoration zone, *Q. platycalyx* was moderately rare (as in the core zone), but *F. hodginsii* and *A.* s*pectabilis* were among the 50% of the rarest tree species (Figs. 5.3B & 5.3C). In these two areas, we observed only limited numbers of *F. hodginsii* and *A. spectabilis* trees, but a large number of *Q. platycalyx* trees (Table 5.2).

Table 5.2. Number of initially positive plots (among the 40 random plots of 400 m^2 per zone), added positive plots (from ACS), edge plots, individual trees$_{≥6cm}$ of three target species, tree density (*n*/ha) (determined by the Hansen-Hurwitz estimator), and DBH. Numbers are means and standard deviations.

	Conservation zone	Initial positive plots	Added positive plots	Edge plots	Detected individuals (tree$_{≥6cm}$)			Density (trees$_{≥6cm}$ /ha)	DBH (cm)
					Initial	Added	Total		
F.hodginsii	Core	5	13	31	11	36	47	4.9±2.5	16.9±11.2
	Buffer	2	1	4	4	1	5	1.9±1.3	29.2±13.4
	Restoration	1	0	4	1	0	1	0.6±0.6	8.3±*NA*
A. spectabilis	Core	8	37	53	12	62	74	5.1±2.2	17.3±10.1
	Buffer	1	0	4	1	0	1	0.6±0.6	12.7±*NA*
	Restoration	1	1	6	1	1	2	0.6±0.6	16.6±14.4
Q. platycalyx	Core	7	6	38	7	6	13	4.4±1.2	27.8±18.8
	Buffer	6	8	31	7	11	18	4.9±2	22.4±15.3
	Restoration	4	1	18	29	1	30	16.6±8	17.3±5.5

NA: not available

5.3.3 Regeneration

We examined 40 random subplots of 25 m^2 to assess tree regeneration. The highest density of regeneration of all tree species was in the core zone (31.9 trees$_{<6cm}$/subplot), and the lowest density was in the restoration zone (22.2 trees$_{<6cm}$/subplot) (Table 3). There were 133 regenerating species in the core zone, 130 in the buffer zone, and 80 in the restoration zone. When determined by the Chao2 estimator, the predicted species richness was 195 ± 17 species (mean ± standard deviation) in the core zone, 205 ± 19 in the buffer zone, and 84 ± 10 in the restoration zone (Table 5.3).

Table 5.3. Species richness and density of regenerating tree species in the three conservation zones. The results are from 40 random sample subplots of 25 m^2 per zone. Numbers are means and standard deviations; different superscript letters indicate significant differences ($p \leq 0.05$).

	Core zone	**Buffer zone**	**Restoration zone**
Observed species richness ($trees_{< 6\ cm}$, sp./40 subplots)	133	130	80
*Predicted species richness ($trees_{< 6\ cm}$, sp./120 subplots)	195 ± 17	205 ± 19	84 ± 10
Tree density ($trees_{< 6cm}$/subplots)	31.9 ± 22.6^{a}	24.7 ± 16.6^{ab}	22.2 ± 12.1^{b}
F. hodginsii ($trees_{< 6cm}$/40 subplots)	2	0	2
A. spectabilis ($trees_{< 6cm}$/40 subplots)	2	2	0
Q. platycalyx ($trees_{< 6cm}$/40 subplots)	7	1	3

*Richness of regenerating species was extrapolated from 40 empirical subplots to 120 pooled subplots by Chao2 estimator

Our random sampling method indicated regeneration of the three target species in the core zone. However, there was no regeneration of *F. hodginsii* in the buffer zone and no regeneration of *A. spectabilis* in the restoration zone (Table 5.3 and Fig. 5.4).

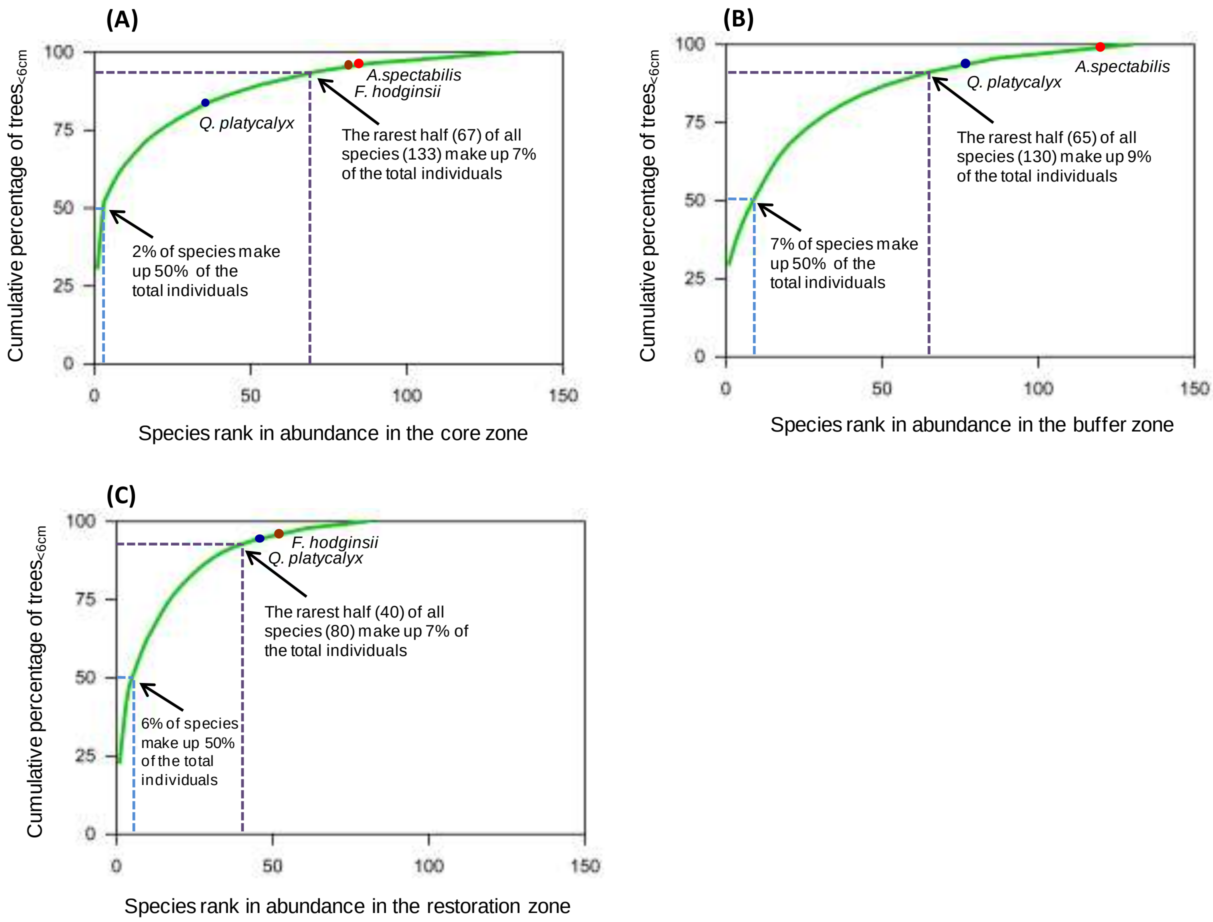

Fig. 5.4. Cumulative abundance of regenerating tree species (trees$_{<6cm}$) in 40 random subplots (5 × 5 m) in the core zone (A, 133 species), buffer zone (B, 130 species), and restoration zone (C, 80 species). The ordinate represents the cumulative percentage of individuals, and the abscissa represents the abundance rank of species, from most common (left) to rarest (right). The rank abundance of the 3 target species is indicated. Note, there were no regenerating *F. hodginsii* trees in the buffer zone (B), and no regenerating *A. spectabilis* trees in the restoration zone (C).

Regeneration was also assessed on ACS plots. In the core zone, these subplots had 17 regenerating *F. hodginsii* trees and 52 regenerating *A. spectabilis* trees. All of the edge plots – which had no target trees$_{\geq 6cm}$ – the subplots also had no regenerating trees of *F. hodginsii* and *A. spectabilis* (Table 5.4). For *Q. platycalyx*, the four initial sample subplots had 7 regenerating trees, but no more regenerating trees were detected in subplots inside positive added plots and edge plots. In the buffer zone, we observed no regenerating trees of *F. hodginsii* in any of the added subplots, and only one regenerating tree of *A. spectabilis* in the restoration zone. These results indicate that regenerating trees of *F. hodginsii* and *A. spectabilis* often appeared in the vicinity of large conspecifics in the core zone (Fig. 5.5).

Table 5.4. Number of initially positive subplots for trees$_{<6\ cm}$ (among 40 random subplots of 25 m^2 per zone), added positive subplots (from ACS of trees$_{\geq 6cm}$), subplots in edge plots, and total trees$_{<6cm}$ of three target species.

	Conservation zone	Random sampling		ACS added plots base on trees$_{\geq 6cm}$				Total detected tree$_{<6cm}$
				Subplots in added positive plots		Subplots in edge plots		
		Positive subplot	Tree$_{<6cm}$	Subplot	Tree$_{<6cm}$	Subplot	Tree$_{<6cm}$	
F. hodginsii	Core	1	2	7	17	31	0	19
	Buffer	0	0	0	0	4	0	0
	Restoration	2	2	0	0	4	0	2
A. spectabilis	Core	2	2	23	52	53	0	54
	Buffer	2	2	0	0	4	0	2
	Restoration	0	0	1	1	6	0	1
Q.platycalyx	Core	4	7	0	0	38	0	7
	Buffer	1	1	3	4	31	0	5
	Restoration	2	3	0	0	18	0	3

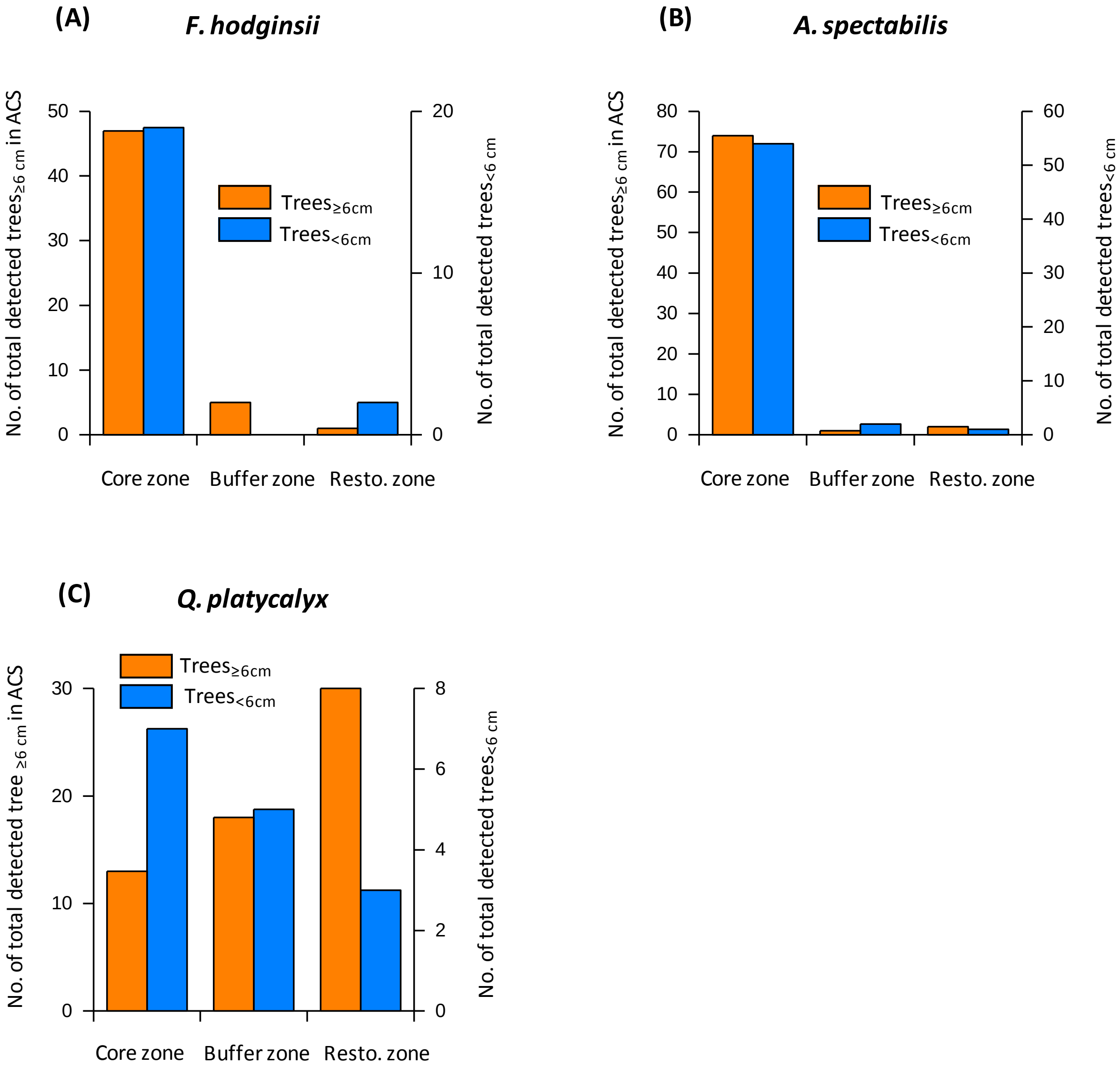

Fig. 5.5. Numbers of large individuals (tree$_{\geq 6cm}$) and regenerating individuals (tree$_{<6cm}$) of the *F. hodginsii* (A), *A. spectabilis* (B) and *Q. platycalyx* (C) in the core, buffer, and restoration zones. Large trees were detected by ACS, and regenerating trees were assessed in subplots of positive and edge plots.

5.4 Discussion

Our study of the tree communities indicates that overall tree species diversity was greatest in the core zone, intermediate in the buffer zone, and lowest in the restoration zone. Moreover, the abundance of *F. hodginsii* and *A. spectabilis* was highest in the core zone, and much lower in the buffer and restoration zones. In contrast, the abundance of *Q. platycalyx* was greatest in the restoration zone. We found regeneration of all three target species in the core zone; however, there was no regeneration, or regeneration of just one or two seedlings of *F. hodginsii* and *A. spectabilis* in the buffer and restoration zones. *F. hodginsii* and *A. spectabilis* had aggregated distributions, and regenerating trees of these species were mostly near large conspecific trees in the core zone.

F. hodginsii was found greatest density in the core zone, and there were much lower densities in the buffer and restoration zones. The mature trees had a highly aggregated distribution in the strictly protected core zone. This finding is in line with the results of a study of *F. hodginsii* in Chu Yang Sin National Park, in the Central Highlands of Vietnam (Dang 2010). This previous study measured distances from individuals to their nearest neighbors (Clark and Evans 1954), and the results indicated that *F. hodginsii* had a clumped distribution. In Vietnam, the main reason for the declining population of *F. hodginsii* is over-exploitation because of its valuable timber (Luu and Thomas 2004; Farjon 2010). Mature *F. hodginsii* trees have been heavily harvested by legal and illegal logging over the last 50 years (Nguyen et al. 2015). Although many recent laws protect and limit use of this species' timber (Osborn 2004), there is still a declining number of mature trees. For example, *F. hodginsii* is currently one of the most exploited species in the Hoang Lien - Van Ban Nature Reserve (Lam and Yen 2013).

Regenerating *F. hodginsii* trees were most abundant in the core zone; however, there were no regenerating trees in the buffer zone and only two seedlings in the restoration zone. Intensive logging of large-diameter trees may have led to an insufficiency of seeds for natural regeneration and low seedling densities in the logged forests (Plumptre 1995). Furthermore, some biological attributes of *F. hodginsii* seeds, such as low germination rate (30–360 days), and a relatively hard seed coat (Nguyen et al. 2015), may also contribute to its poor regeneration. In this study, we only found offspring of *F. hodginsii* in the vicinity of conspecific adult trees in the core zone. In general, the Janzen-Connell hypothesis (Janzen 1970; Connell 1971) postulates that host-specific pests could reduce recruitment near reproductive adults. Findings from other studies also supported the negative density dependence that constrains juvenile performance near reproductive conspecifics (Comita et al. 2014). However, *F. hodginsii* seems to be different. Hubbell (1979) and Hubbell and Foster (1983) previously reported that roughly half of tree species in dry and moist neotropical forests germinate in dense aggregations beneath their parents. The study in Chu Yang Sin National Park (Dang 2010) also found regenerating *F. hodginsii* trees only near mature conspecifics. The greater seed density beneath the parent trees and an appropriate microhabitat for germination and seedling survival (Wright 2002; Crawley 2009) may explain the presence of regenerating trees near parents in the core zone. In case of *F. hodginsii* chemical exudates from the adult trees may also support the survival of juveniles near mature trees. Several studies indicated that the essential oils of *F. hodginsii* are a rich in sesquiterpenes and had high efficacy against mosquitoes and other insects (Lesueur et al. 2006; Paluch 2009). However, only a limited number of previous studies have examined the spatial distribution of regenerating *F. hodginsii* trees. Thus the spatial pattern of regenerating and adult *F. hodginsii* trees requires more rigorous testing, and the ecological reasons for its aggregated distribution remain very speculative. Our results, however, clearly show that adult and regenerating *F. hodginsii* trees are strongly confined to the core zone, making this an important refuge for this species.

The distribution pattern of *A. spectabilis* is similar to that of *F. hodginsii*. In particular, most trees were observed in clusters in the core zone, an intermediate number occurred in the buffer zone, and the fewest occurred in the restoration zone. In addition, many regenerating trees were concentrated near conspecific adults in the core zone, but regenerating trees were very rare in the buffer and restoration zones. Our results indicate that *A. spectabilis* is an endangered tree species, and the core zone is important for its persistence.

On the other hand, the distribution pattern of *Q. platycalyx* was very different those of *F. hodginsii* and *A. spectabilis*. The greatest number of individuals was found in a few initial random plots in the restoration zone. Regenerating *Q. platycalyx* trees were present in all three conservation zones, although their numbers were low and their distribution was scattered. In our study area, the restoration zone was disturbed by previous shifting cultivation, so it is evident that *Q. platycalyx* can colonize disturbed sites. It is likely to be one of the species occupying early successional habitats and has good regeneration after coppicing (Nguyen et al. 1996; Le and Le 2000). Thus, our data would not support the classification of *Q. platycalyx* as ‘vulnerable’ in the Vietnam Red List (Nguyen et al. 2007).

5.5 Conclusion

In conclusion, our data do not support conservation concerns regarding *Q. platycalyx* in used and secondary forests, which may influence its status in the next assessment of endangered species. However, *F. hodginsii* and *A. spectabilis* were mostly confined to the core zone, and regeneration of these species was absent or very rare in the buffer and restoration zones. For these two species, the unused core zone was the most important refuge, so continued conservation of this zone is important for the preservation of these species.

Acknowledgments

This study was supported by the Vietnamese Government, the German Academic Exchange Service (DAAD), and the Rufford Small Grants Foundation. We thank Nguyen Q.D., Luong V.P., Luong V.T., Dang V.L., Dao V.P., Nguyen M.T., Pham K.C., Vang A.S., and Vang A.C. for their assistance during different phases of the fieldwork; two botanists, Trinh N.B. and Phan V.D., for tree identification; Tran T.H. and Nguyen T.H. for help in soil sample analysis; Dr. Ngo T.L., Dr. Peque D., Phan T.N., and Le T.K. for their comments on our research; and the managers and local people in the Ta Xua Nature Reverse for helping us conduct this study. We also thank the journal’s anonymous reviewers for their valuable comments on earlier versions of the manuscript.

5.6 References Chapter 5

Bruner AG, Gullison RE, Rice RE, da Fonseca GAB (2001) Effectiveness of parks in protecting tropical biodiversity. Science 291: 125–128. doi: 10.1126/science.291.5501.125

Buckley BM, Stahle DK, Luu HT, Wang SYS, Nguyen TQT, Thomas P, Le CN, Ton TM, Bui TH, Nguyen VT (2016) Central Vietnam climate over the past five centuries from cypress tree rings. Clim Dyn. doi: 10.1007/s00382-016-3297-y

Chao A (1987) Estimating the population size for capture-recapture data with unequal catchability. Biometrics 43(4): 783–791. doi: 10.2307/2531532.

Chape S, Harrison J, Spalding M, Lysenko I (2005) Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Phil Trans R Soc B 360(1454): 443–455. doi: 10.1098/rstb.2004.1592

Clark PJ, Evans FC (1954) Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology 35(4): 445–453. doi: 10.2307/1931034

Cochran WG (1977) Sampling techniques. John Wiley and Sons, New York

Colwell RK (2013) EstimateS, Version 9.10: Statistical estimation of species richness and shared species from samples. (Software and User's Guide). Freeware published at http://viceroy.eeb.uconn.edu/estimates.

Colwell RK, Chao A, Gotelli NJ, Lin SY, Mao CX, Chazdon RL, Longino JT (2012) Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. J Plant Ecol 5(1): 3–21. doi: 10.1093/jpe/rtr044.

Colwell RK, Mao CX, Chang J (2004) Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85(10): 2717–2727. doi: 10.1890/03-0557

Comita LS, Queenborough SA, Murphy SJ, Eck JL, Xu K, Krishnadas M, Beckman N, Zhu Y (2014) Testing predictions of the Janzen–Connell hypothesis: a meta-analysis of experimental evidence for distance-and density-dependent seed and seedling survival. J Ecol 102(4): 845–856. doi: 10.1111/1365-2745.12232

Connell JH (1971) On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. In Dynamics of Populations, Proceedings of the Advanced Study Insti- tute on Dynamics of Numbers in Popula- tions, Oosterbeek, 1970, ed. PJ den Boer, GR Gradwell, pp. 298-312. Wageningen, Netherlands: Cent. Agric. Publ. Doc.

Crawley MJ (2009) Plant–herbivore dynamics. In: Crawley MJ (ed) Plant Ecology, 2nd edn. Blackwell, London

Dang HP (2010) Determining ecological factors affecting the distribution and regeneration of Fokienia hodginsii in Chu Yang Sin National Park, Central Highlands of Vietnam. Master thesis, University of Tay Nguyen, Vietnam.

Dao THH, Hölscher D (2015) Red-listed tree species abundance in montane forest areas with differing levels of statutory protection in north-western Vietnam. Trop Conserv Sci 8(2): 479-490.

Dao THH, Saborowski J, Hölscher D (2016) Patterns of tree community differences in the core and buffer zones of a nature reserve in north-western Vietnam. Glob Ecol Conserv 8: 220–229. doi:10.1016/j.gecco.2016.09.011

DeFries R, Hansen A, Newton AC, Hansen MC (2005) Increasing isolation of protected areas in tropical forests over the past twenty years. Ecol Appl 15(1): 19–26. doi: 10.1890/03-5258.

Dirzo R, Raven PH (2003) Global state of biodiversity and loss. Annu Rev Environ Resour 28: 137–167. doi: 10.1146/annurev.energy.28.050302.105532

Facelli JM, Pickett STA (1991) Plant litter: its dynamics and effects on plant community structure. Bot Rev 57(1): 1–32. doi: 10.1007/BF02858763

Farjon A (2010) A Handbook of the World's Conifers. Brill, Leiden.

Fearnside PM (1997) Protection of mahogany: a catalytic species in the destruction of rain forests in the American tropics. Environ Conserv 24(4): 303–306.

Forest Inventory and Planning Institute (FIPI) (2002) Project of conservation and development forest resources of Ta Xua Nature Reserve. Hanoi

Gaston KJ (1994) Rarity, Chapman & Hall, London.

Gibson L, Lee TM, Koh LP, Brook BW, Gardner TA, Barlow J, Peres CA, Bradshaw CJ, Laurance WF, Lovejoy TE (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. Nature 478: 378–381. doi: 10.1038/nature 10425.

Hubbell SP (2013) Tropical rain forest conservation and the twin challenges of diversity and rarity. Ecol Evol 3(10): 3263–3274. doi: 10.1002/ece3.705

Hubbell SP (1979) Tree dispersion, abundance, and diversity in a tropical dry forest. Science 203: 1299–1309.doi: 10.1126/science.203.4387.1299.

Hubbell SP, Foster RB (1983) Diversity of canopy trees in a neotropical forest and implications for conservation. In Sutton SL, Whitmore TC and Chadwick AC (eds) Tropical Rain Forest: Ecology and Management. Blackwell, London.

IUCN (2014) The IUCN Red List of Threatened Species. Version 2014.3. http://www.iucnredlist.org. Accessed 21 Nov 2014

Janzen DH (1970) Herbivores and the number of tree species in tropical forests. Am Nat 104: 501–528.

Joppa LN, Pfaff A (2010) Global protected area impacts. Proc R Soc B doi:10.1098/rspb.2010.1713

Lam HV, Yen HM (2013) Hoang Lien–Van Ban Nature Reserve. In: Evidence-Based Conservation: Lessons from the Lower Mekong. Earthscan, London, 2013.

Laurance WF (1999) Reflections on the tropical deforestation crisis. Biol Conserv 91: 109–117. doi: 10. 1016/S0006-3207(99)00088-9.

Law No.29/2004/QH 11, 2004. Protection and development of forest, the National Assembly of the Socialist Republic of Vietnam

Le MC, Le TH (2000) Forest plants. Agricultural Publishing House, Hanoi.

Lesueur D, Ban NK, Bighelli A, Muselli A, Casanova J (2006) Analysis of the root oil of Fokienia hodginsii (Dunn) Henry et Thomas (Cupressaceae) by GC, GC–MS and 13C-NMR. Flavour Frag J 21(1): 171–174. doi: 10.1002/ffj.1557.

Luu NDT, Thomas PI (2004) Conifers of Vietnam: an illustrated field guide. World Publishing House, Hanoi.

Nguyen DQ, Phan TPH, Dao VT (2015) Effect of storage time and pretreatment on seed germination of the threatened coniferous species Fokienia hodginsii. Plant Species Biol 30(4): 291–296. doi: 10.1111/1442-1984.12062.

Nguyen HN (2000) Some threatened tree species of Vietnam. Agricultural Publishing House, Hanoi.

Nguyen NC, Cao TC, Vu VC, Nguyen XD, Vu VD, Nguyen KD, Tran H, Tran TO, Nguyen BQ, Nguyen NT (1996) Vietnam forest trees. Agricultural Publishing House, Hanoi.

Nguyen TB, Tran DL, Nguyen KK (2007) Vietnam red list. Part II: Plants. Science and Techniques Publishing House, Hanoi.

Osborn T (2004) Preparation and implementation of a strategy for the management of Fokienia hodginsii in Vietnam by 2008. A desk study for the Hoang Lien Son Project, Fauna and Flora International Vietnam.

Paluch GE (2009) Characterization of botanical terpene activity in arthropods. Dissertation, Iowa State University, USA

Philippi T (2005) Adaptive cluster sampling for estimation of abundances within local populations of low-abundance plants. Ecology 86(5): 1091–1100. http://www.jstor.org/stable/3450870

Plumptre AJ (1995) The importance of “seed trees” for the natural regeneration of selectively logged tropical forest. Commonwealth For Rev 74(3): 253–258. http://www.jstor.org/stable/42608376

Sano M, Buckley BM, Sweda T (2008) Tree-ring based hydroclimate reconstruction over northern Vietnam from Fokienia hodginsii: eighteenth century mega-drought and tropical Pacific influence. Clim Dyn 33, 331. doi:10.1007/s00382-008-0454-y

Sodhi NS, Koh LP, Brook BW, Ng PK (2004) Southeast Asian biodiversity: an impending disaster. Trends Ecol Evol 19(12): 654–660. doi: 10.1016/j.tree.2004.09.006

Sodhi NS, Koh LP, Clements R, Wanger TC, Hill JK, Hamer KC, Clough Y, Tscharntke T, Posa MRC, Lee TM (2010) Conserving Southeast Asian forest biodiversity in human-modified landscapes. Biol Conserv 143(10): 2375–2384. doi: 10.1016/j.biocon.2009.12.029

Sodhi NS, Lee TM, Koh LP, Brook BW (2009) A Meta-Analysis of the Impact of Anthropogenic Forest Disturbance on Southeast Asia’s Biotas. Biotropica 41(1): 103–109. doi: 10.1111/j.1744-7429.2008.00460.x

ter Steege H, Pitman NC, Sabatier D, Baraloto C, Salomão RP, Guevara JE, Phillips OL, Castilho CV, Magnusson WE, Molino JF (2013) Hyperdominance in the Amazonian tree flora. Science 342, 1243092. doi: 10.1126/science.1243092

Thai VT (1998) Ecosystem of tropical forests in Vietnam. Science and Technique Publishing House, Hanoi.

Thomas P, Yang Y (2013) Fokienia hodginsii. The IUCN Red List of Threatened Species 2013. http://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T32351A2815809.en

Thompson SK (1990) Adaptive cluster sampling. J Am Stat Assoc 85(412): 1050–1059.

Thompson SK, Seber GAF (1996) Adaptive sampling. John Wiley and Sons, New York.

Williams PH, Burgess ND, Rahbek C (2000) Flagship species, ecological complementarity and conserving the diversity of mammals and birds in sub-Saharan Africa. Anim Conserv 3(3): 249–260.

Wright JS (2002) Plant diversity in tropical forests: a review of mechanisms of species coexistence. Oecologia 130(1): 1–14. doi:10.1007/s004420100809

5.7 Appendix Chapter 5

Appendix 5.1. Rank abundance of the most common species that account for 50% of total individuals in each conservation zone.

	Trees$_{\geq 6cm}$				Trees$_{<6cm}$			
	Rank	**Scientific name**	**Percentage (%)**	**Cumulative percentage**	**Rank**	**Scientific name**	**Percentage (%)**	**Cumulative percentage**
Core zone	1	*Croton poilanei* Gagnep	6.8	6.8	1	*Croton poilanei* Gagnep	30.8	30.8
	2	*Eberhardtia tonkinensis* Lecomte	4.9	11.6	2	*Alphonsea squamosa* Finet & Gagnep.	11.2	42.0
	3	*Illicium sp.*	4.4	16.0	3	*Engelhardia roxburghiana* Wall.	9.7	51.7
	4	*Lithocarpus corneus* (Lour.) Rehder	4.3	20.3				
	5	*Alphonsea squamosa* Finet & Gagnep.	2.8	23.2				
	6	*Trivalvaria costata* (Hook.f. & Thomson) I.M.Turner	2.6	25.7				
	7	*Sp*	2.4	28.2				
	8	*Aglaia lawii* (Wight) C.J. Saldanha	2.4	30.6				
	9	*Madhuca pasquieri* (Dubard) H.J. Lam	2.4	33.0				
	10	*Castanopsis tonkinensis* Seemen	2.4	35.3				
	11	*Engelhardia roxburghiana* Wall.	2.2	37.6				
	12	*Litsea verticillata* Hance	2.1	39.7				
	13	*Cryptocarya sp.*	1.9	41.6				
	14	*Magnolia fordiana* (Oliv.)Hu	1.7	43.2				
	15	*Dimocarpus fumatus* (Blume) Leenh.	1.6	44.8				
	16	*Macropanax undulatus* (Wall. ex G.Don) Seem.	1.5	46.3				
	17	*Diospyros sylvatica* Roxb	1.4	47.6				
	18	*Osmanthus matsumuranus* Hayata	1.3	48.9				
	19	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	1.2	50.1				
Buffer zone	1	*Croton poilanei* Gagnep	6.6	6.6	1	*Croton poilanei* Gagnep	29.8	29.8
	2	*Altingia siamensis* Craib	5.7	12.3	2	*Ardisia fordii* Hemsl.	3.5	33.3
	3	*Litsea cubeba* (Lour.) Pers.	5.0	17.3	3	*Eberhardtia tonkinensis* Lecomte	3.3	36.7
	4	*Styrax tonkinensis* Craib ex Hartwich	3.9	21.2	4	*Schefflera heptaphylla* (L.) Frodin	2.7	39.4
	5	*Ficus glandulifera* (Wall. ex Miq.) King	3.9	25.2	5	*Litsea cubeba* (Lour.) Pers	2.6	42.0
	6	*Mallotus paniculatus* (Lam.) Müll.Arg	2.8	28.0	6	*Engelhardia roxburghiana* Wall.	2.4	44.5

	7	*Lithocarpus corneus* (Lour.) Rehder	2.4	30.4	7	*Castanopsis sp2*.	2.2	46.7
	8	*Alphonsea squamosa* Finet & Gagnep	2.2	32.6	8	*Castanopsis cerebrina* (Hickel & A.Camus) Barnett	1.9	48.6
	9	*Macaranga denticulate* (Blume) Müll.Arg	2.1	34.7	9	*Camellia sinensis* (L.) Kuntze	1.9	50.6
	10	*Engelhardia roxburghiana* Wall.	1.9	36.6				
	11	*Alniphyllum fortune* (Hemsl.) Makino	1.9	38.6				
	12	Tarenna attenuata (Voigt) Hutch	1.9	40.4				
	13	*Diospyros dasyphylla* Kurz	1.6	42.0				
	14	*Sp*	1.6	43.6				
	15	*Prunus arborea* (Blume) Kalkman	1.6	45.2				
	16	*Phoebe sp.*	1.4	46.6				
	17	*Eberhardtia tonkinensis* Lecomte	1.4	48.0				
	18	*Schefflera heptaphylla* (L.) Frodin	1.2	49.2				
	19	*Castanopsis indica* (Roxb. ex Lindl) A. DC	1.2	50.4				
Restoration zone	1	*Styrax tonkinensis* Craib ex Hartwich	12.5	12.5	1	*Croton poilanei* Gagnep	23.0	23.0
	2	*Styrax argentifolius* H. L. Li	8.5	21.0	2	*Litsea cubeba* (Lour.) Pers	9.2	32.2
	3	*Alniphyllum fortunei* (Hemsl.) Makino	6.0	27.1	3	*Pavetta graciliflora* Wall. ex Ridl.	9.0	41.2
	4	*Altingia siamensis* Craib	5.9	32.9	4	*Litsea balansae* Lecomte	5.7	47.0
	5	*Ilex cymosa* Blume	4.5	34.7	5	*Engelhardia roxburghiana* Wall.	3.2	50.1
	6	*Diospyros dasyphylla* Kurz	4.2	41.6				
	7	*Litsea cubeba* (Lour.) Pers.	4.1	45.7				
	8	*Castanopsis tonkinensis* Seemen	3.6	49.3				
	9	*Cryptocarya concinna* Hance	3.4	52.7				

Chapter 6: Synthesis

6.1 Forests and protected areas in Vietnam

Vietnam is one of the most biodiversity-rich countries of the world because of its tropical climate and complex terrain (Facelli and Pickett 1991; Thai 1998). The country has been evaluated as one of the 16 most biologically diverse in the world, where over 310 mammals, 850 species of birds and over 12000 plant species have been recorded (WCMC 1992). Many species was found only in Vietnam or in few other places in the world (Carew-Reid et. al 2010). Under natural conditions, the most extensive and widely distributed terrestrial ecosystems in the country would be tropical evergreen forests of various types (inc. Lowland evergreen forests; Deciduous forests; Limestone forest; Montane evergreen forests). The coastal ecosystems include mangrove forests in the north and the south of the country. However, natural forests of Vietnam have been severely degraded for reasons including wars and over-exploitation. Forest status in Vietnam in 2010 can be seen in (Fig. 6.1). Recently, the forest of Vietnam has recovered with the increase of forest area and percentage of forest cover. For example, in 2015 Vietnam has 14 061 856 ha of forest land and the forest cover accounts for 40.84% (MARD 2015). Nevertheless, the quality of the covering forest is still poor in timber productivity and species diversity.

To rehabilitate and restore the degraded forests and protect the main ecosystems represented in Vietnam, threatened and endemic species, remaining habitats, and valuable landscapes for culture, ecology and biodiversity, Vietnam established a system of protected areas throughout the country occupying around 7% of the total area (Fig. 6.2).

Protected areas are divided into four different categories: National Parks, Nature Reserves, Species or Habitat Conservation Areas and Landscape or Seascape Protected Areas. National Parks are established to protect the ecosystems, species or landscapes that have important roles for country and the world, and also facility for scientific study and eco-tourism. Nature Reserves are to protect and maintain ecosystems, floral and faunal species in their natural condition and also provide for scientific study and environmental management. Species or Habitat Conservation Areas aim to protect and assist particular threatened species and their environment. Landscape or Seascape Protected Areas are to protect famous natural landscapes or national cultural properties. They are also to protect the natural beauty of forests, caves, waterfall, sand dunes, coral islands and volcanic craters.

However, due to several limitations in conservation effectiveness of protected areas (FTSA 2001), many species in Vietnam are therefore endangered and prone to extinction, of which 464 plant species are listed as '*threatened*' to varying degrees (Nguyen et. al 2007). Relatively few studies have assessed the abundance of red-listed tree species associated to the impact of ecological and anthropogenic factors, and the changes of tree community and some special high value timber species in different conservation zones in order to evaluate the conservation efficacy of different conservation regimes.

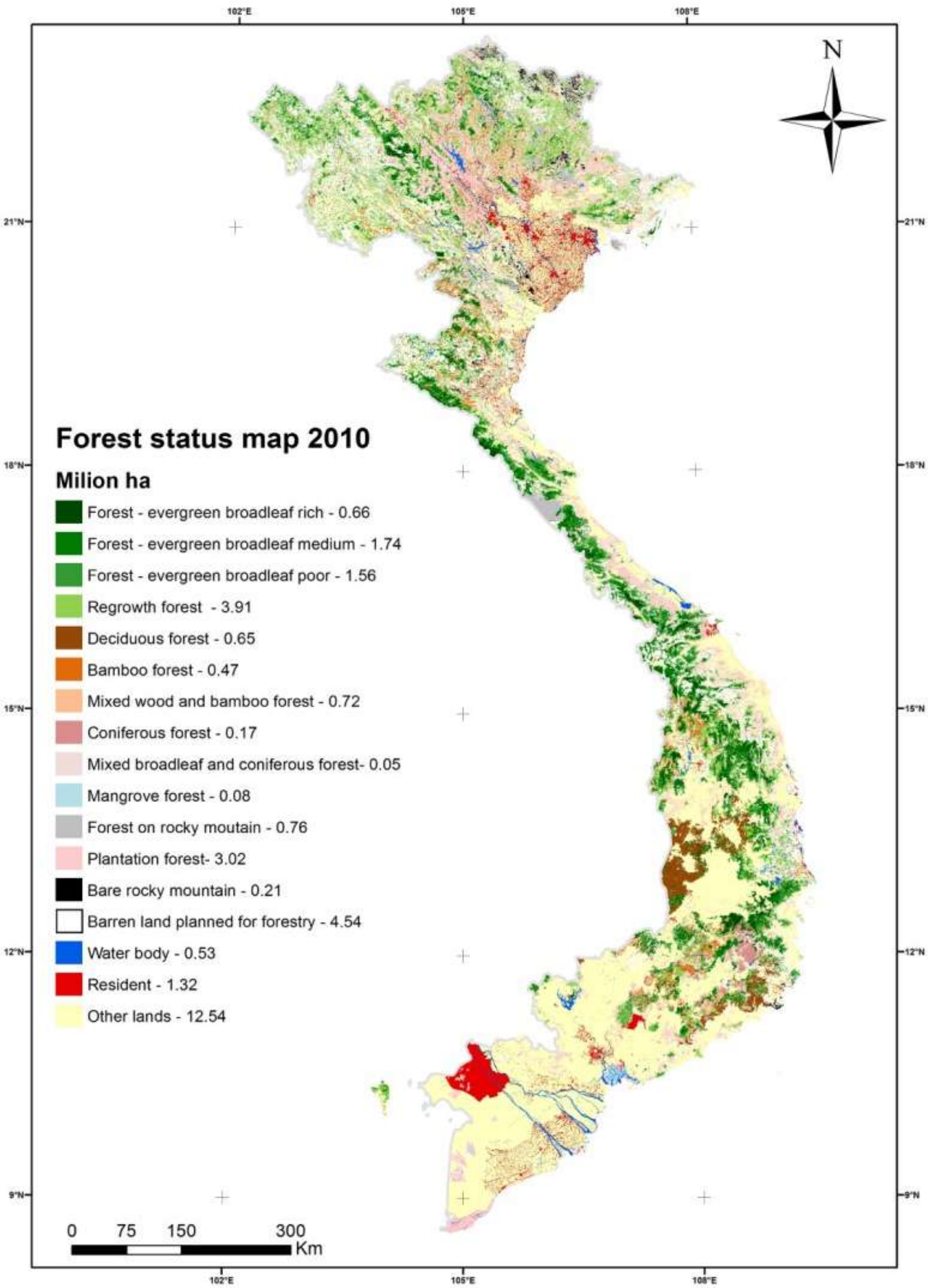

Fig. 6.1. Map of Forest status in Vietnam in 2010. *Source: Forest Inventory and Planning Institute of Vietnam, 2010.*

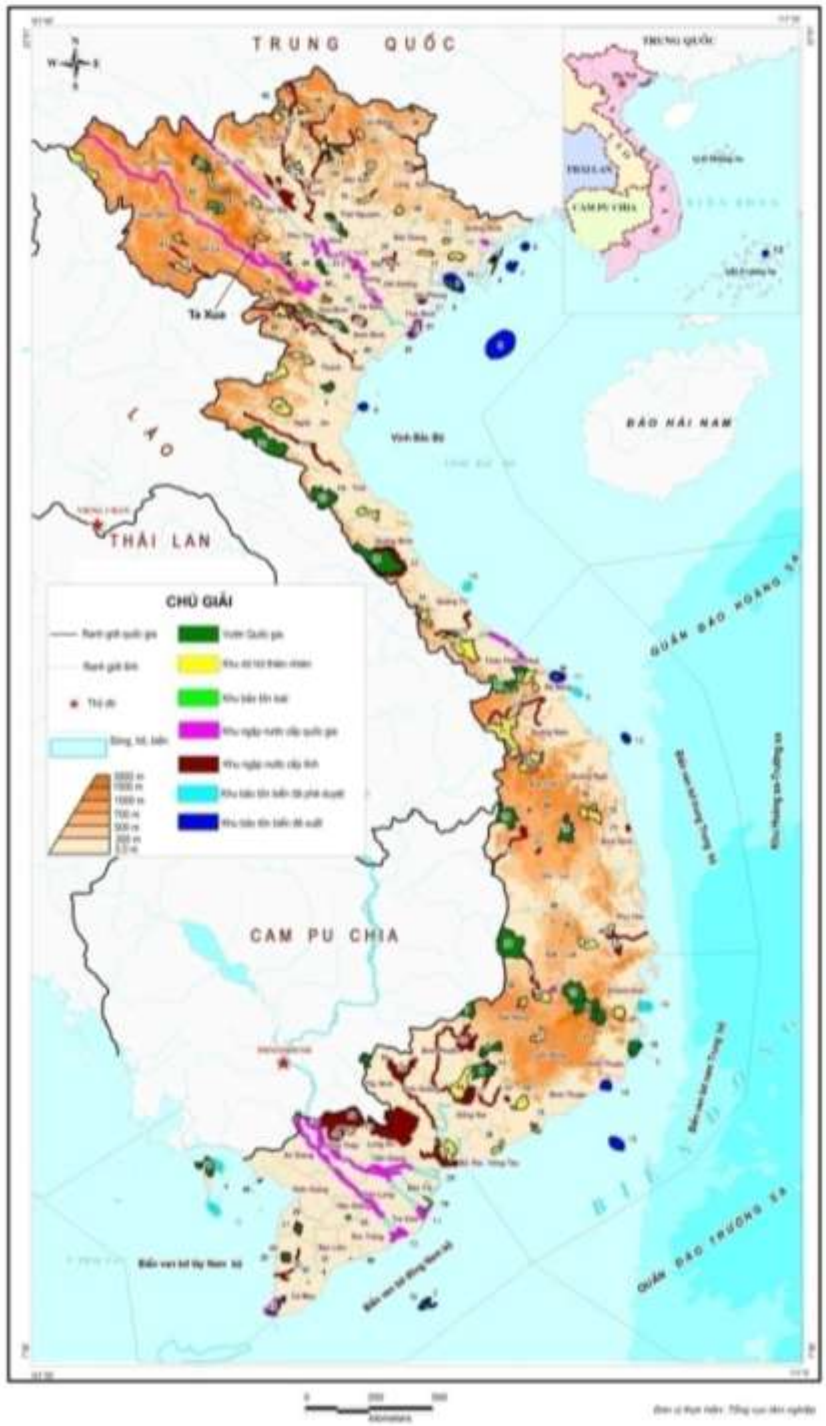

Fig. 6.2. Map of Protected areas throughout Vietnam. *Green: Nation Park; Yellow: Nature Reserve; Lime green: Species/habitat conservation area; Light purple: National important wetlands; Maroon: Provincial important wetlands; Aqua: Marine protected area (established); Blue: Marine protected area (planned). Source: Vietnam Administration of Forestry, 2015.*

In this research, we studied the abundance of red-listed tree species in three different conservation zones **(Chapter 3)**, analyzed the pattern of tree community differences between the strictly protected core zone and the low intensity forest use buffer zone **(Chapter 4)**, and assessed the population status of an iconic tree species *F. hodginsii* and two threatened tree species *A. spectabilis* and *Q. platycalyx* **(Chapter 5)** in the Ta Xua Nature Reserve, a protected area in north-western Vietnam.

6.2 Abundance of red-listed tree species (Chapter 3)

Based on random sampling method, 193, 173 and 135 tree species with DBH of at least 6 cm were encountered in the strictly protected core zone, the buffer zone and the restoration zone, respectively. Totally 18 red-listed tree species were detected in three conservation zones. Red-listed tree species declined from 16 species in the core zone, to 10 species in the buffer zone, and five species in the restoration zone. Most red-listed species reached their highest densities in the core zone, but one species (*Q. platycalyx*) was quite abundant in the restoration zone. Canonical correspondence analysis suggested the reduce abundance of red-listed species caused by anthropogenic activities. The results emphasized the importance of strictly exclusive statutory protection measure in protecting of threatened tree species.

6.3 Patterns of tree community differences in the core and buffer zones (Chapter 4)

Overall, 249 tree species (trees$_{\geq 6cm}$) were encountered in the core zone and buffer zone in which 120 tree species provided non-timber forest products, 54 tree species were valuable timber species, 35 tree species were multiple-use species (providing both NTFPs and valuable timber).

79 tree species were rare in at least one of the zones, and 18 tree species were red-listed tree species. The tree communities between the core zone and buffer zone are similar in tree density, but significantly different in tree diameter and species richness. In the tree level, logistic regression analysis indicated *red-listed status*, *large diameter*, and *low density* increased while *NTFP use* reduced the probability of tree absence in the buffer zone. However, *valuable timber* was not a significant variable in predicting model. Most NTFP species had different densities in the core and buffer zones, and this correlated with signs of human interference. At the species level, the *density of species* was the most important variable, and rarity strongly increased the probability of species absence. Our models can allow the evaluation of conservation effectiveness in a given nature reserve over time and among nature reserves and national parks, and also facilitates the development of conservation strategies by quantifying the effects of different forest management measures on the presence or absence of trees and species.

6.4 Fujian cypress and two other threatened tree species across conservation zones of a nature reserve of north-western Vietnam (Chapter 5)

Adaptive cluster sampling method was applied for inventorying the abundance of three threatened tree species, *F. hodginsii, A. spectabilis* and *Q. platycalyx,* across three conservation zones. Similar pattern was found for *F. hodginsii* and *A. spectabilis* with the highest number of mature in the core zone, intermediate in the buffer zone and lowest in the restoration zone. In contrast, *Q. platycalyx* had its highest density in the restoration zone. Regenerations of all three target species were found in the core zone; however, no regeneration or only one or two seedlings of *F. hodginsii* and *A. spectabilis* were detected in the buffer and regeneration zones.

The distribution of *F. hodginsii* and *A. spectabilis* was aggregated and their regeneration was mostly found in the vicinity of conspecific adult trees. Our data do not support conservation concerns regarding *Q. platycalyx* in used and secondary forests, which may influence its status in the next assessment of endangered species. However, *F. hodginsii* and *A. spectabilis* were mostly confined to the core zone, and regeneration of these species was absent or very rare in the buffer and restoration zones. For these two species, the unused core zone was the most important refuge, so continued conservation of this zone is important for the preservation of these species.

6.5 Future outlook

Our results strongly emphasize the importance of strictly exclusive statutory protection measures for protecting rare and threatened tree species. Our models also allow evaluation the conservation effectiveness based on the significant variables affected to probability of tree absence and species absence in the buffer zone in the Ta Xua Nature Reserve over the time and among other nature reserves and national parks. *F. hodginsii* and *A. spectabilis* are really endangered and were strongly confined to the core zone, but *Q. platycalyx* was not endangered in secondary forests, therefore, its status should be re-evaluated in the next assessment of endangered species. However, our findings are only at the beginning of understanding about the abundance of threatened tree species associated with ecological factors and human interference in different conservation regimes. This study also can be constrained by pseudo-replication when the study was conducted in a single nature reserve. Therefore, further studies across more protected areas with similar statutory zonation characteristics would be very welcome in order to draw more general conclusions. Application of several different approaches and methods also including remote sensing technologies for forest monitoring is one of the important development steps. Studies of the spatial patterns of regeneration of *F. hodginsii* in relation to adult trees; breeding and nursery techniques and transplant experiments for two endangered tree species, *F. hodginsii* and *A. spectabilis*, should be conducted in order to comprehend their biology and ecology attributes and facilitate the protection and conservation of these species. Furthermore, some other studies on ecosystem services would be also added to assess the benefits people obtain from ecosystems as well as the social and economic values of forest ecosystems, that so facilitate the managers, policy-makers release suitable legal regulations to balance conservation and socio-economic objectives.

6.6 References Chapter 6

Carew-Reid, J., Kempinski, J., & Clausen, A. (2010). Biodiversity and development of the hydropower sector: Lessons from the Vietnamese Experience–Volume i: Review of the effects of hydropower development on biodiversity in Viet Nam. *Hanoi: International Centre for Environmental Management (ICEM)*.

Facelli, J. M., & Pickett, S. T. (1991). Plant litter: its dynamics and effects on plant community structure. *The Botanical Review*, *57*(1), 1–32.

Forest Techniques and Science Association of Vietnam, (FTSA) (2001). *National Parks in Vietnam*. Agricultural Publishing House, Hanoi.

Ministry of Agriculture and Rural Development (MARD) (2015). Decision No. 3158/QĐ-BNN-TCLN. Forest status in Vietnam 2015.

Nguyen ,T.B., Tran, D.L., Nguyen, K.K. (2007) Vietnam red list. Part II: Plants. Science and Techniques Publishing House, Hanoi.

Thai, V.T. (1998) Ecosystem of tropical forests in Vietnam. Science and Technique Publishing House, Hanoi.

World Conservation Monitoring Centre, (WCMC). (1992). Development of a national biodiversity index. A discussion paper prepared by the World Conservation Monitoring Centre. Cambridge, UK.

Index of Figures

Index of Tables

Acknowledgement

First and foremost, I would like to express my special appreciation and deeply-felt thanks to my supervisor, Prof. Dr. Dirk Hölscher, for his warm encouragement, thoughtful guidance and continuous support of my PhD study. His guidance, motivation, and immense knowledge helped me in all the time of research, during field work, data analysis, writing and publishing process. He offered me so much advice, patiently supervising me, and always guiding me in the right direction. I have learned a lot from him and I am very grateful to him. It will not be enough to express my gratitude to him in words.

I am very grateful to Prof. Dr Joachim Saborowski for fruitful collaborations and contributive comments on this study.

I would like to give my sincere thanks to Prof. Dr. Christian Ammer and Prof. Dr. Holger Kreft for agreeing to be on the committee.

Special thanks are also given to the Vietnamese Government, the German Academic Exchange Service, the Rufford Small Grants Foundation, and the International Tropical Timber Organization for financial support for this study.

I am thankful to Vietnam National University of Forestry for providing all required support during the whole period of my Ph.D study. A word of thanks is extended to Prof. Dr. Vu Tien Hinh, Assoc Prof. Dr. Vu Nham, and Prof. Dr. Tran Huu Vien for their advice and help.

I would like to express my appreciation to the managers, staffs and local people in the Ta Xua Nature Reverse for helping me during my field visits. I also thank Nguyen Quang Dung, Luong Vuong Phong, Luong Vuong Tai, Dang Van Long, Dao Van Phuc, Nguyen Minh Tri, Pham Kim Cuong, Vang A Say, Vang A Chu, for their assistance during different phases of the fieldwork; Phan Van Dung, Phung Van Phe, Trinh Ngoc Bon, Nguyen Van Huy, Vuong Duy Hung for tree identification; Tran Thi Hang, Tran Thi Hop for help in soil sample analysis; Phan Thanh Noi and Le Thi Khieu for preparing the map of my study site.

I gratefully acknowledge all my colleagues at the department of Tropical Silviculture and Forest Ecology for providing an environment of support and encouragement during my stay in Göttingen. Special thanks to Dr. Denis Peque and Dr. Ngo The Long for sharing of ideas, insightful comments and discussions on rare and threatened tree species.

I am also grateful to my parents and my parents-in-law for their understanding and their love that encouraged me to work hard and to continue pursuing a PhD project abroad. I am also thankful to my beloved husband Nguyen Quang Dung for his love, support and encouragement in all the time of my study in Göttingen. Special thanks are also given to my beloved daughter Nguyen Dao Thao Nhi for coming into my life, being my baby, and bringing such happiness into my life. She is the best thing in my life and I love her so much.

Declaration of honor

I hereby declare that I am the sole author of this dissertation entitled "THREATENED TREE SPECIES ACROSS CONSERVATION ZONES IN A NATURE RESERVE OF NORTH-WESTERN VIETNAM". All the references and data sources that were used in this dissertation have been acknowledged. I further declare that this work has never been submitted in any forms as part of any other dissertation procedure.

Göttingen, January 2017 ______________________________

(Dao Thi Hoa Hong)

Curriculum vitae

Personal details	
Full name	**Dao Thi Hoa Hong**
Date of birth	5th October 1982
Place of birth	Thanh Oai, Ha Noi, Vietnam
Nationality	Vietnamese
Contact address	Faculty of Silviculture Vietnam National University of Forestry Xuan Mai town, Chuong My district, Hanoi, Vietnam Tel: +84 433 608 423 Mobile: +84 984 849 772 Email: daothihoahong82@gmail.com
Education	
Primary school (1987-1992)	Tam Hung Primary school, Vietnam
Secondary school (1992-1996)	Tam Hung Secondary school, Vietnam
High school (1996-1999)	Thanh Oai B Specialized high school, Vietnam Specification: Mathematic
Higher education	
BSc (1999-2003)	*Silviculture*, Vietnam National University of Forestry
MSc (2006-2009)	*Silviculture*, Vietnam National University of Forestry.
PhD (2013-2017)	*Forest Sciences and Forest Ecology*, Tropical Silviculture and Forest Ecology, Georg-August-Universität Göttingen.
Work experience	
Lecturer (2005 – Now)	Forest Inventory and Planning, Faculty of Silviculture, Vietnam National University of Forestry, Hanoi, Vietnam

Scientific researcher

2005-2010	Collaborator of a project: "Transformation of *Magnolia conifera* (*Dandy) V.S.Kumar* and *Cunninghamia lanceolata (Lamb.) Hook.* plantations from providing small wood to big wood in Ha Giang and Tuyen Quang provinces, Vietnam".
2007-2009	Collaborator of a project: "Assessments of non-timber forest product resources for making sustainable development plan in Ha Tay province, Vietnam"
2007	Project leader of a study "Determine the main reasons that caused the degradation of *Dendrocalamus membranaceus*

	Munro and propose suitable solutions to sustainable harvesting in Nguyet An commune, Ngoc Lac district, Thanh Hoa province, Vietnam.
2008	Project leader of a study “Determine some appropriate silviculture techniques for IIIA3 forest status to provide industrial wood for Con Cuong enterprise”
2009	Project leader of a study “Analysis the principles, attributes and demands of sustainable development in tropical forest management and reality in Vietnam”
	Project leader of a study “Assessment of two forest inventory methods for planning sustainable community forest management”
	Project leader of a study “The impact of local communities on protecting and managing community forests in Dien Bien province, Vietnam”

Peer-reviewed publications

2009	Dao T.H.H. (2009). Assessment of two forest inventory methods for planning sustainable community forest management. *Journal of Agriculture and Rural Development: 75-80*
2009	Dao T.H.H and Pham T.Q. (2009). Analyzing the principles, particularity and demands of sustainable development in tropical forest management and reality in Vietnam. *Journal of Ecological Economy 60-67.*
2015	Dao T.H.H. and Hölscher D. (2015). Red-listed tree species abundance in montane forest areas with differing levels of statutory protection in north-western Vietnam. *Tropical Conservation Science 8, 479-490.*
2016	Dao T.H.H., Saborowski, J., Hölscher, D. (2016). Patterns of tree community differences in the core and buffer zones of a nature reserve in north-western Vietnam. *Global Ecology and Conservation 8, 220-229.* doi:10.1016/j.gecco.2016.09.011