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

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Abstract

Background: Fujian cypress (*Fokienia hodginsii*) is a highly valued but 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 120 random sample plots of 400 m^2, we applied adaptive cluster sampling for trees with a diameter at breast height (DBH) of at least 6 cm. In addition, tree regeneration (DBH < 6 cm) was assessed.

Results: In the core zone, *F. hodginsii*, *A. spectabilis* and *Q. platycalyx* occurred at moderate densities (4.9, 5.1 and 4.4 trees·ha^{-1}, respectively). *F. hodginsii* and *A. spectabilis* were however 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 were only a few regenerating trees of *F. hodginsii* and *A. spectabilis* in the buffer and regeneration zones. Regeneration of *F. hodginsii* and *A. spectabilis* was mostly in the vicinity of conspecific adult trees.

Conclusions: *F. hodginsii* and *A. spectabilis* were mostly confined to the core zone, and regeneration of these species was rare in the buffer and restoration zones. For these two species, the core zone was the most important refuge, so continued conservation of this zone is important for the preservation of these species. The results of this study in the Ta Xua Nature Reserve do not confirm the classification of *Q. platycalyx* as 'vulnerable' in the Vietnam Red List. Further forest monitoring including repeated population assessments is needed to evaluate the vulnerability of threatened tree species.

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

Background

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).

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A major forest conservation strategy involves the establishment of strictly protected zones to safeguard remaining habitats and species (Bruner et al. 2001; Joppa and Pfaff 2010). These zones are often surrounded by low-use buffer zones, which enhance the conservation value of the protected area and provide forest products for the local population (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 may serve as '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 in various ways. Low-intensity selective logging may have little detrimental effect on biodiversity (Gibson et al. 2011); however intensive 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 effectiveness of different conservation practices.

Vietnam has a high biodiversity because of its tropical climate and complex terrain (Facelli and Pickett 1991; Thai 1998). However, wars and over-exploitation have 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, the 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 are using 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 of its population (Nguyen 2000). This species is now rare, and mainly occurs in certain protected areas (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 two species is of good quality, highly valued and used for construction and furniture. Populations of *A. spectabilis* and *Q. platycalyx* are 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. In previous surveys based on random sampling, we found that red-list status and large diameter were predictors of rarity (Dao et al. 2016). However, rare and moderately rare species may not be well represented in random sampling, because such species may be absent in many sampling units, causing errors in the estimates of population sizes (Cochran 1977; Gaston 1994). In such cases adaptive cluster sampling (ACS) can be an effective sampling method (Thompson 1990; Philippi 2005). Therefore, we applied ACS to determine the population status of *F. hodginsii*, *A. spectabilis* and *Q. platycalyx* in the Ta Xua Nature Reserve. The 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 about the vulnerability of these species, and may serve to guide conservation efforts. More generally, the 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.

Methods

Study area

The Ta Xua Nature Reserve (21°13′ – 21°26′ N, 104°16′ – 104°46′ E, Fig. 1) was established in 2002. The Nature Reserve has high, steeply sloping mountains rising from 320 m to 2765 m a.s.l. The climate is humid-tropical, influenced by the north-easterly 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.

The reserve has a core zone of 15,211 ha which is 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. Forest cover in the core zone is 87%, and forest types range from evergreen and broad-leaved rainforest at lower elevations to coniferous forest mixed with some evergreen and broad-leaved species on the higher peaks (Forest Inventory and Planning

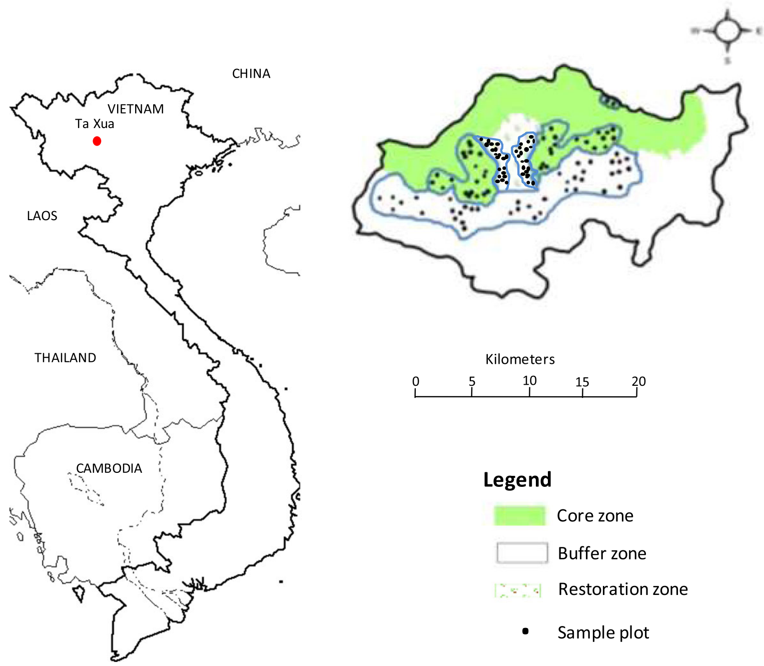

Fig. 1 Location of the Ta Xua Nature Reserve in north-western Vietnam (left), and detail of the study area, which is enclosed by blue lines (right; 1000–1700 m a.s.l.). Black dots indicate initial random sample plots (40 plots per zone)

Fig. 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

Table 1 Number of initially positive plots (among the 40 initial random plots per zone), added positive plots, added negative plots (from ACS), and individual trees$_{\geq 6cm}$ of the three target species. Means and standard deviations of DBH and tree density (trees$_{\geq 6cm}$·ha^{-1}) were determined by the Hansen-Hurwitz estimator

	Conservation zone	Initial positive plots	Added positive plots	Added negative plots	Detected individuals (tree$_{\geq 6cm}$)			Density (n·ha^{-1})	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

Institute (FIPI), 2002). The core zone can only be reached by footpaths. These paths were either created before the nature reserve had been established, or were established to facilitate ranger patrols, research activities, or access for tourists.

The buffer zone encompasses 24,674 ha above 900 m a.s.l. and has 44% forest cover. The zone 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/QH 11, 2004). Based on these regulations, a maximum of 25 trees may be felled per year in a forest area of 10,856 ha. However, during field work, signs of illegal tree felling were observed. Land below 900 m a.s.l. is mainly agricultural land, with upland rice, maize, and sugarcane predominating (Forest Inventory and Planning Institute (FIPI), 2002).

A protected restoration zone was also established within the reserve, consisting of 2439 ha enclosed within the core zone, and partly bordering on 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 (Forest Inventory and Planning Institute (FIPI), 2002).

Target tree species

Three tree species (*Fokienia hodginsii* (Dunn) A. Henry & H.H. Thomas (Fujian cypress), *Aglaia spectabilis (*Miq.) S.S. Jain & S.S.R. Bennet, and *Quercus platycalyx* Hickel & *A. Camus*; Fig. 2), were surveyed in this study.

Table 2 Site conditions and forest structural characteristics of the three conservation zones. Numbers are means and standard deviations, with 40 initial random plots per zone

	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^{-1})	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$_{\geq 6cm}$; m^{2}·ha^{-1})	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. per 40 plots)	193	173	135
Mean species richness (trees$_{\geq 6cm}$, sp. per plot)	22.1 ± 5.1^{a}	19.3 ± 5.9^{b}	16.8 ± 5.0^{c}
Observed red-listed species richness (trees$_{\geq 6cm}$, sp. per 40 plots)	16	10	5
Stumps (no. per plot)	0.6 ± 0.8^{a}	1.6 ± 1.6 ^{b}	1.7 ± 1.4^{b}
Footpaths (no. per plot)	0.9 ± 0.6^{a}	1.5 ± 0.8^{b}	1.1 ± 0.9^{a,b}

Significant differences in the means of three conservation zones at the level of $p \leq 0.05$ were indicated in different superscript letters

F. hodginsii is native to southern, south-western and south-eastern China (Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hunan, Jiangxi, Sichuan, Yunnan, Zhejiang), Lao People's Democratic Republic and Vietnam (IUCN 2014). It 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).

A. spectabilis has a wide distribution, and occurs in Southeast Asia, China, and India. It is usually found in near natural or slightly disturbed forests and grows on deep, clay and well-drained soil. The tree species is long-lived, reaching great size. Seeds are dispersed by mammals (especially civets and squirrels), birds, or ballistic dehiscence (Nguyen et al. 1996). The natural population is fragmented due to habitat destruction and over-exploitation.

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. This species is threatened by selective logging for its timber.

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 to randomly place the sample plots. Forty plots of 20 m × 20 m were established in each conservation zone, with the center of each plot located in the center of a selected cell (Dao et al. 2016).

Adaptive cluster sampling (ACS) initially uses randomly located plots, then successively adds plots close to those having a target species. Any additional plots having the species have more neighboring plots added, leading to a cluster of plots. This method is particularly suitable for finding trees and effective if the population of interest species is rare and clustered (Thompson 1990). The method leads to an unbiased estimate of mean abundance via the Hansen-Hurwitz estimator (Thompson and Seber 1996). The 40 random sample plots of 400 m^2 (20 m × 20 m) per conservation zone were the initial plots. This procedure was applied separately for each of the three target species with a focus on big trees with a diameter at breast height (DBH) of at least 6 cm ($tree_{\geq 6cm}$). The final number of established plots is presented in Table 1.

For the inventory of tree regeneration (DBH < 6 cm), in the center of each initial random plot and also in additional ACS plots, a subplot of 25 m^2 (5 m × 5 m) was established.

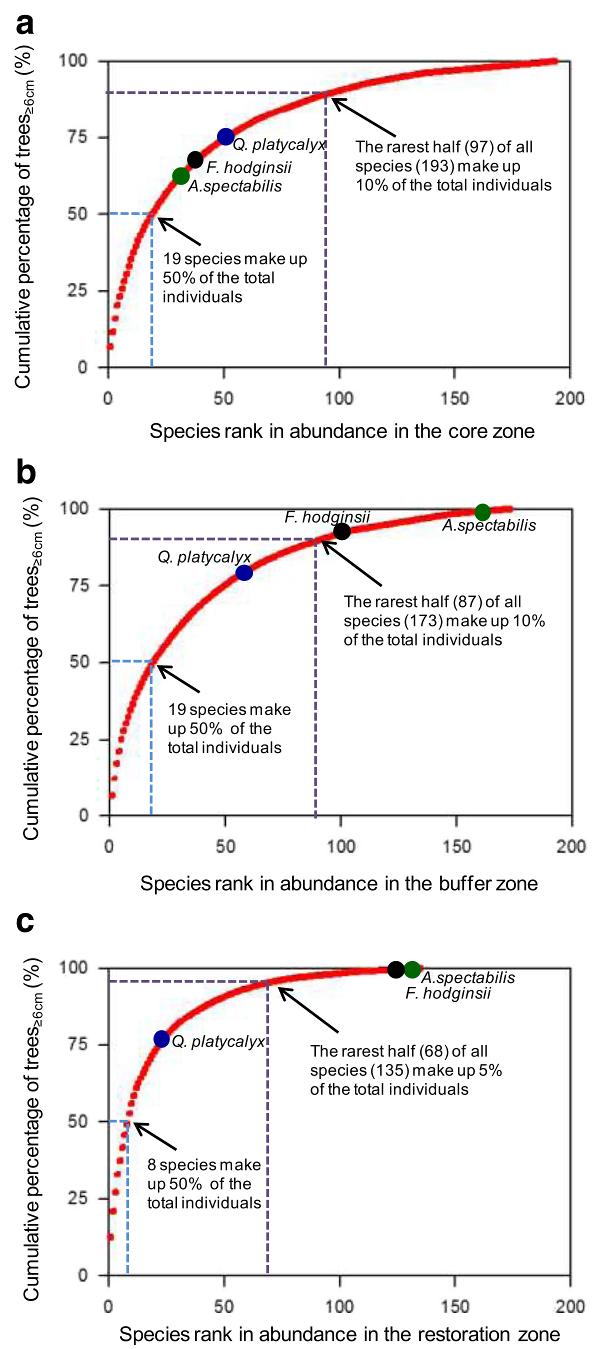

Fig. 3 Cumulative abundance of tree species ($trees_{\geq 6cm}$) in 40 initial random plots in the core zone (**a**, 193 species), buffer zone (**b**, 173 species), and restoration zone (**c**, 133 species). The ordinate represents the cumulative percentage of individuals, and the abscissa represents the abundance rank of species, from most abundant (left) to rarest (right). The rank abundance of the three target species is indicated

Data collection

Field work was conducted in 2014. In the initial and adaptively added plots, each target and non-target $\text{tree}_{\geq 6\text{cm}}$ was counted, and its DBH was measured. All $\text{trees}_{\geq 6\text{cm}}$ in the 400 m^2 plots, and regenerating $\text{trees}_{<6\text{cm}}$ 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 at species level were classified by genus or family, and sorted into morpho-species. Some information about site conditions including elevation, slope inclination and soil pH, forest structure characteristics such as canopy closure, tree density and basal area, and human interference (numbers of stumps and footpaths) in the initial random sample plots was also collected.

The three conservation zones had similar basic site characteristics such as soil pH and slope inclination (Table 2). The two signs of human disturbance, number of stumps and number of footpaths, were lowest 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).

Statistical analysis

An ANOVA was used to determine the significance of differences in the means of the three conservation zones (significant if $p \leq 0.05$) if the data satisfied the criteria of normal distribution and equality of the variances. When these requirements were not met, the non-parametric Kruskal-Wallis *H* test was applied. The mean densities of the three target species from adaptive cluster sampling were calculated using the modified and unbiased Hansen-Hurwitz estimator (Thompson and Seber 1996). The total population sizes of the three target tree species ($\text{trees}_{\geq 6\text{cm}}$) in each conservation zone were estimated based on the average densities as derived from the adaptive cluster sampling, total area of the zone and percentages of forest cover in the respective zone.

Results

Abundance of the three target species

In the core zone, the three target species were moderately rare tree species. The abundance ranks of *F. hodginsii*, *A. spectabilis* and *Q. platycalyx* were 34, 32 and 49, respectively (Fig. 3a). The average density of *F. hodginsii* was 4.9 trees·ha^{-1}; *A. spectabilis* was 5.1 trees·ha^{-1}, and *Q. platycalyx* was 4.4 trees·ha^{-1} (Table 1). *F. hodginsii* and *A. spectabilis* were much less abundant in the buffer and restoration zones; however, *Q. platycalyx* had its highest density in the restoration zone (Table 1, Fig. 3b & c).

A rough estimation of the total population sizes of *F. hodginsii*, *A. spectabilis* and *Q. platycalyx* ($\text{trees}_{\geq 6\text{cm}}$) results in 64,844, 67,491 and 58,228 $\text{trees}_{\geq 6\text{cm}}$, in the core zone, respectively; 20,627, 6,513 and 53,197 $\text{trees}_{\geq 6\text{cm}}$ in the buffer zone; and 834, 834, 23,078 $\text{trees}_{\geq 6\text{cm}}$ in the restoration zone.

Regeneration

We examined 40 random subplots of 25 m^2 to assess tree regeneration. There were 133 regenerating tree species in the core zone, 130 in the buffer zone, and 80 in the restoration zone. The highest density of regeneration of all tree species was in the core zone, and the lowest density was in the restoration zone (Table 3).

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 3 and Fig. 4).

Regeneration was also assessed in the subplots of the adaptive cluster sampling plots. In the core zone, these subplots had 17 regenerating *F. hodginsii* trees and 52 regenerating *A. spectabilis* trees. None of the subplots inside the added negative plots – which had no target $\text{trees}_{\geq 6\text{cm}}$ – had any regenerating trees of *F. hodginsii* and *A. spectabilis* (Table 4). For *Q.*

Table 3 Species richness and density of regenerating tree species in the three conservation zones. The results are from 40 initial random subplots per zone

	Core zone	Buffer zone	Restoration zone
Observed species richness ($\text{trees}_{<6\text{cm}}$, sp. per 40 subplots)	133	130	80
Tree density ($\text{trees}_{<6\text{cm}}\cdot\text{subplots}^{-1}$)	31.9 ± 22.6^{a}	24.7 ± 16.6^{ab}	22.2 ± 12.1^{b}
F. hodginsii ($\text{trees}_{<6\text{cm}}\cdot(40\ \text{subplots})^{-1}$)	2	0	2
A. spectabilis ($\text{trees}_{<6\text{cm}}\cdot(40\ \text{subplots})^{-1}$)	2	2	0
Q. platycalyx ($\text{trees}_{<6\text{cm}}\cdot(40\ \text{subplots})^{-1}$)	7	1	3

Significant differences in tree density of three zones at the level of $p \leq 0.05$ were indicated in different superscript letters. Numbers are means and standard deviations

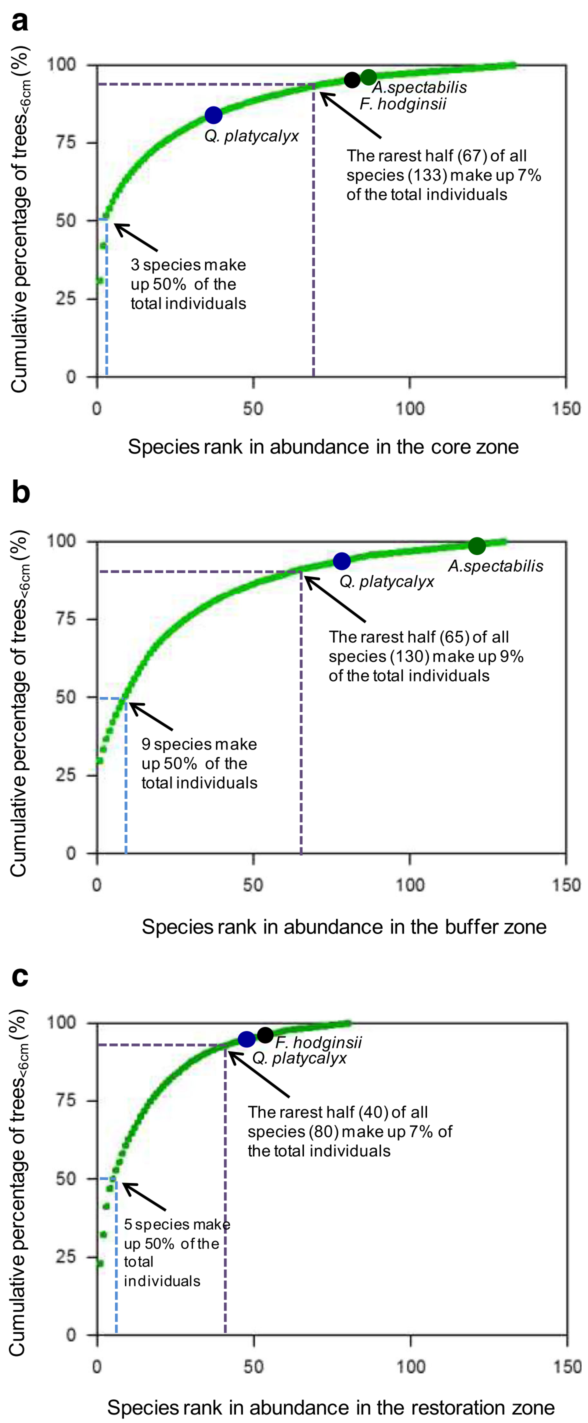

Fig. 4 Cumulative abundance of regenerating tree species (trees$_{<6cm}$) in 40 initial random subplots in the core zone (**a**, 133 species), buffer zone (**b**, 130 species), and restoration zone (**c**, 80 species). The ordinate represents the cumulative percentage of individuals, and the abscissa represents the abundance rank of species, from most abundant (left) to rarest (right). The rank abundance of the three 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**)

platycalyx, the four initial sample subplots had 7 regenerating trees, but no more regenerating trees were detected in subplots inside added positive and added negative plots. In the buffer zone, we observed no regenerating trees of *F. hodginsii* in any of the added subplots, and in the restoration zone only one regenerating tree of *A. spectabilis* was observed. These results indicate that regenerating trees of *F. hodginsii* and *A. spectabilis* often appeared in the vicinity of large conspecifics in the core zone.

Discussion

Our study indicates that 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, a small number of regeneration individuals of *F. hodginsii* and *A. spectabilis* was found 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.

The greatest density of *F. hodginsii* was found in the core zone. Densities were much lower 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). In that previous study distances were measured from specific individuals to their nearest neighbors using the Clark and Evans (1954) index of aggregation. The results indicated that *F. hodginsii* occurred in a clumped distribution. In Vietnam, the main reason for the declining population of *F. hodginsii* is overexploitation because of the valuable timber of this species (Luu and Thomas 2004; Farjon 2010). Mature *F. hodginsii* trees have been heavily harvested by legal and illegal logging over the past 50 years (Nguyen et al. 2015). Although many recent laws protect and limit the use of this species' timber (Osborn 2004), the number of mature trees is still declining. 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 only a few regenerating individuals in the buffer zone and the restoration zone. Intensive logging of large-diameter trees may have led to 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 a low germination rate (30–360 days), and a relatively hard seed coat (Nguyen et al. 2015), may have also contributed to the poor regeneration.

Table 4 Number of initially positive subplots for regenerating trees$_{<6cm}$ (among 40 initial random subplots per zone); subplots and trees$_{<6cm}$ in added positive plots and added negative plots (from ACS of trees$_{\geq 6cm}$), and total detected trees$_{<6cm}$ of three target species

	Conservation zone	Random sampling		ACS added plots base on trees$_{\geq 6cm}$				Total detected tree$_{<6cm}$
		Positive subplot	Tree$_{<6cm}$	Subplots in added plots		Subplots in added negative plots		
				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

In this study, we only found seedlings 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 may reduce recruitment near reproductive adults. Findings from other studies also supported the negative density dependence that constrains juvenile performance near reproducing conspecifics (Comita et al. 2014). However, the same does not seem to apply to *F. hodginsii*. Hubbell (1979) and Hubbell and Foster (1983) previously reported that roughly half of the 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 a favorable microhabitat for germination and seedling survival (Wright 2002; Crawley 2009) may explain the presence of regenerating trees near parents in the core zone. In the 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 rich in sesquiterpenes with strong defence mechanisms against mosquitoes and other insects (Lesueur et al. 2006; Paluch 2009). However, only a limited number of previous studies did examine the spatial distribution of regenerating *F. hodginsii* trees. The spatial pattern of regenerating and adult *F. hodginsii* trees requires therefore more rigorous analysis, otherwise the ecological reasons for the aggregated distributions remain speculative. Our results, however, clearly show that adult and regenerating *F. hodginsii* trees are mainly confined to the core zone, making that zone 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, but a few occurred in the buffer and restoration zones. 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.

The distribution patterns of *Q. platycalyx* was very different when compared to those of *F. hodginsii* and *A. spectabilis*. The greatest number of individuals was found in the restoration zone, a moderate number occurred in the buffer zone, and the lowest number occurred in the core 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* is able to colonize disturbed sites. *Q. platycalyx* 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).

Conclusion

Our results indicate that *F. hodginsii* and *A. spectabilis* were mostly confined to the core zone, and regeneration of these species was rare in the buffer and restoration zones. For these two species, the protected core zone was the most important refuge. Continued conservation of this zone is therefore essential to ensure the preservation of these rare and important species. The high occurrence of *Q. platycalyx* in the Ta Xua Nature Reserve does not confirm the need to classify this species as 'vulnerable' in the Vietnam Red List. This study, which is based on a one-time census, should be complemented by future research initiatives that will investigate population dynamics. Forest monitoring with repeated population assessments is needed to estimate the vulnerability and long-term survival of a threatened tree species.

Appendix

Table 5 Rank abundance of the most common tree 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

Table 5 Rank abundance of the most common tree species that account for 50% of total individuals in each conservation zone *(Continued)*

	Trees$_{\geq 6cm}$				Trees$_{<6cm}$			
	Rank	Scientific name	Percentage (%)	Cumulative percentage	Rank	Scientific name	Percentage (%)	Cumulative percentage
	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				

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Authors' contributions
The first author collected data, performed the data analysis and wrote the manuscript. The second author conceived the study, provided guidance and reviewed the manuscript. Both authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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