Short Communication

Reproductive size thresholds of dipterocarps in Cambodian dry forests

Eriko ITO[1,*], CHANN Sophal[2], TITH Bora[2], KETH Samkol[2], LY Chandararity[2], OP Phallaphearaoth[2], Naoyuki FURUYA[1] & Yukako MONDA[3]

[1] Hokkaido Research Center, Forestry and Forest Products Research Institute, 7 Hitsujigaoka, Toyohira, Sapporo, Hokkaido, 062-8516 Japan.

[2] Institute of Forest and Wildlife Research and Development, Forestry Administration, Hanoi Street 1019, Phum Rongchak, Sankat Phnom Penh Thmei, Khan Sen Sok, Phnom Penh, Cambodia.

[3] Graduate School of Agriculture, Kyoto University, Kyoto City, Kyoto, 606-8502 Japan.

* Corresponding author. Email iter@affrc.go.jp

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Tree size at the transition from juvenile (sterile) to adult (fertile) is an important species-specific character used to gain insight into the mechanisms governing forest structure and species coexistence. Various studies of this relationship in tropical forests have been attempted (Wright *et al.*, 2005). From a conservation perspective, such information also has practical applications. Seasonal tropical forest, representing 42% of tropical forests, is one of the most threatened ecosystems in the tropics (Murphy & Lugo, 1986). Currently, human population growth is causing deforestation pressure in Cambodia. For aseasonal dipterocarp forests, it has been proposed that management programmes should ensure genetic diversity and pollination efficacy (Tani *et al.*, 2009, 2012). To develop guidelines for sustainable forest use in Cambodia, basic information on forest stands and their regeneration is necessary. To this end, we determined the flowering size for components of a Cambodian dry dipterocarp forest.

The study was conducted in two permanent sample plots established in typical dry dipterocarp forests in Cambodia (Fig. 1). The first was a 4 ha (200 m × 200 m) study plot centered on a flux tower in Kratie Province (KRC, 12.9°N, 106.2°E; elevation: 74–85 m). The KRC plot has three dominant deciduous dipterocarp species: *Dipterocarpus tuberculatus* Roxb. (ca. 31% of stand basal area and 20% of stand tree number), *Shorea siamensis* Miq. (19% and 40%, respectively), and *S. obtusa* Wall. ex Blume (18% and 9%, respectively), which are associated with *Terminalia alata* Heyne ex Roth (13% and 14%, respectively). Tree density and basal area for stems with a diameter at breast height (DBH, 1.3 m above ground level) of ≥ 5 cm were 557 stem ha^{-1} and 13.6 m^2 ha^{-1}, respectively. Tertiary and quaternary sedimentary rocks underlie much of the forest (Toriyama *et al.*, 2010), and the soil type is plinthic hydromorphic. The KRC plot, in part, experiences an annual fire regime based on a plentiful supply of grasses as fuel and usually involves man-made fires created while hunting for wildlife.

The second plot was a 0.24 ha (30 m × 80 m) study plot located in Kampong Thom Province (KPT, 12.8°N, 105.5°E; elevation: 70 m). The KPT plot has one dominant dipterocarp species, *Dipterocarpus obtusifolius* Teijsm. ex Miq. (ca. 50% of stand basal area and 60% of stand tree number), which is associated with *Gluta laccifera* (Pierre) Ding Hou (35% and 6%, respectively) (Hiramatsu *et al.*, 2007). The forest does not show distinct deciduousness, but irregular, incomplete leaf shedding of its components (Ito *et al.*, 2007). Nevertheless, the forest is placed in the deciduous forest category in the Cambodian forest type classification (Forestry Administration, 2011). Tree density and basal area for stems with DBH ≥ 5 cm were

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408 stem ha^{-1} and 12.3 m^2 ha^{-1}, respectively. The site was located on extensive quaternary sedimentary rock and its soils are classified as acrisols, but with albic and arenic features that suggest a closer relationship with arenosols (Toriyama *et al.*, 2007).

The climate of the research areas is seasonal tropical, and the months from November through April are dry. Mean annual temperature is 27 °C. Annual rainfall (mean ± SD) is 1,643 ± 272 mm in KRC and 1,542 ± 248 mm in KPT (2000–2010: NIS, 2012).

We investigated the reproductive size thresholds of the four dipterocarp species mentioned above. We recorded the presence/absence of reproductive organs on trees within the KRC study plot in February 2009 (n = 68), 2010 (n = 68), 2011 (n = 1,186), 2012 (n = 953), and January–February 2014 (n = 1550, all trees). The same was done for all living trees within the KPT study plot in May 2003 and 2005, and in December 2005 and 2009. For all four dipterocarp species, flowers and flower buds were found in the dry season (December–February), while fruits were found in the subsequent early wet season (May). During our censuses, we measured the DBH of stems to the nearest 1 mm for all standing woody stems with DBH ≥ 5 cm. Tree size with and without reproduction was defined as DBH at the first recorded presence of reproductive organs and the last recorded absence of reproductive organs, respectively. We then determined the minimum tree size for reproduction in *D. obtusifolius*, *D. tuberculatus*, *S. obtusa*, and *S. siamensis* using nominal logistic regression models.

Sist *et al.* (2003) recommended a procedure for setting diameter-based cutting limits for trees according to their diameter at the onset of reproduction. All of the dipterocarps we studied are included in official guidelines which indicate their diameter-based cutting limits (0.50 m DBH for *D. tuberculatus*, 0.45 m DBH for the other species: MAFF, 2005). We found the mean diameters of reproductive trees were lower than these diameter limit criteria (Table 1). A reproductive tree population could therefore persist despite selective logging using these criteria (Fig. 2). Tree size significantly predicted the presence/absence of reproduction for all of our study species ($p<0.0001$). Nominal logistic regression models also indicated that >90% of individual trees start reproduction at smaller tree sizes than the diameter limit criteria (Fig. 3). These data suggest that the MAFF (2005) guidelines are sustainable in terms of diameter cutting limits for all of the dry dipterocarp species we studied.

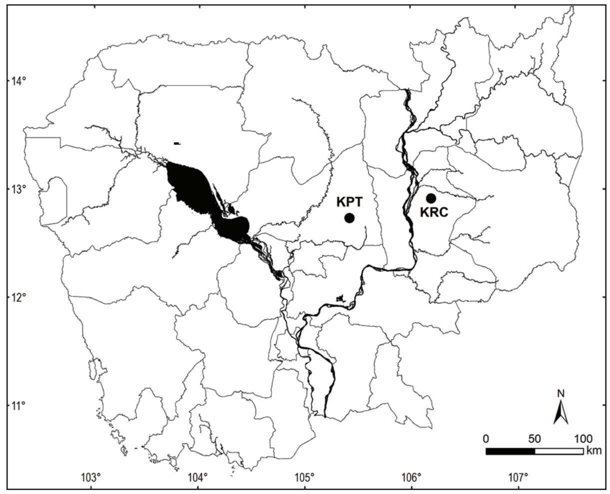

Fig. 1 Location of sample plots in Cambodia. KPT: Kampong Thom Province; KRC: Kratie Province.

Table 1 Minimum tree size for reproduction and reproductive tree density of dipterocarp species in Cambodian dry forests.

	D. obtusifolius	*D. tuberculatus*	*S. obtusa*	*S. siamensis*
Density (all trees) [1]	254	112	50	229
Density (reproductive trees) [1]	83	85	32	34
Tree DBH (all trees) [2]	15.5 ± 8.6 (46.4)	20.1 ± 8.7 (52.5)	23.6 ± 10.0 (55.8)	11.0 ± 5.3 (46.5)
Tree DBH (reproductive trees) [3]	22.8 ± 9.6 (12.0)	23.0 ± 7.4 (10.8)	27.4 ± 8.5 (9.8)	18.4 ± 6.8 (5.6)
DBH at 50% of tree reproduction [4]	18.8 (16.2–23.9)	12.3 (11.1–13.3)	17.9 (15.2–20.1)	18.1 (17.3–19.1)
DBH at 90% of tree reproduction [4]	27.1 (22.7–42.5)	20.0 (18.6–21.8)	31.5 (28.2–37.3)	24.3 (22.9–26.3)

[1] Stem ha^{-1}

[2] Mean ± SD (max.) [cm]

[3] Mean ± SD (min.) [cm]

[4] Estimated (95% CI) [cm]

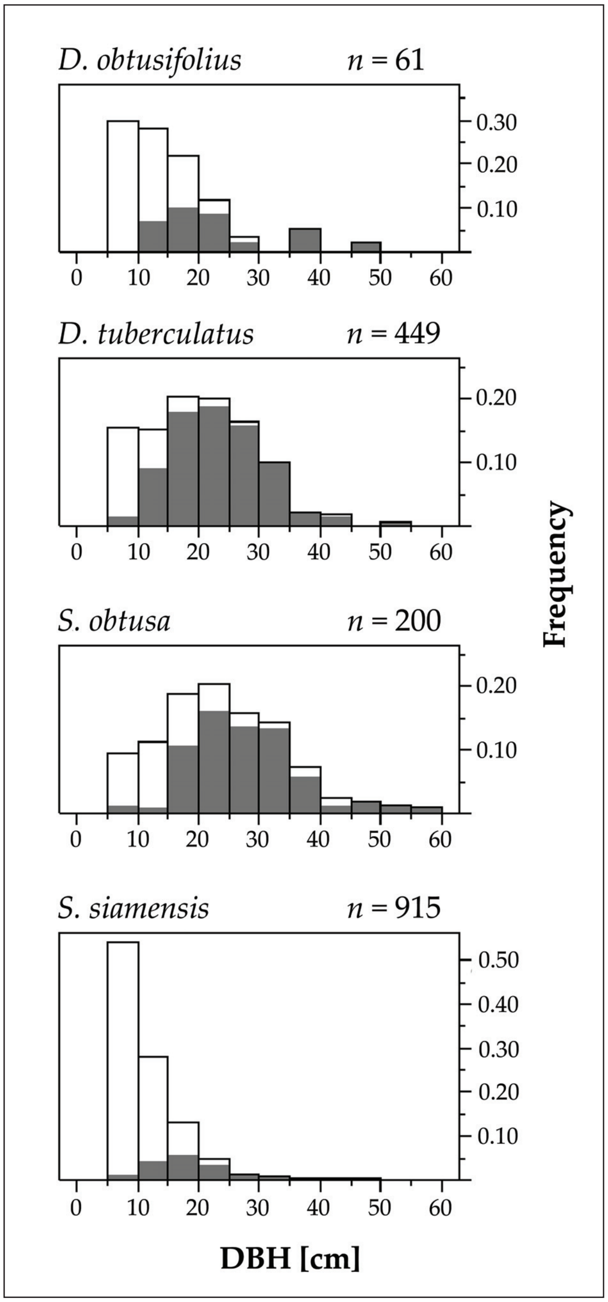

Fig. 2 Size (diameter at breast height, DBH) distribution of dipterocarp species in the study plots. Gray and white areas indicate trees with and without reproductive organs, respectively. Tree size with and without reproduction was defined as DBH at the first recorded presence of reproductive organs and the last recorded absence of reproductive organs, respectively.

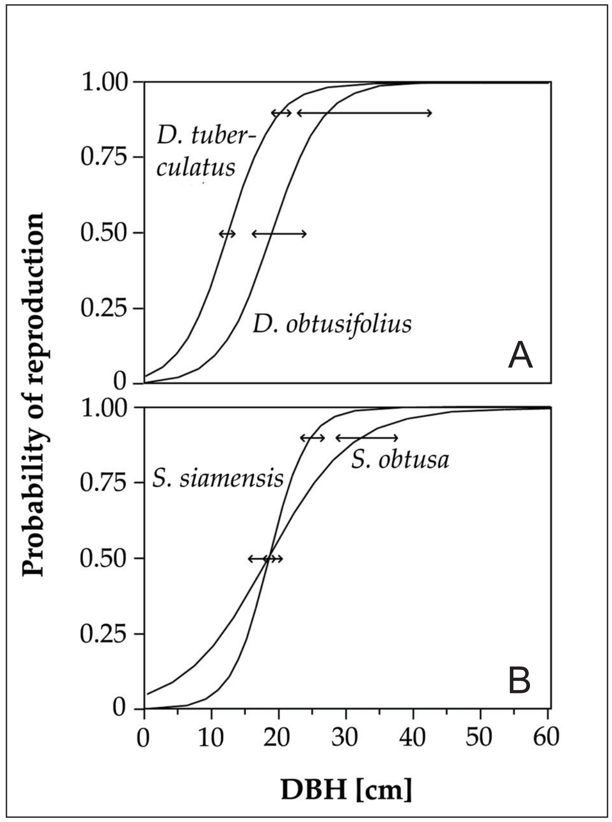

Fig. 3 Probability of reproduction based on the DBH estimated using nominal logistic regression for four dipterocarp species in Cambodian dry forests: A) *Dipterocarpus* spp.; B) *Shorea* spp. Horizontal arrows indicate the estimated 95% confidence interval of DBH at 50% and 90% probability of reproduction.

Reproductive target tree densities have been proposed as an acceptable vulnerability index value (>5 reproductive trees ha^{-1}) for Bolivian seasonally dry forests (Pinard *et al.*, 1999). The reproductive tree densities recorded in our study plots far exceeded this value (32–85 stems ha^{-1}, Table 1). However, total basal areas in the Bolivian forests were three times higher than the values in the dry dipterocarp forests we studied. A basal area mismatch of this magnitude indicates that the criteria for vulnerability index scoring should be independently verified in Cambodian forests.

The distribution of diameters differed among the species in our study (Fig. 2). Only *S. siamensis* showed a negative exponential distribution, indicating continual recruitment of juvenile trees, whereas *D. tuberculatus* and *S. obtusa* had unimodal distributions with peaks in the 15–25 cm DBH class. These data suggest low recruitment rates in *D. tuberculatus* and *S. obtusa*. This was obviously not due to a lack of flowering trees. Micro-sites suitable for the establishment of dipterocarp seedlings may be limited by topography or light conditions (Yagihashi *et* *al*., 2010). In addition, fire in the dry season and grass shading in the wet season may inhibit seedlings in the KRC plot. In turn, the relatively higher recruitment of *S. siamensis* may be due to its frequent occurence in rocky soils (Rollet, 1972) as the lower grass biomass of these areas would weaken the impacts of fire and shading. For sustainable management, reproductive target tree densities should remain at high levels until the exact reasons for these differences in recruitment are known.

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