FINAL REPORT

Project: Environmental and anthropogenic factors that affect an ecologically and economically important tree, *Castanopsis indica*, in northeastern Thailand

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Funded by the Biodiversity Research and Training Program

Acknowledgements

We are grateful for the support provided by the Biodiversity Research and Training Program (BRT 142020). The principal investigators would like to thank graduate students: Suttasinee Arcompat, Hataya Sangnnetra, Sansanee Sriamonmongkol, and Tharathip Sriboon for providing data for this report. We would also like to thank the people of Bor Muang Noi and Huay Nam Pak, Nahaeo National Park officers and other local officers of the Royal Forest Department and Royal Thai Military for providing logistical support.

BRT_142020

ปัจจัยทางด้านสิ่งแวดล้อมและมนุษยวิทยาที่มีผลต่อต้นก่อข้าวซึ่งเป็นไม้ที่มีความสำคัญทางด้านนิเวศวิทยาและเศรษฐกิจในภาคตะวันออกเฉียงเหนือของประเทศไทย (BRT-142020)

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บทคัดย่อ

แม้ว่าประโยชน์ของป่าชุมชนในระยะสั้นต่อการเมืองและเศรษฐกิจของชาวบ้านท้องถิ่นจะเป็นที่ประจักษ์ชัดก็ตาม แต่ประโยชน์ของป่าชุมชนในระยะยาวต่อความหลากหลายทางชีวภาพยังไม่เป็นที่แน่ชัด นอกจากนี้ในบางกรณีป่าชุมชนอาจทำให้เกิดความเสียหายต่อสิ่งมีชีวิตบางกลุ่มในระบบนิเวศน์ได้ เนื่องจากข้อมูลทางด้านวิทยาศาสตร์ที่เกี่ยวข้องกับการประเมินข้อดีและข้อเสียของป่าชุมชนต่อความหลากหลายทางชีวภาพมีอยู่น้อยมาก จึงอาจทำให้นักวิทยาศาสตร์ ผู้ดูแลรักษาป่าไม้และชุมชนท้องถิ่นประสบปัญหาในการตัดสินใจเลือกการจัดการที่เหมาะสมในระยะยาวได้ การประเมินคุณและโทษของป่าชุมชนสามารถทำได้ก็ต่อเมื่อมีการใช้วิธีการเปรียบเทียบที่เหมาะสม เช่น การเปรียบเทียบความหลากหลายทางชีวภาพในป่าชนิดเดียวกันภายใต้รูปแบบการจัดการที่แตกต่างกันเป็นต้น การศึกษาครั้งนี้จึงได้ทำการศึกษาปัจจัยพื้นฐานทางด้านนิเวศวิทยาบางตัวของต้นก่อข้าว (*Castanopsis indica*) ซึ่งชาวบ้านในภาคเหนือของประเทศไทยใช้เป็นวัตถุดิบในการเพาะเห็ดหอม ข้อมูลที่ได้จากการศึกษาสามารถนำไปใช้ในการถ่ายทอดให้กับชาวบ้านในท้องถิ่นเพื่อการจัดการใช้ประโยชน์ต้นก่อข้าวอย่างยั่งยืน จากการศึกษาต้นก่อข้าว ต้นกล้า และเมล็ดก่อข้าวในป่าชุมชน 2 แห่ง พื้นที่ป่าคุ้มครองซึ่งตั้งอยู่ติดกับป่าชุมชน และในเรือนเพาะชำในช่วงปี พ.ศ. 2541-2545 เกี่ยวกับ (1) ผลของการตัดฟันกิ่งก่อข้าวต่อการเจริญเติบโตและการอยู่รอดของต้นก่อข้าว (2) ผลของการกัดหรือกินเมล็ดโดยสัตว์ (Seed predation) ไฟ และปริมาณแสงที่ได้รับ (ปริมาณทรงพุ่มปกคลุม) ต่อการงอกของเมล็ด การอยู่รอดและการเจริญเติบโตของต้นอ่อนในป่า (3) ผลของแสงและความชื้นต่อการงอกของเมล็ด การเจริญเติบโตและการอยู่รอดของต้นอ่อนในเรือนเพาะชำ และ (4) การเจริญเติบโตและการอยู่รอดของต้นอ่อนที่ย้ายจากเรือนเพาะชำสู่ชุมชนท้องถิ่น พบว่าในระยะสั้นการตัดฟันกิ่งก่อข้าวบางส่วนไม่ส่งผลกระทบทางลบต่อการเจริญเติบโตและการอยู่รอดของต้นก่อข้าว เพื่อยืนยันผลการศึกษาดังกล่าวจึงจำเป็นต้องมีการศึกษาผลกระทบ

ในระยะยาวต่อไป ปัจจัยสำคัญที่มีผลต่อการงอกของเมล็ดก่อข้าวในป่าคือการที่เมล็ดถูกกัดหรือกินโดยสัตว์ เมล็ดก่อข้าวที่ไม่ได้ใช้วัสดุป้องกันเมล็ดจากการกัดหรือกินโดยสัตว์ในทุกแปลงศึกษามีการตายเกือบ 100 เปอร์เซ็นต์ โดยอัตราการถูกกัดหรือกินโดยสัตว์ในป่าชุมชนจะเร็วกว่าในป่าอุทยาน เหตุผลของความแตกต่างดังกล่าวยังไม่ชัดเจนแต่คาดว่าอาจเนื่องจากกิจกรรมของมนุษย์ในการใช้ประโยชน์ในพื้นที่ป่าชุมชนก่อให้เกิดการเปลี่ยนแปลงของสัตว์เลี้ยงลูกด้วยนมขนาดเล็กในด้านต่างๆ ซึ่งควรได้มีการศึกษาประเด็นดังกล่าวต่อไป นอกจากนี้จากการศึกษาการเจริญและการอยู่รอดของต้นกล้าในป่าและเรือนเพาะชำพบว่า เมื่อปริมาณแสงที่ได้รับสูงขึ้น อัตราการเจริญเติบโตของต้นอ่อนสูงขึ้นแต่ต้นกล้ามีความเสี่ยงต่อการตายเนื่องจากความเครียดจากการขาดน้ำเพิ่มขึ้น อย่างไรก็ตามประมาณ 50 เปอร์เซ็นต์ของต้นอ่อนในแปลงศึกษามีสาเหตุการตายเนื่องจากไฟป่าที่เกิดขึ้นเองตามธรรมชาติและการกระทำของมนุษย์ ทั้งนี้แสดงให้เห็นว่าไฟป่าเป็นปัจจัยที่สำคัญอันหนึ่งต่อการตายของต้นอ่อนนอกเหนือจากผลของแสง ในการเพาะขยายพันธุ์ต้นก่อข้าวในเรือนเพาะชำพบว่าอัตราการงอกของเมล็ดและการอยู่รอดมีค่าอยู่ในช่วงประมาณร้อยละ 80-92 และร้อยละประมาณ 73 – 84 ของจำนวนต้นอ่อนที่ย้ายจากเรือนเพาะชำสู่ป่าธรรมชาติตามลำดับ จากผลการศึกษาแสดงให้เห็นว่า การจัดการต้นก่อข้าวทั้งในด้านการใช้ประโยชน์และการขยายพันธุ์ในป่าชุมชนและเรือนเพาะชำสามารถทำให้ประสบผลสำเร็จได้โดยการใช้เทคนิคพื้นฐานการขยายพันธุ์ต้นก่อในเรือนเพาะชำ รวมทั้งต้องมีความระมัดระวังไฟที่ใช้ในการถากถางพื้นที่เกษตรกรรมด้วย

คำสำคัญ: ก่อข้าว (*Castanopsis indica*), ป่าชุมชน, การกัดหรือกินเมล็ดโดยสัตว์, การเจริญเติบโตของต้นอ่อนและการอยู่รอด

Abstract

While the short-term political and economic benefits of community forestry for local people are relatively clear, the long-term benefits for biodiversity are not and furthermore community forestry may in some cases be detrimental to some groups of organisms. However, there is almost no scientific data assessing the advantages and disadvantages of community forestry to biodiversity, thus scientists, forest managers, and local communities will have trouble making appropriate long-term management decisions. Furthermore, assessment of the pros and cons of community forestry can only be made by using appropriate comparisons, i.e., comparing biodiversity in similar forest types under different forms of management. This study examined some basic ecological parameters of *Castanopsis indica*, a tree that is utilized for mushroom cultivation in northern Thailand, in order to provide local people with information that would allow them to sustainably manage this species. Between 1998-2002, we examined *C. indica* adults, seedlings, and seeds in two community forests, one protected area adjacent to the community forests, and in the nursery. The parameters investigated included: (1) the effects of branch cutting on the growth and survival of adult trees, (2) the effects of seed predation, fire, and light availability/canopy cover on seed germination, seedling survival, and seedling growth on forest plots, (3) the effects of light and moisture on seed germination, seedling growth and seedling survival in the nursery, and (4) growth and survival of seedlings transferred from the nursery back to an area in the local community. The results suggested that branch cutting, provided that not all braches were removed, did not negatively affect adult growth and survival at least in the short-term, although more long-term monitoring will be required to answer this question more conclusively. Mortality of unprotected seeds was almost 100% on all plots, however the predation rate was clearly faster in the community forests compared to the national park. The reasons for this difference were unclear, although are likely due to differences in the rodent community presumably caused by anthropogenic induced habitat changes in the community forests. Based on the forest and nursery experiments seedling growth rates were higher in higher light environments, but there appeared to be some greater risk of mortality from draught stress. However, fires started either accidentally or intentionally by local people were responsible for approximately 50% of all seedling mortality in our plots. Germination rates in the nursery were 80-92% and survival was between 73 to 84% for those seedlings transferred out of the nursery to a deforested site. Our results suggest that this species could be successfully managed in community forests and nurseries through the use of some basic precautions with agricultural fires and simple nursery techniques.

Key words: *Castanopsis indica*, community forestry, seed predation, seedling growth and survival

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Introduction

One proposed solution to Thailand's forest resource over-exploitation and land ownership problems is to decentralize control over forest management (Hussain and Doane 1995, Hirsch 1996, Vandergeest 1996). Community forests, areas where people agree collectively to maintain forest resources (Puntasen 1996), which have long existed in Thailand, have been reemphasized in the wake of calls for decentralization. In theory, community-level management creates a framework in which forest resources are used fairly and efficiently and thereby promote sustainable use and conservation (Narintarangkul Na Ayuthaya 1996, Puntasen 1996). While the short-term political and economic benefits of community forestry for local people are relatively clear (Johnson and Forsyth 2002), the long-term benefits for the biodiversity of Thailand are not. This is because community forestry or other decentralized management is inappropriate for some groups of species, particularly those with large home ranges (such as elephants and other large mammals [Parks and Harcourt 2002]) or those that compete directly with humans (such as tigers [Seidensticker et al. 1999]). In addition, decentralized and potentially fragmented management appears to be contrary to current holistic ecosystem management concepts (Silver et al. 1996). Finally, there is almost no scientific data assessing the potential impacts of community forestry on the biodiversity of Thailand particularly which forest species (and under which environmental/ecological/ecosystem conditions) can be effectively managed under increased human use and disturbance and which cannot. Without such clear, scientifically-based information, scientists, forest managers, and local communities will have trouble making appropriate long-term management decisions.

A further complicating factor is that a scientific assessment of the pros and cons of community forestry can only be made by using appropriate comparisons, i.e., comparing biodiversity in similar forest types under different forms of management. Comparative work focusing on conditions under which communities can successfully manage their natural resources is desperately needed because such research is scarce and much of the previous work is biased, in part because social scientists and community forestry activists generally focus on institutions that persist, rather than those that have failed and disappeared (Barrett et al. 2001).

The goal of this 3.5-year study was to examine how environmental and anthropogenic factors influence the growth and survival *Castanopsis indica*, (known as *ko khao* or *ko lim* in Thai) one of several tree species that is used by northern Thai villagers as a growth substrate for cultivating mushrooms. *C. indica* is also used for making charcoal, fuelwood, and many other functions in northern Thailand and elsewhere in the region (e.g. Shrestha and Shengji, undated). Although this species is probably not widely used in Thailand (Schmidt-Vogt 2001), it appears to be a relatively important species both economically and ecologically in upland (900-1500 m) plant communities throughout the region (Shrestha and Shengji undated, Schmidt-Vogt 2001). The geographic range of *C. indica* includes parts of India, Myanmar, Thailand (northern and eastern sections), China, Nepal, Taiwan, Laos, Cambodia, and Vietnam (Barnett 1942).

Specifically, our goals were to:

1) To examine the effects of branch cutting on (a) mortality and (b) fruit production of adult trees of *Castanopsis indica* that have been cut by local people.
2) To determine the primary factors that effect *C. indica* seedling recruitment and measure demographic parameters of *C. indica* including (a) adult growth rate, (b) adult mortality, (c) adult fruit production, (d) seedling growth and mortality, (e) seed germination.
3) To determine the effects of light and moisture levels on *C. indica* seed germination, seedling growth and survival in the nursery, and their survival after being transferred back to the field.

Methods

Study sites

The study sites consisted of three areas, two community forests nearby two villages, Bor Muang Noi (BN) and Huay Nam Pak (HN), in the district of Nahaeo, Loei Province and Nahaeo National Park (NP) (712200 E, 1941300 N UTM zone 47, see Figure 1), which was adjacent to the community forests. The elevations of the three sites, as estimated by GPS, were BN 565 m, HN 740 m, while the Park site ranged between 820 and 910 m. Much of the community forests are used for hunting, collecting of plants and fungi for food and medicine, and timber for charcoal production, home building and mushroom cultivation (G. Gale *pers. obs.*). Parts of the community forests near agricultural lands burn frequently (approximately once per year) because of fires used for land clearing and agricultural land preparation (see below). In the community forests of both villages, tree branches of *C. indica* are cut. The vegetation of NP was probably less impacted by people and branches of *C. indica* are not cut. However, there is intensive hunting and collecting by local villagers in the Park (G. Gale *pers. obs.*). Since 2002 there has also been cattle grazing in the Park, which did affect some of our later experiments (see below).

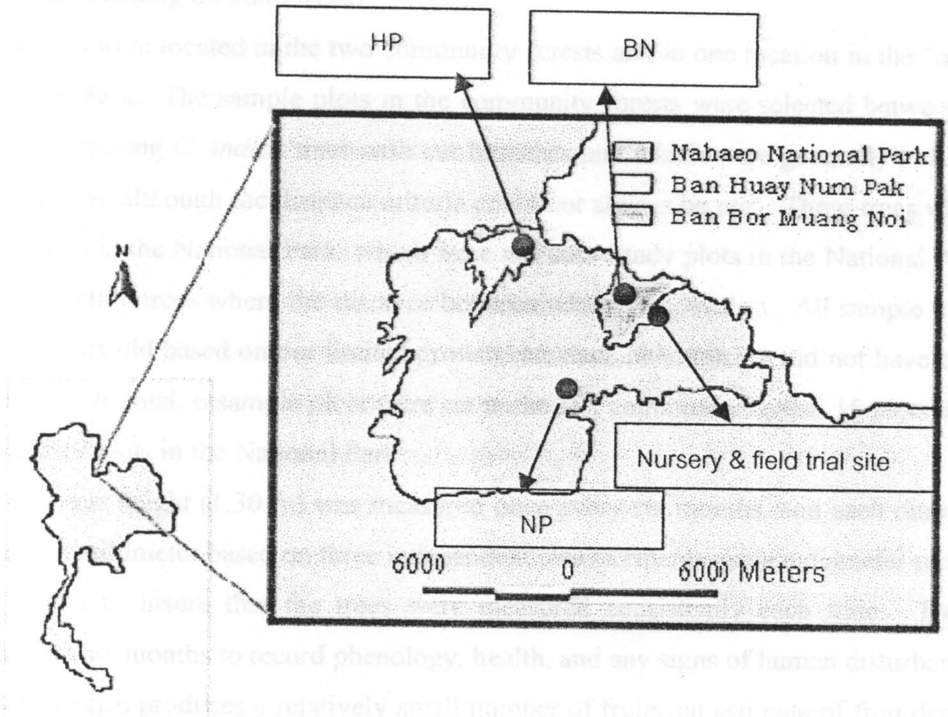

Figure 1. Naheao district. The study sites were located within one site inside Naheao National Park (NP) and in the community forests of Ban Huay Nam Pak (HP) and Ban Bor Muang Noi (BN) as indicated.

Effects of branch cutting on adult trees

All sample plots were located in the two community forests and in one location in the "protected" portion of the National Park. The sample plots in the community forests were selected between August and October 1998 by choosing *C. indica* trees with cut branches and which were generally > 10 m from others of the same species, although the distance criteria could not always be met. These trees where then compared with *C. indica* in the National Park, which were not cut. Study plots in the National Park were also established by selecting trees where the distance between adults was > 10 m. All sample trees were estimated to be > 10 years old based on our limited growth rate data, although we did not have tree cores to confirm this directly. In total, 6 sample plots were set in the HN community forest, 15 plots in the BN community forest and 17 plots in the National Park.

Diameter at breast height (1.30 m) was measured once every six months, and each diameter was estimated to the nearest millimeter based on three independent measurements using a diameter tape. Trees were marked with nails to insure that the trees were measured consistently each time. Trees were examined every three to six months to record phenology, health, and any signs of human disturbance.

Because this species produces a relatively small number of fruits, an estimate of fruit density was taken during August and early September of each year by directly counting the number of ripe and unripe (green) fruits just prior to fruit fall between August and November. Counting was aided by using 10-power binoculars.

Establishment of plots for monitoring seedling growth and survival

Starting in August 1998, circular plots, 10.5 m. in radius were established around each sampled adult tree. A radius of 10.5 m was chosen based on the median seed dispersal distance of three other species in the same family (Fagaceae) that had similar seed morphology to *C. indica* (median dispersal distance of those species was between 5.6 to 10.6 m, [Ribbens et al.1994]).

Starting in October 1998, we counted seedlings that were shorter than 50 cm. in height in each circular plot. We recorded the number of seedlings and tagged them with uniquely numbered aluminum tags.

Effects of fire on seedling growth and survival

Sample plots in BN were accidentally burned by a fire that spread from an agricultural field between 15 and 16 March 1999 and 15.5 plots in the Park were burned between 1 and 13 April 1999, by fires intentionally set by villagers for hunting purposes (at least part of some sites including HN burned in subsequent years as well, see below). In each sample plot, we recorded seedlings that were killed and those that survived the fires. For a subsample of seedlings for which we had height data, we were able to estimate survival relative to height (see below).

Seedling growth rate was measured on a randomly chosen subsample of twenty seedlings per plot (5 seedlings from each cardinal direction). For quadrants with less than 5 seedlings, all seedlings were measured. The maximum vertical height of the seedlings was measured every two months with a tape measure to the nearest millimeter. We then compared the effects of fire on seedling growth rates by comparing the seedlings of the burned plots with seedlings from the unburned plots. The relative growth rate (RGR) (%/year) was calculated following the methods of Calow (1998). A relative performance index (RPI) was calculated also following the methods of Zangkum *et al.* (2000; see below). RPI combines survival and growth rate into one index, thus if RPI is high this suggests that seedlings have both a high relative growth rate and a high relative survival rate.

$$RGR = \frac{(LnH_2 - LnH_1) \times 365*100}{(t_2 - t_1)}$$

where H_1= (height, radial diameter or leaf area) starting time (cm., or mm.)
H_2=(height, radial diameter or leaf area) final time (cm., or mm.)
$(t_2\text{-}t_1)$ = time between first and last measurements (days)

$$RPI = \frac{\text{mean \% Survivial*10}}{\text{Max. mean \% Survival}} \times \frac{\text{mean RGR*10}}{\text{Max. mean \% RGR}}$$

Effects of the light availability on seedling growth and survival

Beginning in October 1998, we estimated the percentage of canopy cover in each plot using modified methods from James and Shugart (1970). Along the four transects within each circular plot (N, S, E, W), a total of 28 evenly spaced samples of canopy cover (7 estimates of canopy cover per transect) were recorded by pacing off along the transects and sighting into the ocular tube (1.5 inches in diameter and 10 cm long). The estimation was be done by looking through the ocular tube vertically at the tree canopy and estimating the percentage of non-vegetation (sky) visible in the circle of the tube. Estimates were repeated every two months. We measured seedling survival and growth using the same methods as above. The relationship between canopy cover, growth rate and survival was also analyzed using regression techniques.

Every two months starting in January 1999, we measured the canopy cover over the 20 selected seedlings in the plots by using an ocular tube We also measured light availability that hit the seedling by using a lux meter (Extech, model 401025). We estimated the light availability by comparing the lux reading at the seedling with a simultaneous lux reading in a nearby open area. We measured seedling survival and growth using the same methods as above. The relationship between light availability, growth rate and survival was analyzed by using regression techniques.

Seed germination, seed predation and seedling establishment in the forest

Around four of the sampled trees in each forest, four, 1.5 x 1.5 m plots were located in four general habitats with different levels canopy cover and ground vegetation cover, ranging from open canopy cover and sparse ground vegetation cover to closed canopy and dense ground vegetation cover. These included:

1) Full canopy cover and dense/ ground vegetation cover
2) Full canopy cover and partial or no ground vegetation cover.
3) No canopy cover and dense/ ground vegetation cover
4) No canopy cover and partial or no ground vegetation cover

A plot was considered to have " low" canopy cover if the cover was less than 20% and canopy cover was considered closed if the cover was higher than 20 %. Ground vegetation cover was greater called "low" if cover was less than 25 % and vegetation cover was considered "high" if it was greater than 25 %. In each of these plots, 30 seeds were placed and divided into 3 treatments to assess the affects of predators and to examine methods of protecting seeds: no cage (no protection from predators), small cages (7.5 x 5 x 9 cm made from wire mesh), and large cages (16 x 16 x 16 cm), assuming that larger cages might offer more protection to young seedlings from herbivores after germination.

Seed germination and the effects of light availability on seedling growth in the nursery

Seeds of *C. indica* were collected within the community forests of BN and HN under parent trees and sown in a nursery located near the village of BN (elevation 630 m). Seeds damaged by insects or other factors were discarded. Seed viability was also tested through floatation (Clintra, 1997). Three treatments were applied, full sunlight, partial shade (30% of full sun), and heavy shade (15% of full sun) and 25 seeds were used for each treatment. Each treatment was set up in a randomized complete block design with four replicates. Full sun was performed by growing the seeds in an open area, which received a minimum of 4 hours of midday sun. Partial and heavy shade treatments were performed by shading the seeds with one or more layers of shade cloth. Seeds were planted in seed trays with two layers of filter paper in experiments to test for the effect of light on germination. Tests of the effect of light intensity on germination and seedling establishment used REX tray root-trainers (300 cm^3) filled with forest soil. Germination media in all treatments were kept moist by regular watering two times per day following the methods of Hardwick *et al.* (1997). Germination on either the filter paper medium or forest soil medium was recorded at 15-day intervals. In the filter paper experiment, a seed was recorded as germinated once the radicle had emerged through the seed testa (Fenner, 1985). The emergence of epicotyl was used as a measure of germination in the forest soil experiment because seeds were buried. Monitoring of germination ceased when no more seeds had germinated for at least 1 week.

The number of surviving seedlings was counted and root length (in the filter paper medium) and height (in the forest soil medium) were measured with a measuring tape to the nearest millimeter. The relative growth rate (RGR) and relative performance index (RPI) were calculated following the methods of above. The growth rate was checked twice a month for the first two months and once a month thereafter. The seedlings were measured for a total of 171 days (September 2000 to March 2001); the experiment was terminated prematurely due to a temporary lack of water.

Effects of moisture and light availability on seedling survival in the nursery

In an separate experiment from above, we removed approximately 1-year old seedlings of *C. indica* from a disturbed patch of roadside forest that were of similar height and stem width (approximately 12 cm tall with a 1.6 mm. stem diameter) on 20 December 1999. Seedlings were planted in individual bags (8 x 25 cm) containing forest soil and rice husk to improve water absorption (2:1, soil: husk).

We randomly assigned seedlings to be grown in one of three light treatments (full sunlight, partial shade (30% of full sun), and heavy shade (13% of full sun) and two watering treatments (low moisture and high moisture) using a factorial design with 24 seedlings per treatment. Full sun was provided by growing the plants in an open area, which received a minimum of 4 hours of midday sun. Partial and heavy shade treatments were provided by shading the plants with one or two layers of shade cloth respectively. Seedlings in the low moisture treatment were subjected to natural rainfall only, while high moisture treatments received supplementary water two times per day in the full sun treatment, once per day in the partial shade and in the heavy shade every other day following the methods of Hardwick *et al* (1997). The growth rates were checked weekly for the first two months; the number of surviving seedlings was counted and vertical growth, radial growth and leaf area were measured. The maximum vertical height of each seedling was measured with a tape measure to the nearest millimeter (from the base of the soil to the shoot apex). For radial growth, calipers were used to measure (to the nearest 0.1 mm.) stem diameter at ground level or at the top of the root collar following the methods of Kobe (1999). Area of healthy leaves was estimated using a regression equation (see below) using leaf length and leaf width as independent variables. To develop the regression equation, a sample of thirty leaves of *C. indica* of several sizes were harvested and a Calcomp 9100 digitizer with Arc/Info software was used to digitize the area of each leaf.

We calculated RGR and RPI as above. The seedlings were measured for a total of 261 days (25 January to 12 October 2000).

Seedlings in the nursery were also compared with seedlings in an additional forest plot approximately 2 km from the nursery. Forest plots were chosen near (<50 m) from where seedlings for the nursery study were collected (seedling also had similar heights and stem widths to those used in the nursery experiment). The locations were chosen randomly for 5, 2 x 2 m plots. Five seedlings per plot were randomly chosen for measurement which included height, stem radius and leaf area following the same methods used in the nursery. These data were compared with the seedlings grown in the nursery. The seedlings were also measured during the same 261 days as above.

Growth and survival of seedlings transferred from the nursery to the field:

A second set of seedlings grown under similar conditions in the nursery was transferred to the field. The site was located at BN next to a villager 's home adjacent to the nursery. One half of the site had canopy trees (50% of full sunlight), but all of the understory was removed. The other half of the site had no understory or canopy cover (100% full sun). Both areas had short (< 15 cm.) grasses and other weedy vegetation.

Each treatment plot was 20 x 25 m and the distance between each seedling was 5 m. The distances between treatments was 10 m. Seedlings were placed in 50 x 50 x 50 cm. pits. On 2 November 2000, a total of 60 seedlings were transferred from the nursery to the field. Seedlings, which were in good health, were transferred from partial shade or heavy shade treatments in the nursery. The seedlings had been in the nursery for 9 months (January 2000 - October 2000). Seedlings were randomly assigned to field treatments and were labeled to insure that any difference caused by the different nursery pre-treatments could be recorded.

Light directly above each seedling of both treatments was measured using a light meter (Lux). Visual estimates of canopy cover were measured using an ocular tube as above. Water was given everyday until the rainy season began in June of 2001. Weeding was done once every 3 months during the dry season, and once per month during the rainy season. The experiment was monitored every 2 weeks for the first 4 months and once per month for the remaining 8 months. The seedlings were measured using the same methods as above.

Results

Effects of branch cutting on adult trees

A total of 38 trees were measured during at least one year of the four year period: 6 in HN, 15 in BN, and 17 in NP. The number of branches removed was not significantly different between the two community forests (Mann-Whitney U-test, P > 0.05). However, their appeared to be more cutting in BN, where three trees had all of their branches cut, three trunks (basal stems or boles) of three trees with multiple trunks were completely removed, and two trees were completely removed. One tree was cut down in HN.

Median circumference growth rate of the remaining trees was 0.5 % / year for all forest combined, and the medians for each forest were 0.4, 0.6, and 0.7 for BN, the Park, and HN respectively. These differences were not significant between the community forests and National Park or between the community forests themselves (Mann-Whitney, $P > 0.05$), but the sample size was small and additional time may be required before effects become apparent.

Fruit production varied among years and plots (Figure 2). In 1999 nearly no nuts were produced and but no exact counts were made. Years 1998 and 2000 were relatively productive, while in 1999, 2001, and 2002 little or no fruit was produced. However, individual trees appeared to be highly variable in their productivity. Because it cannot produce fruit from the main trunk, *C. indica* cannot reproduce (sexually) if all of its branches are removed. Trees in BN produced notably less fruit, presumably due to the intensive branch cutting. Per tree fruit production in BN was less than HN in all years that fruit production was measured (1998, 2000-2002) and significantly less in BN than HN in 1998 and 2001 (Mann-Whitney, $P < 0.05$) and nearly so in 2000 and 2002 ($P < 0.1$). BN fruit production was less than the Park in three of the four years measured, but not significantly. The reason for the lack of significance is that median fruit production in both areas was near zero, where as average production was notably higher in NP because of the high productivity of a few individual trees. The productivity was significantly higher in HN than the Park in 1998 ($P < 0.05$) and nearly so in 2002 ($P < 0.1$). There appeared to be no relationship between tree diameter and fruit production ($F = 0.01$, $P > 0.05$).

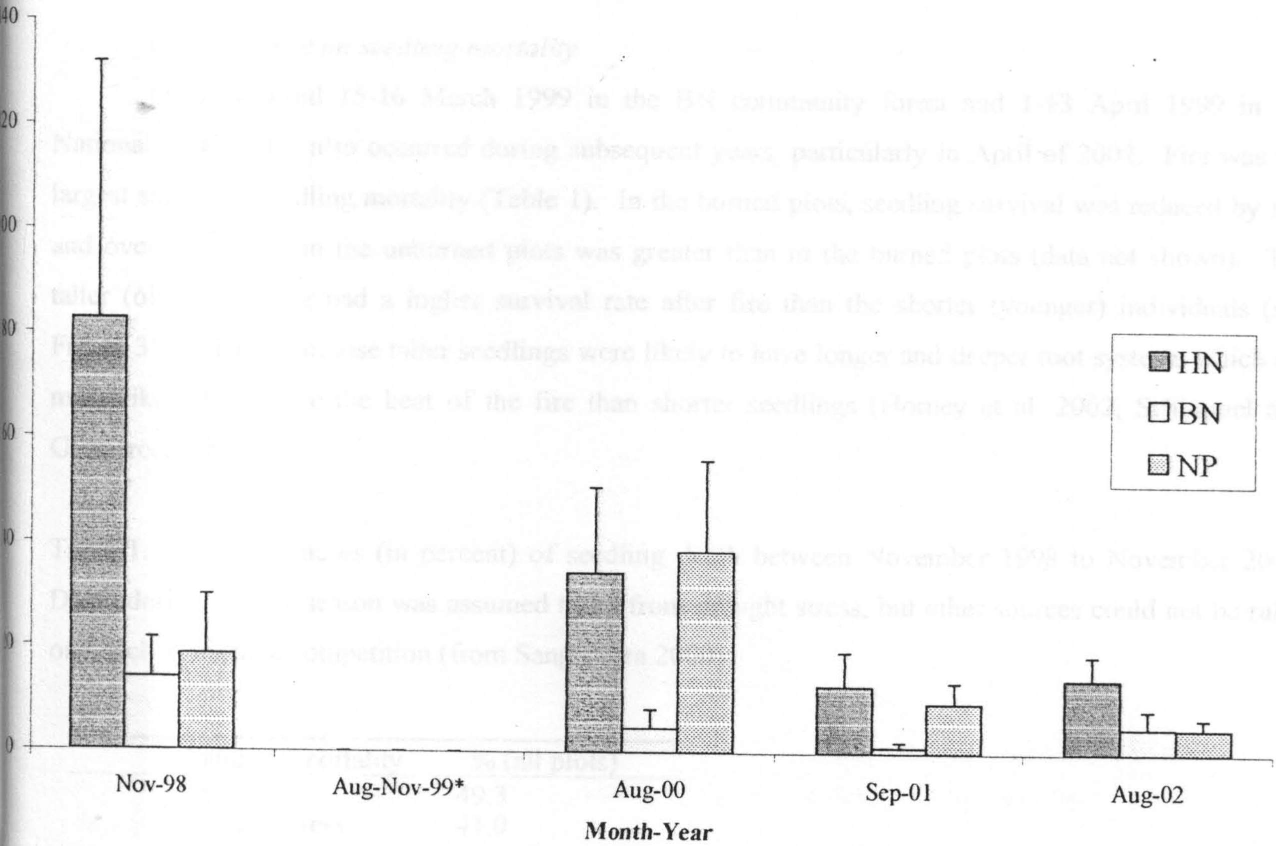

Figure 2. Average number of fruits per *C. indica* tree observed 1998-2002 on the study sites. (*nearly zero fruit was produced in 1999, but no exact measurements were taken; error bars represent the standard error).

Effects of fire on seedling mortality

Fires occurred 15-16 March 1999 in the BN community forest and 1-13 April 1999 in the National Park. Fires also occurred during subsequent years, particularly in April of 2002. Fire was the largest source of seedling mortality (Table 1). In the burned plots, seedling survival was reduced by fire and overall survival in the unburned plots was greater than in the burned plots (data not shown). The taller (older) seedling had a higher survival rate after fire than the shorter (younger) individuals (see Figure 3), probably because taller seedlings were likely to have longer and deeper root systems which are more likely to survive the heat of the fire than shorter seedlings (Horney et al. 2002, Schimmel and Granstrom 1996).

Table 1. Probable causes (in percent) of seedling death between November 1998 to November 2000. Death during the dry season was assumed to be from drought stress, but other sources could not be ruled out, such as nutrient competition (from Sanganetra 2000).

Source of mortality	% (all plots)
Fire	49.3
Drought stress	41.0
Herbivores	0.9
People	7.4
Unknown	1.5

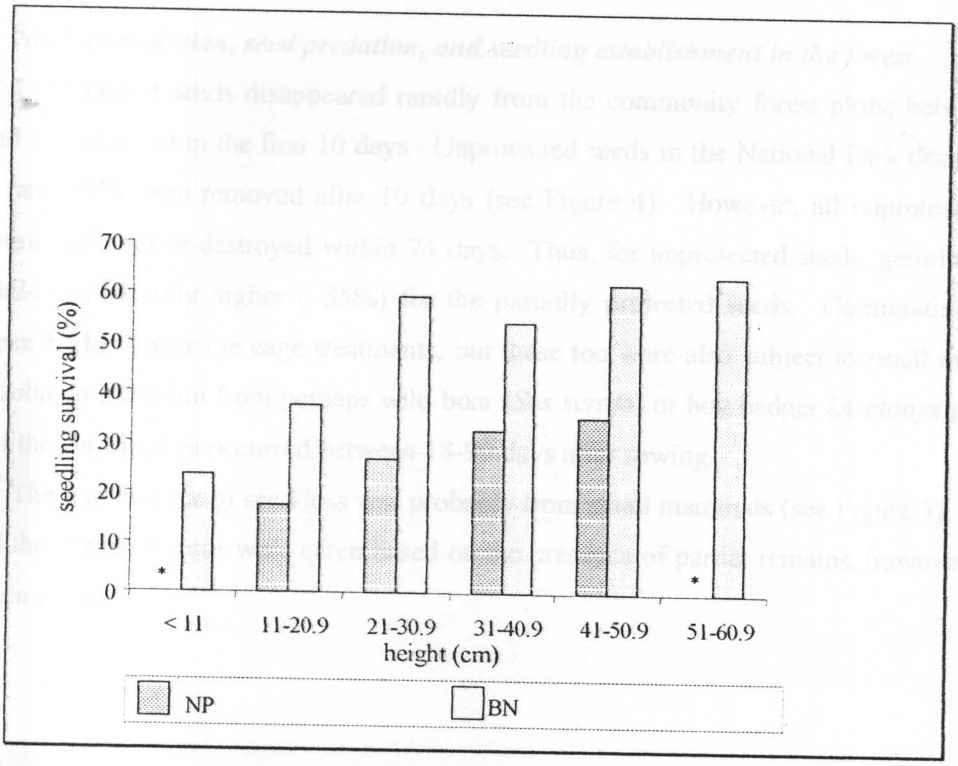

Figure 3. Percentage of seedling survival from fire in terms of seedling height in the two burned study areas (* insufficient sample size in this category, n = 2; from Sanganetra [2000]).

Seed germination, seed predation, and seedling establishment in the forest

Unprotected seeds disappeared rapidly from the community forest plots; between 89-99% were removed or eaten within the first 10 days. Unprotected seeds in the National Park disappeared at a much slower rate; 39% were removed after 10 days (see Figure 4). However, all unprotected seeds from all plots were removed or destroyed within 74 days. Thus, for unprotected seeds, germination was low, 0-5%, while significantly higher (~35%) for the partially protected seeds. Germination probably would have been higher under the cage treatments, but these too were also subject to small mammal as well as some probable predation from perhaps wild boar (*Sus scrofa*) or hog badger (*Arctonyx collaris*). Most (> 90%) of the germination occurred between 18-90 days after sowing.

The main source of seed loss was probably from small mammals (see Figure 5). We assumed that most of the removed seeds were eaten based on the presence of partial remains, however some seeds may have been cached.

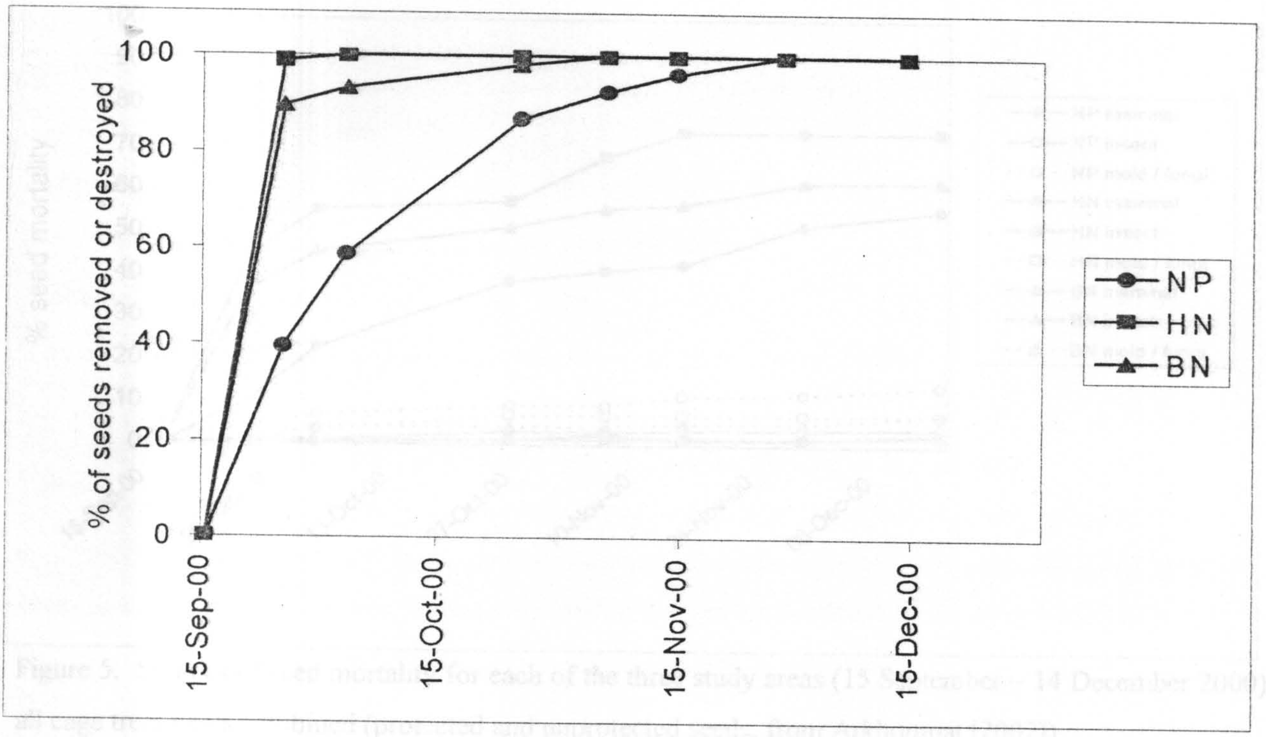

Figure 4. Seed mortality rate for unprotected seeds (15 September – 14 December 2000) in the three study areas (from Arkhompat [2002]).

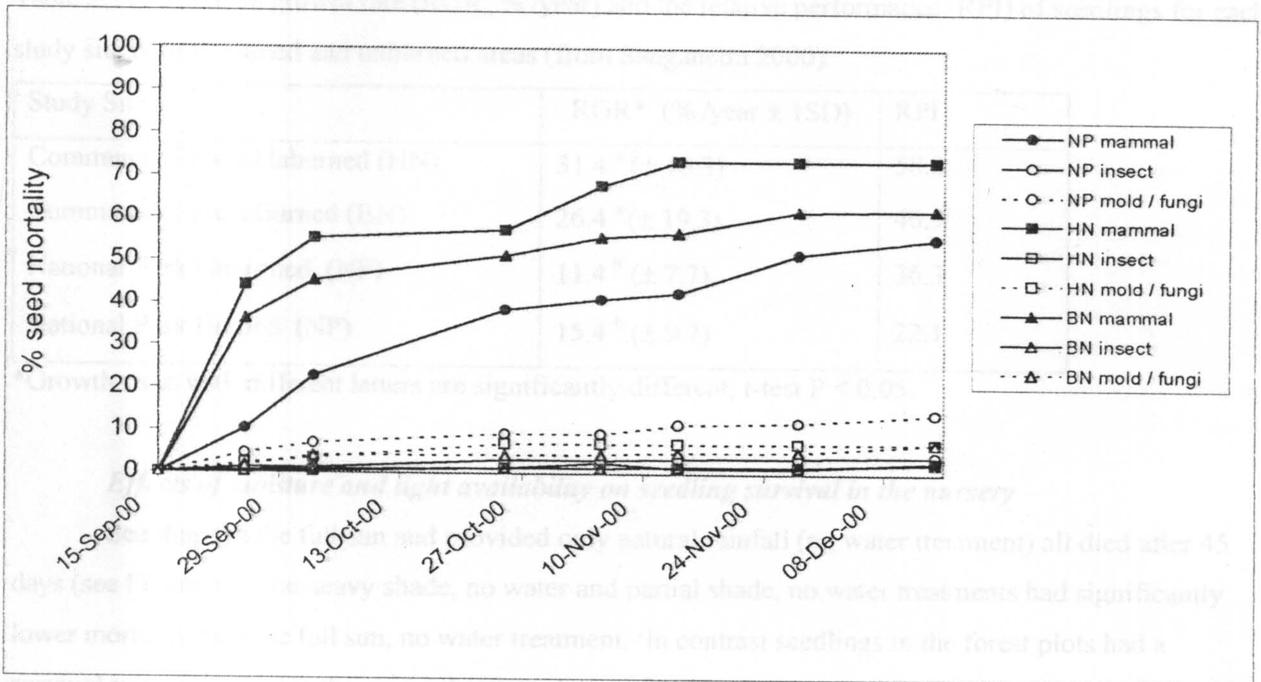

Figure 5. Sources of seed mortality for each of the three study areas (15 September – 14 December 2000) all cage treatments combined (protected and unprotected seeds; from Arkhompat [2002]).

Effects of light availability on seedling survival in the forest

Canopy cover was greater in the National Park than in the community forests, but this difference was not significant. Median light intensity was 4.8 % vs. 4.6 % respectively above alive and dead seedlings, which was also not significantly different.

Effects of light availability and canopy cover on seedling growth rates in the forest

Relative growth rate (RGR) was higher in the community forest than the National Park ($P < 0.05$, see Table 2). Visual estimates of canopy openness (ocular tube) above seedlings was also weakly, but significantly positively correlated with RGR ($R^2 = 0.07$, $P = 0.01$).

Table 2. The relative growth rate (RGR; % /year) and the relative performance (RPI) of seedlings for each study site both in burned and unburned areas (from Sanganetra 2000).

Study Site	RGR* (% /year ± 1SD)	RPI
Community Forest Unburned (HN)	31.4 [a] (± 16.3)	58.8
Community Forest Burned (BN)	26.4 [a] (± 19.3)	40.9
National Park Unburned (NP)	11.4 [b] (± 7.7)	36.3
National Park Burned (NP)	15.4 [b] (± 9.7)	22.1

*Growth rates with different letters are significantly different, t-test $P < 0.05$.

Effects of moisture and light availability on seedling survival in the nursery

Seedlings in the full sun and provided only natural rainfall (no water treatment) all died after 45 days (see Figure 6). The heavy shade, no water and partial shade, no water treatments had significantly lower mortality than the full sun, no water treatment. In contrast seedlings in the forest plots had a survival rate of 100%, but their growth rate was significantly slower (see below).

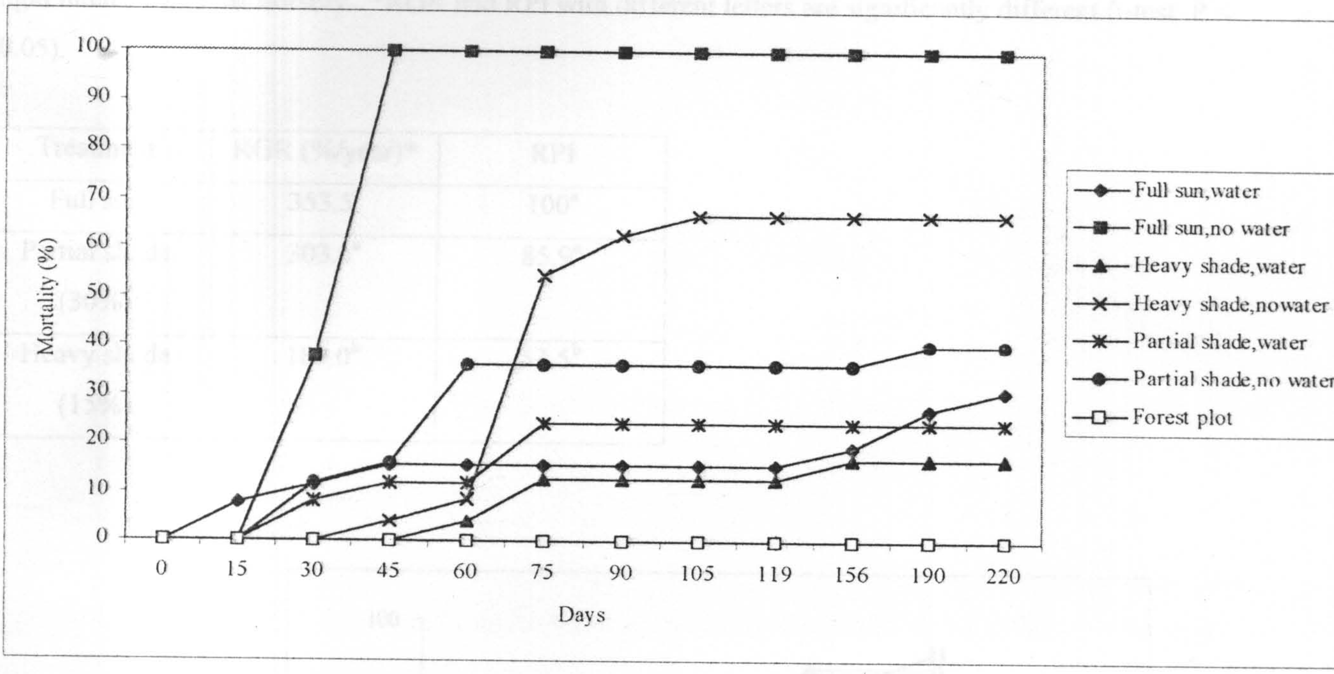

Figure 6. Mortality rates for seedlings in the nursery between January 2000 and August 2000 (from Sriamonmongkol 2000)

Effects of light availability on seed germination and seedling growth in the nursery

The overall germination on the filter paper medium was high for all treatments, ranging from 80% to 92% (Figure 7). The highest percent germination was observed in the partial shade treatment, but these differences were not statistically significant (χ^2 test, $p > 0.05$). More than 40 % of the seeds germinated within 2 weeks and the remaining seeds that did germinate, did so within two months.

Light significantly affected seedling vertical growth. Seedlings grown in full-sun and partial shade had a significantly higher relative growth rate (RGR) and relative performance (RPI) than seedlings grown under heavy shade (Table 3).

Table 3. Relative growth rates (RGR) and relative performance (RPI) of seedlings grown under different light intensities in the nursery. *RGR and RPI with different letters are significantly different (t-test, $P < 0.05$).

Treatment	RGR (%/year)*	RPI
Full sun	353.5^a	100^a
Partial shade (30%)	303.6^a	85.9^a
Heavy shade (15%)	189.0^b	53.5^b

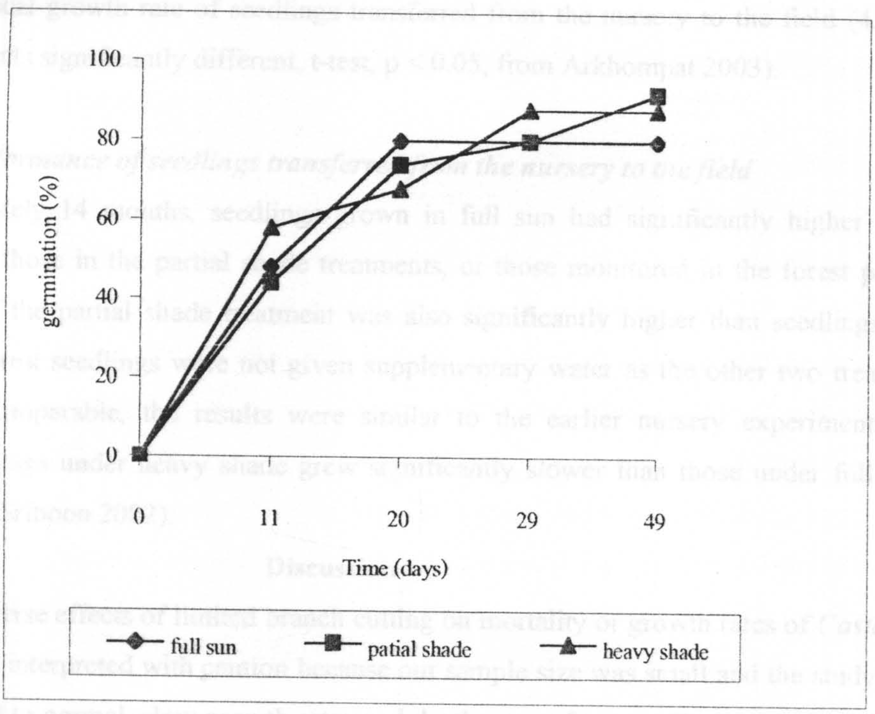

Figure 7. Percentage seed germination on filter paper media at different light availabilities (from Sriboon 2002).

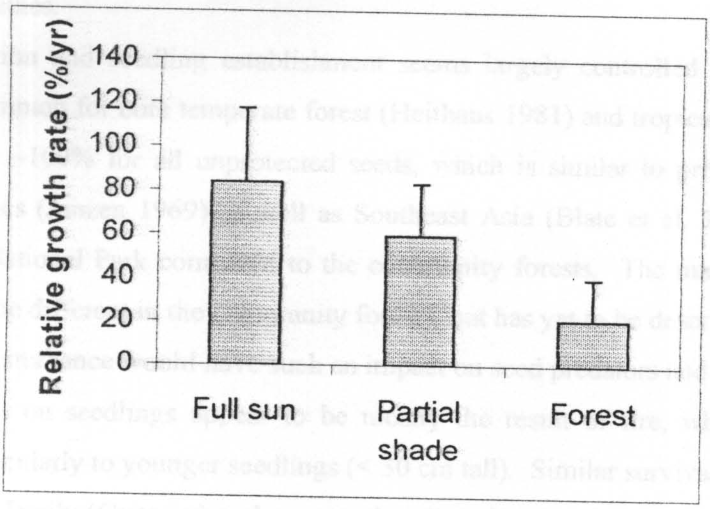

Figure 8. Relative vertical growth rate of seedlings transferred from the nursery to the field (431 days after transfer, all treatments significantly different, t-test, $p < 0.05$, from Arkhompat 2003).

Growth and performance of seedlings transferred from the nursery to the field

After approximately 14 months, seedlings grown in full sun had significantly higher relative growth rates than either those in the partial shade treatments, or those monitored in the forest plot (see Figure 8). The RGR of the partial shade treatment was also significantly higher than seedlings in the forest. Although, the forest seedlings were not given supplementary water as the other two treatments, and thus not directly comparable, the results were similar to the earlier nursery experiment where seedlings in which seedlings under heavy shade grew significantly slower than those under full sun or partial shade treatments (Sriboon 2002).

Discussion

We found no adverse effects of limited branch cutting on mortality or growth rates of *Castanopsis indica*, but this should be interpreted with caution because our sample size was small and the study period relatively short compared to normal, slow growth rates and death rates of trees. (For example, the Center for Tropical Forest Science collects tree growth data once every five years [CTFS 2003]). However, removing all branches of *C. indica* probably will impact the adult trees by preventing reproduction and is likely affect their long-term survival. Although several branch lopping studies have been conducted in Asia on fast growing species (e.g., Gupta et al. 1996, Vishwanatham et al. 1999), there appears to be little available data for species in this family (Fagaceae). Thus, in the absence of precise data or data from similar species, we recommend keeping at least 75% of the tree crown, particularly the upper-most productive branches, as a reasonable tradeoff between economic benefits and the growth and reproduction needs of the tree. However, further information on the effects of cutting will be needed for long-term management of this species.

Seed germination and seedling establishment seems largely controlled by predation by small mammals, which is common for both temperate forest (Heithaus 1981) and tropical rainforest (Blate et al. 1998). Predation was ~100% for all unprotected seeds, which is similar to previous results for some species in the neotropics (Janzen 1969) as well as Southeast Asia (Blate et al. 1998), but the rate was clearly slower in the National Park compared to the community forests. The mammalian seed predator community appears to be different in the community forests, but has yet to described and it is unclear at this time why human disturbance would have such an impact on seed predators and seed predation.

Human impacts on seedlings appear to be mostly the result of fire, which caused significant mortality (~ 50%), particularly to younger seedlings (< 30 cm tall). Similar survival rates have been found for species in the same family (*Quercus*) and suggest that *C. indica* is relatively fire tolerant (Huddle and Pallardy 1999). Fordyce et al. (1997) and others have found that fire tolerance is often age dependent, and at least partially dependent upon the ability to resprout, which is at least partly correlated with the amount of starch in the roots (Huddle and Pallardy 1999).

Castanopsis indica is a relatively slow-growing species (~50 cm of vertical growth / year). However, the survival of this species in deep shade (5% of full sun) can be relatively high (> 80%) at least over a relatively short time span (~ 1 year). This appears to fit the general paradigm that there is a clear trade-off between growth rate and survivorship at low light levels (Kobe et al. 1995, Veneklaas and Poorter 1998). *C. indica* seedling growth rates appear to be best in high light environments and were significantly higher in the community forests, which was probably due to increased light availability and perhaps soil nutrient availability (although no soil nutrient data were collected). Higher survival and growth rates in high light environments are common in tropical tree species (Augspurger 1984). However, a relatively small increase of shade dramatically increased the survival of drought-stressed seedlings in the nursery, which suggests that areas of open canopy in the forest (such as in gaps created by branch and tree cutting) may occasionally increase mortality rates of young *C. indica* seedlings during particularly long periods of drought.

In conclusion, *C. indica* seems to tolerate moderate branch cutting, germinates and survives well in the nursery and can be successfully transferred from the nursery to the field. Thus, in theory *Castanopsis indica* probably could be effectively managed at the community level through long-term planning. In particular, a more logical and careful management of agricultural fires could greatly reduce the mortality rates of this and many other species in forested areas adjacent to agricultural fields. However, fires were also started in the National Park presumably for hunting purposes and this represents a more serious problem of law enforcement in addition to education.

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