EFFECT OF LOGGING ON THE STRUCTURE AND REGENERATION OF IMPORTANT FRUIT BEARING TREES IN A WET EVERGREEN FOREST, SOUTHERN WESTERN GHATS, INDIA

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GANESAN, R. & DAVIDAR, P. 2003. Effect of logging on the structure and regeneration of important fruit bearing trees in a wet evergreen forest, southern Western Ghats, India. The effect of selective and clearcut logging on stem density and regeneration of six important resource trees, namely, *Cullenia exarillata, Aglaia bourdillonii, Artocarpus heterophyllus, Myristica dactyloides, Gomphandra coriacea* and *Palaquium ellipticum,* were studied. Forests logged 24 years ago were compared with an unlogged forest. Belt transects (10 × 100 m) were established to enumerate adult trees (>10 cm dbh). Sub-plots (10 × 10 m) along the belt transects at 0–10, 40–50 and 90–100 m were enumerated for saplings (1–10 cm dbh). Adult stem density was significantly lower in both selectively logged and clearcut logged sites for all species except *A. heterophyllus. Palaquium ellipticum* was missing in clearcut logged sites. The higher dbh class (>50 cm) remained missing in the logged forests after 24 years. Sapling densities of *A. heterophyllus* and *P. ellipticum* were significantly reduced in the selectively logged forests. In the clearcut logged forest, other species had significantly reduced sapling density except *A. bourdillonii. Palaquium ellipticum* had no saplings in the clearcut logged forest. The adult:sapling ratios were generally high in the unlogged forest. Low adult density and reduced regeneration potential of these species in the logged sites suggest that the medium elevation evergreen forest at Kalakad-Mundanthurai Tiger Reserve, Agasthyamalai Range, is degraded by logging.

Key words: Logging effect - population structure - Agasthyamalai - disperser and pollinators

GANESAN, R. & DAVIDAR, P. 2003. Kesan pembalakan terhadap struktur dan pemulihan pokok berbuah yang penting di hutan malar hijau lembap, Western Ghats, selatan India. Kesan pembalakan tebangan memilih dan tebangan habis terhadap kepadatan batang dan pemulihan enam pokok sumber yang penting, *Cullenia exarillata, Aglaia bourdillonii, Artocarpus heterophyllus, Myristica dactyloides, Gomphandra coriacea* dan *Palaquium ellipticum,* dikaji. Hutan yang dibalak 24 tahun dahulu dibandingkan dengan hutan tidak dibalak. Transek jalur (10 × 100 m) dibangunkan untuk mengira pokok dewasa (>10 cm dbh). Petak kecil (10 × 10 m) di sepanjang transek jalur pada 0–10, 40–50 dan 90–100 m dikira untuk anak pokok (1–10 cm dbh). Kepadatan batang dewasa adalah lebih rendah dengan bererti dalam kedua-dua tapak yang ditebang secara memilih dan tapak yang dibalak secara tebangan habis bagi kesemua spesies kecuali *A. heterophyllus. Palaquium ellipticum* tidak terdapat di tapak yang ditebang secara

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KUMARAN, K., SURENDRAN, C. & PALANI, M. 1996. Effect of presowing chemical treatment on germination and seedling growth in neem (*Azadirachta indica* A.Juss). *Indian Journal of Forestry* 19(1): 87–88.

LEE, H. S., KIM, G. P. & LEE, K. H. 1986. Effect of GA_3 and B-9 treatment on the growth and yield under monocropping and after barley cropping sesame. Research reports of the rural development administration. *Crops Korea Republic* 28 (1): 185–193.

LOWRY, O. H., ROSEBROUGH, N. J., FARR, A. L. & RANDALL, R. J. 1951. Protein measurement with folin phenol reagent. *Journal of Biological Chemistry* 193: 265.

MASILAMANI, P. & DHARMALINGAM, C. 1955. Enhancing germination of silver oak. *The Hindu* September, 28: 28.

MISHRA, K. & MISHRA, G. P. 1984. Effect of gibberellic acid on *Tectona grandis* and *Dendrocalamus strictus* seedlings. *Journal of Tree Science* 3 (1&2): 20–16.

NAYITAL, R. K., DAVID, L., WENNY & VERMA, K. S. 1993. Germination of western larch seed surface sterilized with bleach. *Indian Journal of Forestry* 16(4): 319–322.

PALANI, M., DASTHAGHIR, M. G. & KUMARAN, K. 1995. Effect of persowing chemical treatment on germination and seedling growth in *Acacia nilotica*. *International Tree Crops Journal* 8: 189–192.

PANSE, V. G. & SUKHATME, P. V. 1967. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi. 380 pp.

PEOPLES, T. R. & KOCH, D. W. 1979. Role of potassium in carbon dioxide assimilation in *Medicago sativa L. Plant Physiology* 63: 878–881.

PFLÜGER, R. & MENGEL, K. 1972. The photochemical activity of chloroplasts obtained from plants with different potassium nutrition. *Plant & Soil* 36: 417–425.

RICHA & SHARMA, M. L. 1994. Enhancing the germination of stored bamboo seeds using plant growth regulators. *Seed Science & Technology* 22: 313–317.

SALE, P. W. G. & CAMPBELL, L. C. 1986. Yield and composition of soyabean seed as a function of potassium supply. *Plant & Soil* 96: 317–325.

SINGH, V. K., PUROHIT, C. K. & SACHDEV, T. S. 1984. Influence of phytohormones on growth and dry matter production in *Madhuca latifolia*. *Indian Forester* 10: 936–943.

SIVAGNANAM, K. 1995. Growth Biology, Reproductive Strategy and Seed Production Spectrum in Neem (*Azadirachta indica* A.Juss). Ph.D. thesis, Tamil Nadu Agricultural University, Coimbatore, India.

TALWAR, K. K. & BHATNAGAR, H. P. 1978. Effect of growth rgulators on fresh and dry matter, holocellulose production and mineral uptake by seedlings in *Pinus caribea*. *Indian Forester* 194 (8): 544.

TINUS, R. W. 1982. Effects of dewinging, soaking, stratification and growth regulators on germination of green ash seed. *Canadian Journal of Forestry Research* 12: 931–935.

VERMA, A. N. & TANDON, P. T. 1988. Effect of growth regulators on germination and seedling growth of *Pinus kesiya* Royle ex Gord and *Schima khasiana* Dyer. *Indian Journal of Forestry* 11 (1): 32–36.

WAREING, P. F., HANNEY, C. E .A. & DIGBY, J. 1964. The role of endogenous harmones in cambial activity and xylem differentitation. Pp. 323–344 in Zimmermann, M. H. (Ed.) *The Formation of Wood in Forest Trees*. Academic Press, New York.

WAREING, P. F. & PHILLIPS, I. D .J. 1970. *The Control of Growth and Differentiation in Plants*. Pergamon Press, Oxford.

YOSHIDA, S., FORNO, D. A. & COCK, J. H. 1971. *Laboratory Manual for Physiological Studies of Rice*. IRRI Publication, Philippiness: 36–37.

in the plants (Pflüger & Mengel 1972). Peoples and Koch (1979) reported that potassium promoted CO_2 fixation by direct activation of RUBP carboxylase thereby favouring synthesis of chlorophyll.

The soluble protein content was highest in the KCl treatment followed by the IAA 100 ppm treatment (Table 3). Increased soluble protein contents due to potassium were observed by Sale and Campbell (1986) in many agricultural crops. The enhancement of reserved starch and chlorophyll contents could also be responsible for increased soluble protein content.

The study clearly brings out the advantages of soaking tamarind seed in solutions of growth stimulants, viz. IAA ppm, succinic acid 1% and IBA 100 ppm. Soaking of seed in cow's urine 50/50 v/v increased the leaf area. KCl 3% improved the total chlorophyll and soluble protein contents. Therefore, soaking in growth stimulants of tamarind seed prior to sowing is recommended to increase the field survival of the seedlings.

Table 3 Influence of growth stimulants on total chlorophyll and soluble protein contents in *Tamarindus indica*

Growth stimulant	Total chlorophyll (mg g^{-1})			Soluble protein (mg g^{-1})		
	30 DAS	90 DAS	150 DAS	30 DAS	90 DAS	150 DAS
IBA	0.87	1.22	2.30	0.76	1.36	2.15
IAA	0.72	1.31	2.07	1.21	2.34	3.07
$ZnSO_4$	0.86	1.30	2.53	0.43	0.99	1.82
Succinic acid	0.93	1.39	1.96	0.98	1.53	2.46
KCl	0.91	1.83	1.96	1.63	2.54	3.43
KH_2PO_4	0.74	1.05	2.19	0.65	1.20	1.95
Cow's urine	0.62	1.54	2.34	0.85	1.84	2.67
Control	0.85	1.47	2.05	0.69	1.32	2.10
SEd		0.061			0.082	
CD (p=0.05)		0.123			0.163	

SEd = standard error deviation
CD = critical difference
DAS = days after sowing

References

ABDUL-BAKI, A. A. & ANDERSON, J. D. 1973. Vigour determination of soyabean seeds by multiple criteria. *Crop Science* 13 (6): 630–633.

BHATNAGAR, H. P. & SINGH, V. 1981. Effect of growth regulators on growth and development of *Acacia nilotica* seedlings. *Van Vigyan* 19(4): 128–134.

BRAHMAN, M. 1995. Influence of IAA and IBA on seed germination of some exotic fast-growing tree species: *Enterolobium cyclocarpum* (Jacq.) Griseb. *Advances in Plant Science* 8(1): 21–27.

DAVIS, P. J. 1973. Current theories of the mode of auxin. *Botanical Review* 39: 139–171.

GURUMURTHI, K., CHIBBARM, R. N. & NANDA, K. K. 1974. Evidence for the mediation of indole-3 acetic acid effects through its oxidation products. *Experiments* 30: 997–998.

ISTA. 1993. International rules for seed testing. *Seed Science & Technology* 21: 25–30.

KHAN, A. A. 1977. *The Physiology and Biochemistry of Seed Dormancy and Germination.* Elsevier Scientific Publications Co., Amsterdam.

Cow's urine 50/50 v/v and IBA 100 ppm increased the leaf area (Table 2). Several researchers have demonstrated the positive effect of growth regulators and chemicals on leaf area (Sivagnanam 1995). Extension of leaf surface area is brought about by phytochrome, the production of which is stimulated by an additional supply of growth regulators. The auxins present in cow's urine might have induced the increment in leaf area. In the present investigation, the increased plant growth attributes caused by the various growth stimulants also confirm the above assertions.

IBA 100 ppm gave generally the highest shoot and root dry weights, followed by IAA 100 ppm (Table 2). Similar increases due to auxin application were recorded in *Pinus caribea* (Bhatnagar & Singh 1981), *Dendrocalamus strictus* and *Tectona grandis* (Mishra & Mishra 1984), and *Madhuca latifolia* (Singh *et al.* 1984). The relative increase in dry matter may probably be due to the direct correlation with the growth and development of the root system as well as the uptake and accumulation of mineral nutrients (Talwar & Bhatnagar 1978). Gurumurthi *et al.* (1974) noted the allosteric nature of IAA oxidase and the oxidising products of IAA oxidase that cause a physiological response leading to the accumulation of more photosynthates and nutrients.

Table 2 Influence of growth stimulants on leaf area, shoot dry weight and root dry weight in *Tamarindus indica*

Growth stimulant	Leaf area (cm^2 $plant^{-1}$)			Shoot dry weight (g $plant^{-1}$)			Root dry weight (g $plant^{-1}$)		
	30 DAS	90 DAS	150 DAS	30 DAS	90 DAS	150 DAS	30 DAS	90 DAS	150 DAS
IBA	102.2	127.9	170.0	0.30	0.41	1.04	0.29	0.45	1.91
IAA	47.1	58.0	73.7	3.30	0.33	0.94	0.47	0.71	1.47
$ZnSO_4$	43.5	51.3	64.9	0.19	0.32	1.16	0.28	0.41	1.46
Succinic acid	51.9	62.6	79.9	0.36	0.46	0.81	0.57	0.66	1.17
KCl	79.2	98.1	112.8	0.30	0.34	1.02	0.28	0.65	1.38
KH_2PO_4	36.1	43.0	53.4	0.22	0.42	0.67	0.28	0.56	1.15
Cow's urine	103.0	121.0	176.9	0.24	0.35	0.94	0.39	0.56	1.57
Control	39.2	59.9	80.0	0.21	0.34	0.68	0.29	0.56	1.06
SEd		2.97			0.028			0.025	
CD (p=0.05)		5.93			0.056			0.051	

SEd = standard error deviation
CD = critical difference
DAS = days after sowing

At 150 DAS, seeds soaked in 2% ZnSO4, and at 90 DAS, seeds soaked in 3% KCl, produced seedlings with higher chlorophyll contents than those of other treatments and the control (Table 3). The IBA treatment also gave a high chlorophyll content at 150 DAS. Increased chlorophyll content due to growth promotors like IBA can be attributed to the faster rate of synthesis of chlorophyll pigment than the degradation effect of chlorophyllase (Lee *et al.* 1986). Potassium and other salt solutions also have a similar effect on promoters, possibly due to the increased supply of K and increased photoreduction and photophosphorylation

Chemicals and growth regulators enhance germination mainly by exerting their antagonising effect on the inhibitors present in the dormant seed (Khan 1977). They may cause an increase in cytochrome activity or enhance the rate of metabolism during germination (Verma & Tandon 1988) and they also easily penetrate the seed at their optimum concentrations and are available at the site of action (Tinus 1982). Auxins are critical in the germination of *Thyrsostachys siamensis* and *Dendrocalmus strictus* because of their effect on cell elongation (Richa & Sharma 1994). The promoting effect of auxins on germination may be attributed to their indirect effect on membrane permeability, solubilization of carbohydrates through synthesis of different enzymes and production of some precursors needed for germination. The auxins may exert their primary effect on the cell wall and change subcellular protein concentration.

The longest combined lengths of shoot and root were recorded with cow's urine, followed by IBA and KH_2PO_4 (Table 1). This is in general agreement with the findings of Brahman (1995) in *Enterolobium cyclocarpum* and Sivagnanam (1995) in *Azadirachta indica*. Wareing and Phillips (1970) reported that auxins influence stem elongation significantly. According to Davis (1973), there are two stages in the action of auxin. The first stage is an immediate cell elongation through the breaking of acid liable bonds within the polysaccharide matrix of the cell wall; the second stage is protein synthesis. Increased root length and shoot length due to potassium may be ascribed to the production of osmoticum; osmoticum in root cell sap enables the plant to absorb more water and nutrients from the soil. The auxins present in cow's urine may induce shoot and root growth. The beneficial effect of cowdung solution was also reported by Palani *et al.* (1995) in *Acacia nilotica.*

Table 1 Influence of growth stimulants on germination, vigour index, shoot and root lengths in *Tamarindus indica*

Growth stimulant	Germination (%)	Vigour index	Shoot length (cm)			Root length (cm)		
			30 DAS	90 DAS	150 DAS	30 DAS	90 DAS	150 DAS
IBA	64.5 (53.4)	2883	19.9	24.0	25.6	31.4	34.8	41.9
IAA	85.5 (68.0)	3604	17.2	19.8	22.6	31.4	30.2	41.9
$ZnSO_4$	44.8 (42.0)	1889	12.8	18.3	24.1	25.1	31.6	36.6
Succinic acid	84.0 (66.5)	4150	18.1	21.3	23.1	29.6	34.3	34.1
KCl	72.0 (58.2)	3096	18.8	20.7	26.6	24.8	30.5	35.3
KH_2PO_4	84.5 (67.0)	3368	17.0	22.7	27.2	24.0	37.9	40.0
Cow's urine	70.5 (57.1)	3225	17.2	24.0	26.3	22.9	32.9	42.4
Control	75.0 (60.2)	3145	16.7	19.4	27.9	29.0	33.3	36.4
SEd	2.64	193		0.84			1.62	
CD (p=0.05)	5.44	400		1.67			3.24	

(Figures in parentheses indicate arc sine values).

SEd = standard error deviation
CD = critical difference
DAS = days after sowing

Introduction

The forest zones of India occupy about 22% of the geographical area and a recent aerial survey indicated that only about 12% is functional forest area. The rest can be assumed as non-productive, degraded forest land. The remote sensing data show fast depletion of forest cover. This is of great concern to the environmentalists and scientists. Hence afforestation on a large scale must be taken up.

A major limiting factor in the afforestation of wastelands is drought stress after transplanting. Success can be increased with proper utilization of growth stimulants and growth regulators by promoting root growth. Growth regulators and growth stimulants have been extensively used in forestry to enhance the development of seedlings under nursery conditions (Nayital *et al.* 1993, Kumaran *et al.* 1996) because of their role in promoting root growth and internal differentiation including initiation of cambial activity and xylem differentiation (Wareing *et al.* 1964). Therefore, a study was conducted to examine the response of tamarind (*Tamarindus indica*) seedlings to presowing seed treatment with growth stimulants.

Materials and methods

Seeds of tamarind were scarified in concentrated H_2SO_4 for 15 min and then soaked for 12 h in growth stimulants, viz. indole butyric acid (IBA) 100 ppm, indole acetic acid (IAA) 100 ppm, zinc sulphate ($ZnSO_4$) 2%, succinic acid 1%, potassium chloride (KCl) 1%, potassium dihydrogen phosphate (KH_2PO_4) 3% and cow's urine 50/50 v/v. Unsoaked seeds served as control. Soaked seeds were shade dried for an hour and sown in 10 × 15 cm size polybags filled with nursery soil mixture, which consisted of red soil, sand and farmyard manure (FYM) (2:1:1). The experiment was set up in a completely randomized design with four replications. Each replication comprised 50 polybags.

The seedlings were counted on the 30th day after sowing and expressed in percentage (ISTA 1993). At 30, 90 and 150 days after sowing (DAS), five seedlings in each replication were selected at random and observed for shoot and root lengths, total dry weight, total leaf area (LICOR model LI 3000 leaf area meter), total chlorophyll content (Yoshida *et al.* 1971) and soluble protein (Lowry *et al.* 1951). Vigour index was computed as the integral of the seedling length × germination percentage (Abdul-Baki & Anderson 1973). The data were subjected to statistical analysis following Panse and Sukhatme (1967).

Results and discussion

Of the growth stimulants examined, three (IAA, succinic acid and KH_2PO_4) produced the best germination and vigour in *Tamarindus indica* (Table 1). Several chemicals and growth regulators, known to enhance germination, have been documented (Brahman 1995, Masilamani & Dharmalingam 1995). Increased germination and vigour brought about by soaking the seeds in 2% KH_2PO_4 have also been reported in *Azadirachta indica* (Kumaran *et al.* 1996).

tebangan habis. Kelas dbh yang lebih tinggi (> 50 cm) tidak terdapat di hutan yang dibalak selepas 24 tahun. Kepadatan anak pokok *A. heterophyllus* dan *P. ellipticum* berkurangan dengan bererti di hutan yang ditebang secara tebangan memilih. Di dalam hutan yang ditebang secara tebangan habis, kepadatan anak pokok mengurangkan dengan bererti kecuali bagi *A. bourdillonii.* Tidak terdapat anak pokok *P. ellipticum* di hutan yang ditebang secara tebangan habis. Nisbah pokok dewasa:anak pokok adalah tinggi di hutan dibalak. Kepadatan pokok dewasa yang rendah dan pengurangan potensi pemulihan spesies di tapak yang dibalak menunjukkan bahawa hutan malar hijau berketinggian sederhana di Kalakad-Mundanthurai Tiger Reserve, Agasthyamalai Range, ternyahgred akibat pembalakan.

Introduction

Since tropical forests are known for their unique vegetation types with sets of plant species, impacts of logging on species diversity, structure and regeneration could be specific to forest types and should not be generalized (Whitmore 1984, Gomez-Pompa & Burley 1991, Oldeman & van Dijk 1991). In these forests, logging of a few species can change the diversity, structure and regeneration of the entire plant community (de Zoysa *et al.* 1989, Crome *et al.* 1992, Denslow 1995, Johns 1997) and if these species are an important resource for fauna, it can affect animal community as well (Green & Minkowski 1977, Leighton & Leighton 1983, Johns 1986, Skorupa 1986, Kannan 1994). Studies of logged forests compared with primary forests are essential in understanding the restoration dynamics of the disturbed forest ecosystem and for better management of the secondary forests, which form a substantial part of any country (Balasubramanyan 1987, Primack 1990, Gomez-Pompa & Burley 1991, Waide & Lugo 1992, Lugo 1995).

India's Western Ghats support evergreen forests with diverse floristic composition across different latitudinal, altitudinal and rainfall gradients (Pascal 1988). The medium elevation evergreen forests in the Agasthyamalai Range, south of Western Ghats are floristically and structurally unique from the rest of the Western Ghats (Ganesh *et al.* 1996) supporting more localized endemics (Henry *et al.* 1984). These medium elevation forests have undergone various levels of exploitation in the past for the establishment of tea, coffee, cardamom and timber plantations (Pascal 1988, Nair1991, Ramesh *et al.* 1997). Studies on floristics and stand structure are available for most of the floristically different forests of Western Ghats (Champion & Seth 1968, Rai & Proctor 1986, Pascal 1988, Ganesh *et al.* 1996), but very few on the modified forests (Balasubramanyan 1987, Pascal 1988, Pascal *et al.* 1988, Chandrasekhara & Ramakrishnan 1993, Rajesh *et al.*1996).

The objectives of the study were:

i) to describe the structure and regeneration status of six fruit resource trees and
ii) to determine whether logging affects the abundance of these tree species.

Study area

The study sites are located in Kakachi (77° 24'E, 8° 32'N) at an elevation of 1250 m in the Kalakad-Mundanthurai Tiger Reserve, part of Agasthyamalai Range in southern Western Ghats (Figure 1). The site is covered by a contiguous tract of medium elevation wet evergreen forest of the *Cullenia exarillata-Aglaia bourdillonii-Palaquium ellipticum* type (Ganesh *et al.* 1996). The area receives over 3000 mm of rainfall annually from the Southwest and Northeast Monsoons with about six months of the year receiving over 200 mm of rainfall per month. Mean maximum temperature is 24 °C and mean minimum about 16 °C (Ganesh *et al.* 1996). The red soil is shallow and black in color because of the rich humus.

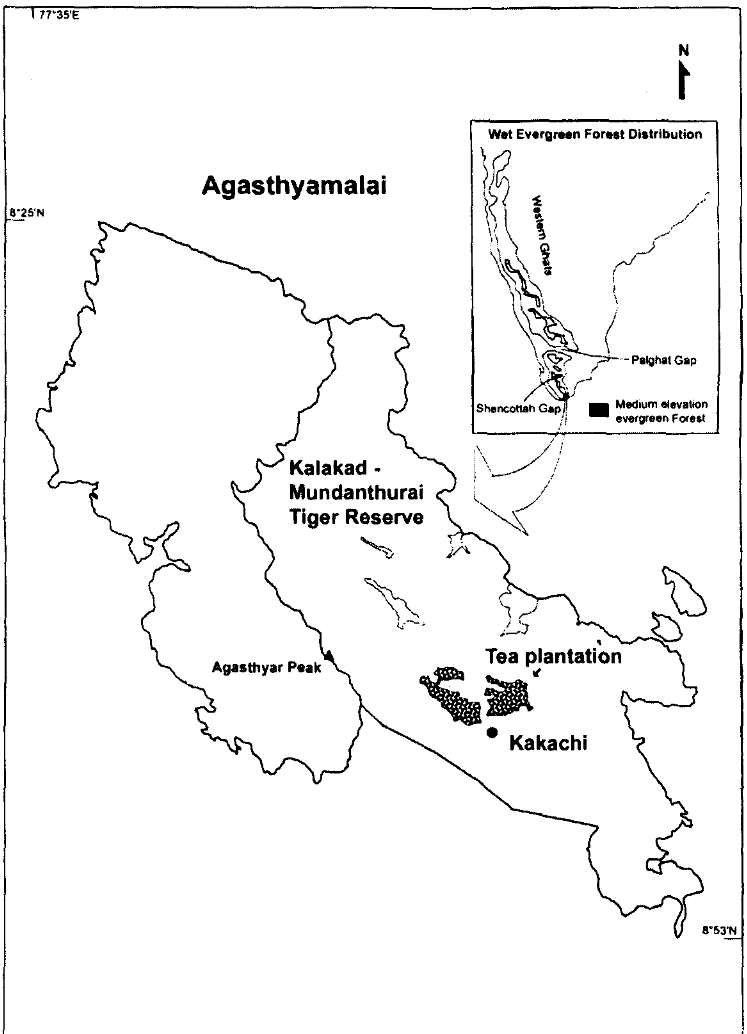

Figure 1 Map of the study site at Kalakad-Mundanthurai Tiger Reserve, southern India

Kakachi is surrounded mostly by undisturbed primary evergreen forest. In 1970 about 100 ha were selectively logged to develop cardamom (*Elettaria cardamomum*) plantations and 150 ha were clearcut logged for eucalyptus (*Eucalyptus* spp.) and coffee (*Coffea arabica*). However, these sites were abandoned without any plantations being put into production. The clearcut logged sites were not burnt as is the customary practice, while logging operations were carried out manually or with elephants with no mechanized harvesting. Logged sites are surrounded by unlogged forests on all sides.

The following six tree species (listed with their botanical and vernacular names) were chosen for study because they are the dominant species in the forest with high relative dominance (66.82) in the unlogged forest stand (Ganesh *et al.* 1996, Ganesan 2001). The species importance value (SIV) of these six species together was 145.6 (48.53 %). Also these species are important resource trees for animals, which are either their pollinators or dispersers (Ganesh 1996, Soubadra Devy 1999).

Aglaia bourdillonii Gamble (Meliaceae) - chandana agil
Artocarpus heterophyllus Lam. (Moraceae) - kattu pala
Cullenia exarillata Robyns. (Bombacaceae) - vedi pala
Gomphandra coriacea Wight (Icacinaceae) - kambuli
Myristica dactyloides Gaertn. (Myristicaceae) - kattu jaathikai
Palaquium ellipticum (Dalz.) Baillon (Sapotaceae) - paalodi

Of these six species *C. exarillata* and *P. ellipticum* were preferred for logging as they have good timber value and are the most abundant trees in the forest stand (Ganesh *et al.* 1996). Abundance of the other four species could have been affected in the process of logging as they are sub-canopy or understorey trees. All these selected trees flower regularly (unpublished data) every year with an extended reproductive phenology (Ganesh 1996).

The flower of *C. exarillata* is *ca.* 5 cm long and the corolla is fleshy with sugary secretions on the inner side. The flower of *P. ellipticum* is 2.5 cm long and cup shaped. It secretes copious sugary nectar. The spinescent fruit of *C. exarillata* is a dehiscent capsule measuring about 20 cm diameter. It encloses not less than 10 brown seeds, each measuring about 8 cm long. The fruit of *A. heterophyllus* has seeds up to 200 and measures about 40 cm long and 20 cm wide. Yellowish, fleshy perianth and the enclosed seeds are the edible parts of the fruit. Seeds measuring 2–3 cm long are the edible part of the rustic coloured fruit in *A. bourdillonii.* The fleshy fruit of *G. coriacea* measures about 1 cm long and is yellow in colour when ripe. The fruit of *M. dactyloides* is a fleshy dehiscent type with a single arillate seed and measures about 5 cm diameter. Both aril and seeds are edible. The flowers and fruit of *C. exarillata* and fruits of *A. bourdillonii, A. heterophyllus, M. dactyloides* and *G. coriacea* are eaten by a wide variety of animals (Ganesh 1996, Ganesh & Davidar1997) and *P. ellipticum* is a major source of nectar and pollen for bees (Soubadra Devy 1999).

Methods

In 1994, almost 24 y after logging, transects were randomly established in the unlogged, selectively logged and clearcut logged forests. For each treatment, 10 belt transects were laid randomly. The minimum distance between transects was about 100 m. These transects were 100 m long and 10 m wide. Each transect was divided into 10 × 10 m sub-plots. Plots with a total area of 1 ha each in unlogged, selectively logged and clearcut logged sites were sampled. Selected tree species >10 cm dbh (measurements taken at 130 cm height) were enumerated in each transect. dbh for trees with large buttress was measured above it.

Three 10 × 10 m sub-plots were laid at 0–10, 40–50 and 90–100 m in the 100 × 10 m belts. Stems of the above six species at 1–10 cm dbh were considered as saplings and enumerated in these sub-plots. The total area sampled for the saplings, was 0.03 ha in each transect and 0.3 ha for each treatment.

Statistics: Data were tested with non-parametric multiple comparison test. Differences in mean density between the three sites were tested with non-parametric one-way ANOVA (Kruskal-Wallis test) and pairwise comparison was done with Dunn's multiple comparison test. The 'L' shaped curve of size class was compared with Kolmogorov-Smirnov test. The adult:sapling ratio was calculated as density of adult trees/density of saplings and the ratio was tested with Kruskal-Wallis and Dunn's multiple comparison tests.

Results

Adult stem density

The mean stem density (>10 cm dbh) between the three sites was significantly different (Kruskal-Wallis test) for all species except for *A. heterophyllus* (Figure 2, Table 1). All five species had low stem density in the logged sites. In the selectively logged site, stem densities of *C. exarillata* (65 ha^{-1}), *G. coriacea* (21 ha^{-1}) and *P. ellipticum* (19 ha^{-1}) were less than 50% of the unlogged forest, while for species such as *A. bourdillonii* (52 ha^{-1}) and *M. dactyloides* (40 ha^{-1}) the adult stem density was 70% of the densities found in the unlogged forest. In the clearcut logged forest stem density decreased drastically for *A. bourdillonii* (15 ha^{-1}), *C. exarillata* (19 ha^{-1}), *G. coriacea* (5 ha^{-1}) and *M. dactyloides* (9 ha^{-1}) while *P. ellipticum* was totally absent. Only for *A. heterophyllus* (17 ha^{-1}) stem density was comparatively higher in the logged forest than the unlogged forest but it was not statistically significant (Table 1).

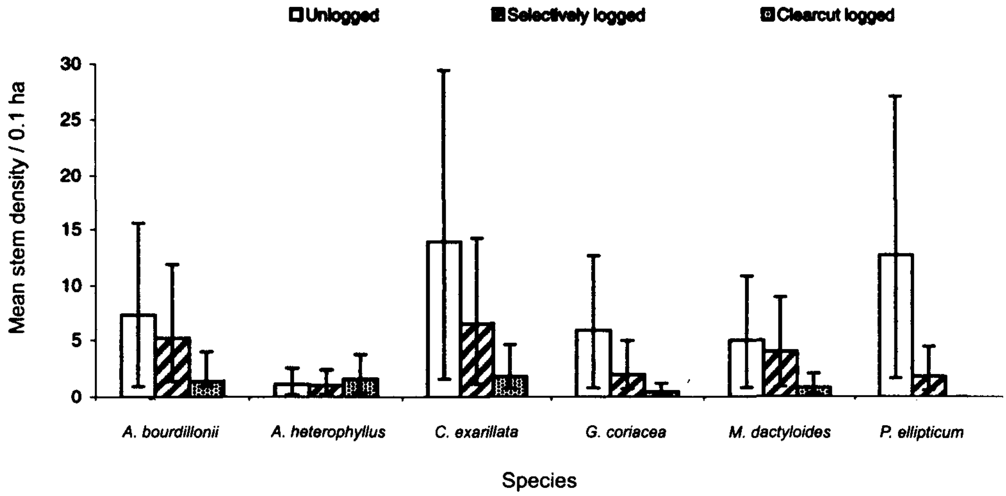

Figure 2 Adult stem density (>10 cm dbh) of important resource trees in the logged and unlogged forests

Table 1 Comparison of stem density (>10 cm dbh) between the logged and unlogged sites. The values indicate Kruskal-Wallis* and Dunn's multiple comparison test# statistics

Species	Unlogged, selectively logged and clearcut logged forests *	Unlogged and selectively logged forests #	Unlogged and clearcut logged forests #	Selectively logged and clearcut logged forests #
Aglaia bourdillonii	10.88	4.5	12.6	8.1
	p<0.01	ns	p<0.01	ns
Artocarpus heterophyllus	0.1529			
	ns	-	-	-
Cullenia exarillata	18.701	9.0	16.950	7.95
	p<0.001	ns	p<0.001	ns
Gomphandra coriacea	15.296	9.3	-14.7	5.4
	p<0.01	p<0.05	p<0.001	ns
Myristica dactyloides	9.152	3.2	11.35	8.15
	p<0.01	ns	p<0.05	ns
Palaquium ellipticum	23.298	10.7	18.1	
	p<0.001	p<0.05	p<0.001	ns

* non-parametric one-way ANOVA — Kruskal-Wallis test (KW); ns - not significant
\# Dunn's multiple comparison test n=10.

Basal area

Basal areas of large girth trees such as *C. exarillata* and *P. ellipticum* were significantly low in the selectively logged sites compared to unlogged sites (Table 2 & Figure 3). In the clearcut logged forest, except *A. heterophyllus*, the rest of the species had significantly low basal area.

Table 2 Comparison of basal area (>10 cm dbh) of stems in the logged and unlogged forests.The values indicate Kruskal-Wallis* and Dunn's multiple comparison test# statistics

Species	Unlogged, selectively logged and clearcut logged forests *	Unlogged and selectively logged forests #	Unlogged and clearcut logged forests #	Selectively logged and clearcut logged forests #
Aglaia bourdillonii	10.712 p<0.01	1.3 ns	11.6 p<0.01	10.3 p<0.05
Artocarpus heterophyllus	0.2572 ns	-	-	-
Cullenia exarillata	19.946 p< 0.0001	9.8 p<0.05	17.5 p<0.001	7.7 ns
Gomphandra coriacea	11.073 0.01	7.5 ns	12.6 p<0.01	5.1 ns
Myristica dactyloides	8.086 p<0.01	1.7 ns	10.3 p<0.05	8.6 ns
Palaquium ellipticum	20.535 p<0.0001	8.7 p<0.001	-	-

*non-parametric ANOVA — Kruskal-Wallis test (KW), n=10; ns - not significant
Dunn's multiple comparison test.

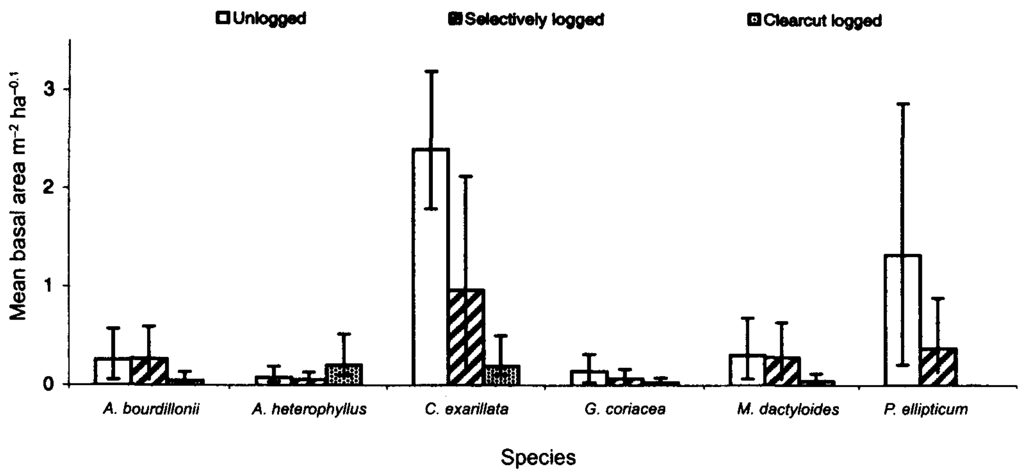

Figure 3 Basal area of important resource trees (>10 cm dbh) in the logged and unlogged forests

Regeneration

The mean sapling densities of unlogged, selectively logged and clearcut forests were significantly different for all species except *A. bourdillonii* (Figure 4, Table 3). Sapling density was significantly low in selectively logged site for only *P. ellipticum* (KW 14.5, p<0.0001) compared with unlogged forest. In the clearcut logged site, sapling density was significantly low for all the species except *A. bourdillonii*, whereas *P. ellipticum* was totally absent (Table 3). Coppicing was not observed for any of these species as a mode of regeneration.

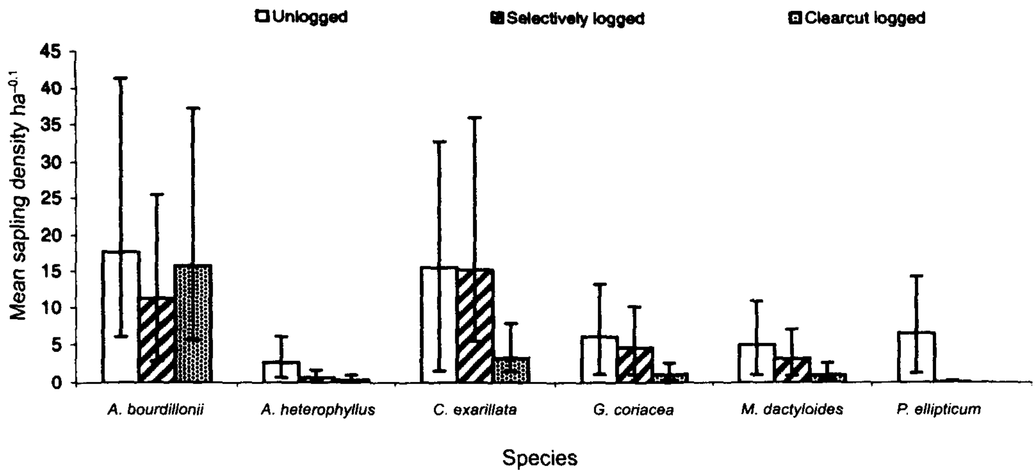

Figure 4 Sapling (1–10 cm dbh) density of important resource trees in the logged and unlogged forests

Table 3 Comparison of sapling density (1–10 cm dbh) in the logged and unlogged forests. The values indicate Kruskal-Wallis* and Dunn's multiple comparison test# statistics

Species	Unlogged, selectively logged and clearcut logged forests *	Unlogged and selectively logged forests #	Unlogged and clearcut logged forests #	Selectively logged and clearcut logged forests #
Aglaia bourdillonii	0.3817	-	-	-
	ns			
Artocarpus heterophyllus	9.141	8.05	10.4	ns
	p<0.01	ns	p<0.05	
Cullenia exarillata	13.003	ns	13.9	9.05
	p< 0.001		p<0.01	ns
Gomphandra coriacea	12.679	2.65	13.1	10.45
	p<0.001	ns	p<0.01	p<0.05
Myristica dactyloides	12.493	5.3	13.6	8.3
	p<0.001	ns	p<0.01	ns
Palaquium ellipticum	26.041	14.5	-	-
	p<0.0001	p<0.001		

*non-parametric ANOVA — Kruskal-Wallis test (KW), n=10; ns - not significant
Dunn's multiple comparison test.

The adult:sapling ratios of *A. bourdillonii* (KW 13.31, p<0.001) and *G. coriacea* (KW 11.85, p<0.002) alone were significantly different between logged and unlogged sites (Table 4). In general all these six species were showing high adult: sapling ratios (>0.5) in the unlogged site (Table 4). Adult:sapling ratios for *A. heterophyllus* in selectively and clearcut logged sites were high (>0.5) compared to unlogged site. In the clearcut logged site, *A. bourdillonii* and *G. coriacea* had low (<0.5) adult:sapling ratios (Table 4) compared to unlogged and selectively logged sites.

Table 4 Adult:sapling stem ratios in the unlogged and logged sites. (SE in parentheses)

Species	Unlogged forest	Selectively logged forest	Clearcut logged forest
Aglaia bourdillonii	1.13 (0.56)	0.81 (0.31)	0.05 (0.03)
Artocarpus heterophyllus	0.54 (0.19)	0.66 (0.19)	1.05 (0.34)
Cullenia exarillata	0.94 (0.17)	1.15 (0.66)	0.95 (0.34)
Gomphandra coriacea	1.12 (0.28)	0.41 (0.18)	0.12 (0.08)
Myristica dactyloides	0.93 (0.12)	1.50 (0.49)	0.59 (0.29)
Palaquium ellipticum	1.90 (0.32)	1.55 (0.42)	0

Population structure

The size class distributions of all the six species show a 'L' shaped distribution pattern in the unlogged and logged forest sites (Figure 5 a-f) except for *P. ellipticum*. The high sapling density of *C. exarillata* and *G. coriacea* in the selectively logged forest and *A. bourdillonii* in the clearcut logged forests makes the 'L' shaped distribution pattern different from the unlogged forest (Figure 5), even though they were not significantly different (KS, ns $p<0.05$) in the logged and unlogged forest. Individuals >50 cm dbh were absent in the logged sites for the large girth class species such as *C. exarillata, A. bourdillonii* and *M. dactyloides* (Figure 5 a-f).

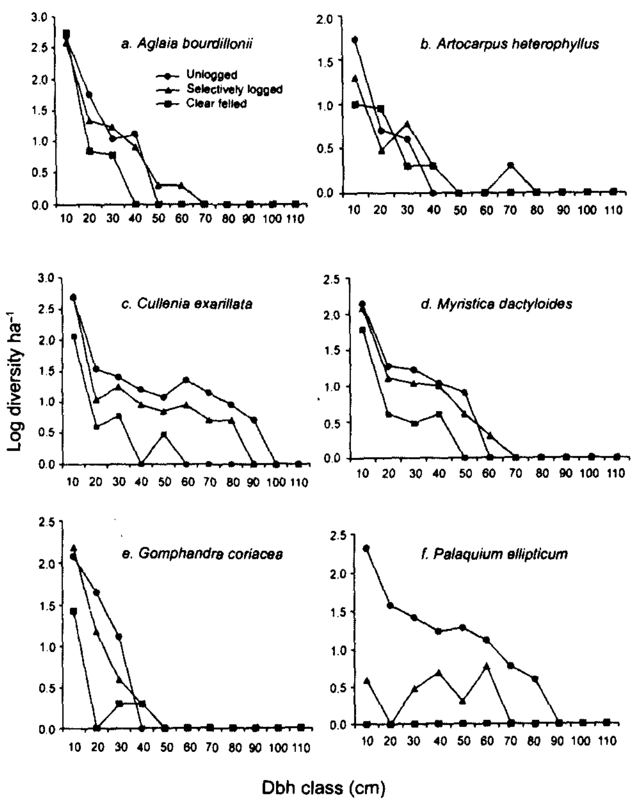

Figure 5 a-f Size class (dbh in cm) distribution of important resource trees in the logged and unlogged forests

Discussion

Selective logging and clearcut logging have had a marked impact on the adult density of all six species. The most affected species are the dominant canopy trees, *C. exarillata* and *P. ellipticum*. These are high density, large girth timber yielding species, which accounted for 70% of the forest stand (Ganesh *et al.* 1996) and were preferred for logging. *Aglaia bourdillonii, A. heterophyllus* and *M. dactyloides* were less affected by logging. *Aglaia bourdillonii,* though a high density species in this forest, has low timber value and was not preferred for logging. *Artocarpus heterophyllus* was also not preferred for selective logging in cardamom plantations because it does not hinder light penetration and adults produce edible fruit. The aril of *M. dactyloides* was one of the important non-timber forest products (pers.com. NTFP collectors) for which it might have been spared from felling.

The low density of these large girth tree species, such as *C. exarillata* and *P. ellipticum,* in >50 cm dbh class, suggests that the growth rate could be low and the 24-y post logging period is too short for many of the residual trees to attain the higher dbh class. Studies about logging impacts have concluded that even a small percentage of timber extraction by selective logging can cause extensive damage to tropical forest stand (Burgess 1971, Whitmore 1984, Johns 1988, Pascal 1988, Uhl & Vieira 1989, Chandrasekhara & Ramakrishnan 1993). In the clearcut logged site very few stems of these species were recorded in higher dbh classes. The few larger individuals in the plots could be those which had survived logging damage or left uncut. Coppicing or root suckering as reported elsewhere (Uhl *et al.* 1981, Swaine & Hall 1983, Woods 1989, Uhl & Vieira 1989) was not observed for these species in this site.

Sapling and sub-adult tree (1–10 cm dbh) composition reflects the future structure of the forest and the regeneration potential of the species. Natural regeneration and establishment for primary forest species are crucial because their requirements are more species specific (Gomez-Pompa *et al.* 1972, Whitmore 1984, Primack 1990). In the case of *A. bourdillonii, C. exarillata, G. coriacea* and *M. dactyloides,* sapling densities were not significantly low in the selectively logged forest, compared to unlogged forest. This could be due to high fruit set and less seed predation by canopy predators in the selectively logged site. The isolated trees of these species had high fruit set and were rarely visited by predators (Ganesh,unpubl.). Also the canopy openings due to selective logging might have enhanced light levels and the percentage of seedlings reaching the larger size classes. However, high adult:sapling ratios, except for *G. coriacea,* in the selectively logged site indicate that the conditions may not be congenial; mortality rates might be higher compared to unlogged forest. Still the canopy of the selectively logged forest is not completely closed compared to unlogged forest and the understorey in the logged gaps was very dense with the light loving shrubs, climbers and secondary species. These undergrowths can suppress the establishment of the saplings of the climax forest species.

In the clearcut logged site, the regeneration ratio has not recovered for all species except *A. bourdillonii* and *G. coriacea* which had low adult:sapling ratios compared with the unlogged forest. One possible reason could be the lack of adult trees of reproductive age in the clearcut logged site. All these species are either passively dispersed or animal dispersed. *Aglaia bourdillonii* and *G. coriacea* are small trees found fruiting in the clearcut logged sites. Also the residual seedlings and saplings could have contributed to the present relatively higher sapling population compared to the other species. *Aglaia bourdillonii* has a layer of thick peltate scales all over the plant and it could be an adaptation to withstand the high light levels and desiccation during the sapling stage. This species is very common in the exposed hill top forests in Kakachi.

The high adult:sapling ratio and low sapling density of *A. heterophyllus* in the clearcut forest show that the regeneration was severely affected. In the selectively logged site the adult:sapling ratio was closer to that of the unlogged forest and the reason could be the availability of parent trees which were left unlogged for their edible fruits. The seeds of *A. heterophyllus* are fairly large and dispersed by civets. Being a sub-canopy tree in the unlogged forest, canopy opening and competition from the other pioneer and secondary species could have slowed down its regeneration in the clearcut logged forest.

Absence of *P. ellipticum* in all size classes in the clearcut logged site and the low number in selectively logged site could be due to its intolerance of increased light levels and to desiccation. Seedlings of *P. ellipticum* found in landslides and tree fall gaps during 1994 had not established as saplings. Aiyar (1932), Kadambi (1941), Balasubramanyan (1987), and Chandrasekhara and Ramakrishnan (1993) reported that regeneration of primary forest species such as *P. ellipticum* in Western Ghats would be severely affected because selective logging gaps were too large compared to naturally occurring gaps. The problem, they asserted, was compounded by the invasive nature of secondary forest plants and weeds. Rajesh *et al.* (1996) suggested that the increase of the sapling density of *P. ellipticum* with the age of the stand in a selectively logged forest of Western Ghats indicated that canopy gap closure could improve the survival rate of the saplings. *Palaquium ellipticum*, being a climax species of the evergreen forests of Western Ghats, would need more time to recover at Kakachi. At present the site is dominated by pioneer species and the conditions are not suitable for the shade loving climax species.

The response of primary forest species to selective logging and clearcut logging is species specific (Whitmore 1984, Gomez-Pompa & Burley 1991, Oldeman & van Dijk 1991, Chandrasekhara & Ramakrishnan 1993). The species studied here, although all of them are climax forest species, responded differently. The low adult:sapling ratios of the species, *A. bourdillonii*, *G. coriacea* and *M. dactyloides*, in the clearcut logged site indicate that such a site is uncongenial for good regeneration of the species logged. This is confirmed by the low sapling densities of these species, with the exception of *A. bourdillonii*. Canopy gaps above the logged gaps in the selectively logged forest are not completely closed and are dominated by the light loving species. In the clearcut logged sites light loving pioneer trees and secondary species (*Clerodendrum viscosum*, *Macaranga peltata* and *Litsea* *wightiana*) dominate the forest stand. Because there are no details available on the quantity of timber removed and the extent of damage caused during logging on the residual trees, recruitment and mortality rates, it is difficult to explain the restoration dynamics completely. Also the factors that influence these trends are probably mediated by both biotic agents (e.g. pollinators and seed dispersers or seed predators) and abiotic agents (e.g. micro-climatic conditions). Successional studies by Pascal (1988) showed that there are different levels of vulnerability to exploitation of the evergreen forests of Western Ghats and it may not be possible for the exploited forests to return to climax conditions. The present study site experiences a short dry season (3-4 months) regime, is rich in localized endemics and appears to regenerate poorly after logging. With such incomplete understanding of the dynamics of this forest, any attempt to do selective logging or clearcut logging may only degrade these medium elevation evergreen forests.

Logging can affect the forest animal community (Burgess 1971, Leighton & Leighton 1983, Whitmore 1984, 1991, Skorupa 1986, Johns 1988, Kannan 1994) and this could also be the case in the present study site. High density trees such as *C. exarillata, P. ellipticum* and *M. dactyloides* provide flowers and fruits that are important resources for a range of animals such as social bees and mammals like the lion tail macaque (*Macaca silenes*), nilgiri langur (*Tracheopithecus johnii*), giant squirrel (*Ratufa indica*) and brown palm civet (*Paradoxurus johnii*) (Ganesh 1996). Such animals are important pollinators and seed dispersers (Green & Minkowski 1977, Ganesh 1996, Ganesh & Davidar 1997, Soubadra Devy 1997) of these forests at Kakachi, southern Western Ghats, India.

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References

AIYAR, T. V. V. 1932. The sholas of the Palghat division: a study in the ecology and silviculture of the tropical rain forests of Western Ghats. *Indian Forester* 58: 414–432.

BALASUBRAMANYAN, K. 1987. *Impact of Selection Felling in a Forest Ecosystem in Kerala.* Kerala Forest Research Institute, Peechi, Kerala, India. 65 pp.

BURGESS, P. F. 1971. The effect of logging in hill dipterocarp forest. *Malayan Naturalist Journal* 24: 231–237.

CHAMPION, H. G. & SETH, S. K. 1968. *A Revised Survey of the Forest Types of India.* The Manager of Publications, New Delhi. 404 pp.

CHANDRASHEKARA, U. M. & RAMAKRISHNAN, P. S. 1993. Gap phase regeneration of tree species of differing successional status in a humid tropical forest of Kerala, India. *Journal of Biosciences* 18: 279–230.

CROME, F. H. J., MORE, L. A. & RICHARDS, G. C. 1992. A study of logging damage in upland rainforest in north Queensland. *Forest Ecology and Management* 49: 1–29.

DE ZOYSA, N. D., GUNATILLEKE, C. V. S. & GUNATILLEKE, I. A. U. N. 1989. Secondary vegetation on an abandoned shifting cultivation site in the Sinharaja rainforest. *The Sri Lanka Forester* 19: 3–16.

DENSLOW, J. S. 1995. Disturbance and diversity in tropical rain forests: the density effect. *Ecological Applications* 5: 962-968.

GANESAN, R. 2001. Tree Diversity and Regeneration in the Logged Wet Evergreen Forest of Agasthyamalai, South Western Ghats, India. Ph.D. thesis, Madras University, India.

GANESH, T. 1996. Fruiting Patterns among Canopy Trees and Fruit Use by Vertebrates in a Wet Evergreen Forest of the Southern Western Ghats, India. Ph.D. thesis, Pondicherry University, India.

GANESH, T. & DAVIDAR, P. 1997. Flowering phenology and flower predation of *Cullenia exarillata* (Bombacaceae) by arboreal vertebrates in the Kalakad-Mundanthurai Tiger Reserve of southern Western Ghats, India. *Journal of Tropical Ecology* 13: 459–468.

GANESH, T., GANESAN, R., SOUBADRA DEVY, M., DAVIDAR, P. & BAWA, K. S. 1996. Assessment of plant biodiversity at a mid elevation evergreen forest of Kalakad-Mundanthurai Tiger Reserve, Western Ghats, India. *Current Science* 71: 379–392.

GOMEZ-POMPA, A. & BURLEY, F. W. 1991. The management of natural tropical forests. Pp. 3–18 in Gomez-Pompa, A., Whitmore, T. C. & Hadley, M. (Eds.) *Tropical Rain Forest Regeneration and Management.* MAB Series Volume 6. UNESCO, Paris.

GOMEZ-POMPA, A., VAZQUEZ-YANES, C. & GUEVARA, S. 1972. The tropical rain forest: a non-renewable resource. *Science* 177: 762–765.

GREEN, K. M. & MINKOWSKI, K. 1977. The lion tailed macaque and its south Indian rain forest habitat. Pp. 289–327 in Bourne G. H. & Price, R. (Eds.) *Primate Conservation.* Academic Press, New York.

HENRY, A. N., CHANDRABOSE, M., SWAMINATHAN, M. S. & NAIR, N. C. 1984. Agastyamalai and its environs: a potential area for a biosphere reserve. *Journal of Bombay Natural History Society* 81: 282–290.

JOHNS, A. D. 1988. Effects of "selective" timber extraction on rain forest structure and composition and some consequences for frugivores and folivores. *Biotropica* 20: 31–37.

JOHNS, A. D. 1997. *Timber Production and Biodiversity Conservation in Tropical Rain Forests.* Cambridge University Press, Cambridge, UK. 225 pp.

KADAMBI, K. 1941.The evergreen ghat rain forests: Agumbe – Kilandur zone. *Indian Forester* 67: 184–203.

KANNAN, R. 1994. Ecology and Conservation of the Great Pied Hornbill (*Buceros bicornis*) in the Western Ghats of Southern India. Ph.D. thesis, University of Arkansas,USA.

LEIGHTON,M. & LEIGHTON, D. R. 1983. Vertebrate responses to fruiting seasonality within a Bornean rain forest. Pp. 181–209 in Sutton, S. L., Whitmore, T. C. & Chadwick, A. C. (Eds.) *Tropical Rain Forest: Ecology and Management.* Blackwell Scientfic Publications, Oxford.

LUGO, A. E. 1995. Management of tropical biodiversity. *Ecological Applications* 5: 956–961.

NAIR, S. C. 1991. *The Southern Western Ghats: A Biodiversity Conservation Plan.* INTACH, New Delhi, India.

OLDEMAN, R. A. A. & VAN DIJK. 1991. Diagnosis of the temperament of tropical rain forest trees. Pp. 21–66 in Gomez-Pompa, A., Whitmore, T. C. & Hadley, M. (Eds.) *Rain Forest Regeneration and Management.* MAB Series Volume 6. UNESCO, Paris.

PASCAL, J. P. 1988. *Wet Evergreen Forest of the Western Ghats of India: Ecology, Structure, Floristic Composition and Succession.* French Institute, Pondicherry, India. 345 pp.

PASCAL, J. P., RAMESH, B.R. & BOURGEON, G. 1988. The Kan Forests of the Karnataka Plateau (India): structure and floristic composition, trends in the changes due to their exploitation. *Tropical Ecology* 8: 9–23.

PRIMACK, R. B. 1990. Regeneration–commentary. Pp. 285–289 in Bawa, K. S. & Hadley, M. (Eds.) *Reproductive Ecology of Tropical Forest Plants.* MAB Series Volume 7. UNESCO, Paris.

RAI, S. N. & PROCTOR, J. 1986. Ecological studies on four rain forests in Karnataka, India. I. Environment, structure, floristics, and biomass. *Journal of Ecology* 74: 439–454.

RAJESH, N., MOHAN KUMAR, B. & VIJAYAKUMAR, N. K. 1996. Regeneration characteristics of selection felled forest gaps of different ages in the evergreen forests of Sholayar, Kerala, India. *Journal of Tropical Forest Science* 8: 355–368.

RAMESH, B. R., MENON, S. & BAWA, K. S. 1997. A vegetation based approach to biodiversity gap analysis in the Agasthyamalai region, Western Ghats, India. *Ambio* 26: 529–536.

SKORUPA, J. P. 1986. Responses of rain forest primates to selective logging in Kibale forest, Uganda: a summary report. Pp. 57–70 in Benirschke, K. (Ed.) *Primates: the Road to Self-Sustaining Populations.* Springer-Verlag, New York.

SOUBADRA DEVY, M. 1997. *Palaquium ellipticum*–Flag species for the pollinators of wet evergreen forest, Kakachi, S. W. Ghats. Proceedings of the Honey Bee Ecology, Bangalore, India.

SOUBADRA DEVY, M. 1999. Pollination of Canopy Trees by Social Bees in a Wet Evergreen Forest of Kalakad Mundanthurai Tiger Reserve, Western Ghats, India. Ph.D. thesis, Madras University, India.

SWAINE, M. D. & HALL, J. B. 1983. Early succession on cleared forest land in Ghana. *Journal of Ecology* 71: 601–627.

UHL, C., CLARK, K., CLARK, H. & MURPHY, P. 1981. Early plant succession after cutting and burning in the Upper Rio Negro region of the Amazon basin. *Journal of Ecology* 69: 631–649.

UHL, C. & VIEIRA, I.C.G. 1989. Ecological impacts of selective logging in the Brazilian Amazon: a case study from the Paragominas region of the State of Para. *Biotropica* 21: 98–106.

WAIDE, R. B. & LUGO, A. E. 1992. A research perspective on the disturbance and recovery of a tropical montane forest. Pp. 173–190 in Goldammer, J. (Ed.) *Tropical Forests in Transition: Ecology of Natural and Anthropogenic Disturbances Processes.* Berkhauser-Verlag, Basel, Switzerland.

WHITMORE, T. C. 1984. *Tropical Rain Forests of the Far East.* 2nd edition. Clarendon, Oxford.

WHITMORE, T. C. 1991. Tropical rain forest dynamics and its implications for management. Pp. 67–90 in Gomez-Pompa, A., Whitmore, T. C. & Hadley, M. (Eds.) *Rain Forest Regeneration and Management.* MAB Series Volume 6. UNESCO, Paris.

WOODS, P. 1989. Effects of logging, drought and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica* 21: 290–298.