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1989

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Paper No.5

AMIC-NCDC-BHU Seminar: Media & Environment (1989)

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INTRODUCTION

Tropical forests represent the greatest store house of biological diversity in the world. Indonesian lowland rain-forests contain 3000 tree species, the Malaya Peninsula supports 2500 species, and all seed plants in New Guinea and Malaysian rain-forests, are estimated to be more than 20,000 species (Curry-Lindhal 1972). Nearly one half (2-5 million species) of the world's plant and animal species are found in these regions. Tropical forests yield many of the prescription drugs of biological origin. For example, rosy Periwinkle, a tropical forest plant yields two drugs which have increased the chances of recovery from leukemia. A great majority of tropical species are of immense significance to industries providing tannins, resins, gums, oils, dyes etc. In context of the energy shortage, the hydrocarbon yielding capacity of tropical species is important. For instance, Capaifera longsdorfii, a tree of Amazon basin, yields sap that can be used directly in diesel engines. In dry tropics in India followings species are promising hydrocarbon producers: Euphorbia lathyris, E.terucalli, E. antisyphilitica, Jatropha carcas, Calotropis procera and Simmondsia chinensis, to name a few. From tropical forest regions important new crop plants have also been discovered; for instance, the perennial corn (Zea diploperennis) from southern Mexico and winged bean (Psophocarpus tetragonolobus) from south-east Asia.

DISTRIBUTION OF TROPICAL FORESTS

About 30% of the earth's surface lies within the geographic tropics, and about 42% of the latter supports a forest cover. Table 1 presnts estimates of the extent of tropical forests for the early 70s. On global basis, 52% of the total forests (2800 million ha) are tropical, but in India tropical forests account for ca. 86% of the total. About 560 million ha land in high rainfall regions of the world supports high stature wet evergreen forests where the species diversity, growth rates and nutrient cycling reach maximum levels (Lugo 1973). With decrease in rainfall the proportion of deciduous species increases; and the dense moist deciduous forests found in medium rainfall area grade into lower statured, open-growth, dry deciduous forests with decrease in rainfall. With further decrease in rainfall microphyllous thorn forests take over. The deciduous forests are distributed over 896 million ha in the tropics, of which the bulk (588 million ha) is of dry type. In India, of the total 64.6 million ha tropical forests area, only 6.3 million ha supports wet evergreen and semi-evergreen types, and the remaining area supports deciduous types, 23.9 million ha moist and 34.4 million ha dry.

Tracts of wet evergreen forests are found in Kalimantan in Indonesia, Pacific coast of Colombia, the Carribean coast of Costa Rica, Thailand-Burmese border, eastern slopes of the Andes in Ecuador and Peru, and in Western Ghats and parts of Assam in India. Fewer human settlements have developed in these regions due to nutrient poor, heavily leached soils which are prone to rapid deterioration upon cultivation; therefore, mostly huntings, firewood and fruit gathering and shifting cultivation have been practised in these areas. Examples of moist deciduous forests are Camposo Cerrados in Brazil, much of the forests in Amazon and Congo, monsoon forests in Asia, and terai forests in India. These forest regions have been preferred as human settlement sites because they contain valuable timber species like teak, and have sustained permanent agriculture and forest plantations for a long time. In dry tropics, where growth is severely limited due to prolonged drought through the year, dry deciduos forests develop, and these grade into thorn forests with increasing aridity. Fire and drought are major ecological factors in dry tropics. Miambo woodland in Africa, caatinga in Brazil, central Peruvian Andes forests, Vindhyan and Rajasthan forests in India are examples of dry deciduous or thorn forests. Permanent human settlements are found near water supply sources, and nomadic culture has been commonly practised.

CLIMATIC CONDITIONS AND FOREST STRUCTURE IN INDIA

Most regions of the country support, or can support, some kind of a forest. The warmer plains and the lower altitudes in the hills are predominantly under one or the other type of forest. Seven main tropical types are recognized: namely, wet evergreen, semi-evergreen, moist deciduous, dry deciduous, thorn, littoral and swamp, and dry evergreen forests. Of these, the first five have significant distribution and their general characteristics are given in Table 2. The mean annual temperature ranges between 20°-30°C and mean temperature of January (generally the coldest month) mostly exceeds 15°C. Commonly, the range for mean temperatures broadens in forests of drier regions. Through the spectrum of wet evergreen to thorn forests, the annual rainfall decreases from 2400 to as low 250 mm, and the number of dry months from 3-5 to 7-10. Thus water scarcity prevails to varying degrees in all tropical forests of India; and the various types of forests are mainly determined by the annual rainfall and the seasonality of rainfall distribution.

The wet evergreen forests, are discontinuously distributed in south-western and north-eastern region of the country, having 4-6 ligneous layers with emergent trees generally extending to 40 m height, are composed almost entirely of evergreen species (Table 2). The species diversity and plant biomass are extremely high. In the Silent valley, for instance, 56 to 84 tree species per 0.4 ha have been recorded. In these forests in Karnataka, tree biomass ranges between 400-600 t/ha, which is probably an underestimate as biomass levels of 1000 t/ha have been commonly reported in other parts of the world. The transition zone between evergreen and moist deciduous forests is occupied by the semi-evergreen forests (synonym : semi-deciduous) whose canopy dominants include many deciduous trees. These ecotonal forests are species-rich, but information is lacking on their functional characteristics.

In the moist regions, the deciduous forests attain high dimensions and contain good number of evergreen species in the sub-canopy. These species-rich, 3-4 storey forests, generally contain 300 t/ha plant biomass and elaborate 15-20 t/ha/yr net production. In old growth forests the biomass may reach upto 700 t/ha. Several important species of moist deciduous forests (e.g., Shorea robusta, Tectona grandis) extend into dry deciduous zone with much reduced stature. Species-poor forests in dry regions are low statured and almost entirely deciduous. The plant biomass decreases from 50-200 t/ha in dry deciduous forests to 10 t/ha in thorn forests. While the net production in thorn forests is very low, in dry deciduous forests it is considerable (10-15 t/ha/yr) relative to plant biomass.

FOREST DEGRADATION

In the developing countries of the tropics and sub-tropics, land use surveys for the period 1979 to 1980 (FAO, 1981a, b) indicated an increase of land area under arable land, permanent crops and pastures by 17%, and a decrease of 4.2% in the area under forests and woodlands (loss of 9.2 million ha per annum). The very high deforestation rates cited from a few available studies can not be extrapolated to the entire tropical forest region. These studies, however, indicate alarming trends.

The principal direct cause of tropical forest loss are : (1) conversion and use for agriculture, (2) firewood gathering, and (3) poorly managed industrial logging.

The Department of Space has mapped the forest cover of India using LANDSAT data of 1972-75 and 1980-82 (Table 3); the total forest (55.5 million ha) in India (geographical area - 328.8 million ha) was 16.89% in 1972-75. Of the total forest, 14.12% was closed forest, 2.67% open forest area and 0.099% mangrove forest. During 1980-82 the forest area decreased to 46.33 million ha, being composed of 10.96% closed forest, 3.06% open forest and 0.081% mangrove forest. Thus, in about eight years, India lost 10.89 million ha closed forest and 0.06 million ha mangrove forest. On the other hand, the open forest area increased by 1.29 million ha due to degradation of the closed forest. In this period, the total cover was reduced by 16.52%, and as the fraction of the geographic area the forest cover was reduced by 2.79%. On average, the states having predominantly tropical forest lost a quarter of their closed forests in about eight years. In most states the forest cover loss ranged between 20-30%. Especially significant was the loss in arid region; for instance, Rajasthan lost 61% of its closed forests.

FOREST NUTRIENT CYCLE

The forest ecosystems are composed of large number of living and non-living pools of nutrients. Vegetation, animals, litter (dead organic material deposited over the soil) and soil are the major pools. Often these are fractionated for greater resolution on the basis of structural and functional characteristics; for instance, vegatation into leaf, stem and root pools, or into tree, shrub and herb pools, and so on. Figure 1 shows a simplified nutrient cycling model of a forest ecosystem. The forest is visualized in this case to consist of six nutrient pools, connected with each other by flows shown by arrows. The flows of the internal cycle, involving greater quantity of nutrients, are represented with thicker arrows, and that of the external cycle by thinner arrows.

Internal Cycle

Nutrients contained in the soil pool are absorbed by the plants, and retained in their components for varying durations. For instance, much of the nutrients reaching the leaves are transferred to litter layer within few months through litterfall and rain leaching. A smaller fraction of leaf nutrients are utilized by consumers, and later returned to litter layer through animal excreta and dead remains. On the other hand, more than one-half of the nutrients invested in stems are locked for several years (only a small quantity being returned to soil annually through barkfall) and are brought into circulation by decomposer activity only after tree death. Roots, specially the thinner ones, return nutrients to the soil pool more quickly by annual mortality and decomposition. The litter pool receives nutrients from biotic pools, and the influence of leaching and microbiological breakdown releases them into soil or air pools. Due to the participation of large variety of living organisms, having different growth requirements, developmental characteristics, and longevity, the quantity of nutrients in pools and flows tend to change with time, both seasonally as well as on long term basis.

The size of a nutrient pool at any instant depends on the historical balance between the input and the output of nutrients. Thus, in a young and growing forest, plant and litter pools distinctly increase over the years compared to soil pool. Eventually a state of equilibrium is attained when the pool sizes and flow dimensions tend to become constant (i.e. Further variations with time are only oscillations around a mean value).

The amount of nutrients in pools at equilibrium stage vary in different ecosystems. In a young forest, for example, the soil pool may account for over 80% of the total nutrients in the ecosystem. But in a primaeval, undisturbed tropical rainforest about 80% nutrients are contained in vegetation and litter pools. Over centuries these forests have evolved as efficient nutrient conserving systems having tight circulation of nutrients in vegetation-litter-soil complex. In fact in rainforests most of the nutrients regenerated by decomposition of the litter are prevented from reaching the soil by direct litter-vegetation tranfers (see Fig 1) through the highly ramifying superficial mycorrhizal fine roots of trees. The high nutrient absorption efficiency of mycorrhiza is believed to be due mainly to increased absorbing surface of the fungus-root symbiosis and the greater absorption rate of the fungus compared to root cells.

External Cycle

The amount of nutrients in the external cycle is strongly influenced by the movement of water and out of the ecosystem. The rainfall directly brings in nutrients (in suspended or solution form) or indirectly helps in soil pool enrichment by rock weathering promotion. Conversion of atmospheric nitrogen into ammonia is done by free living and symbiotic nitrogen fixing micro-organisms. All such gains can be considered as inputs to the ecosystem. These inputs are intercepted by vegetation, litter and soil pools (Fig. 1).

The nutrients are lost from different pools in a variety of ways. The litter and soil pools, both associated with high decomposer activity, lose nutrients in runoff and deep percolating water (e.g. NO3 , K , Ca , particulate matter), or in gaseous form (e.g. NO, NO2). In exploited forests significant amount of nutrients is exported out of the ecosystems through products derived from the vegetation (e.g. tendu leaves, timber, fuelwood, seeds, fruits).

In stable forest ecosystems the total inputs closely match the total outputs, and the amounts in external cycle are much less compared to the internal cycle. The dominance of internal cycle reflects greater biotic regulation of nutrient and hydrological cycling. Excessive exploitation of the forests (e.g. too much logging, too frequent or burning of litter) disrupts its biotic structure and consequently the biotic regulation; therefore, the abiotic regulation increases, promoting greater loss of water and particulate matter from the ecosystem.

FOREST NUTRIENT CYCLE PERTURBATIONS

Certain features of nutrient cycles, such as large pools, long turnover times and large amounts of recycling tend to generate ecosystem resistance (ability to resist displacement) against environmental stresses. Conversely, small pool and rapid turnover and recycling rates make ecosystem more resilient (able to return to original after disturbance). Resistance and resilience are two important aspects bearing on the stability of ecosystem. The ecosystem evolution seems to involve a compromise or balance between resistance and resilience. Generally the streams and lakes are less resistant and less resilient than tropical forests, which in turn is exceeded by temperate forests and grasslands in both aspects.

Shifting Cultivation in Tropics

Shifting cultivation is common in tropics, including north-eastern hilly regions of India. The cutting and burning of small pieces of tropical forests by the tribals releases large quantity of nutrients into the otherwise infertile soil, making subssistence agriculture possible for the next 3-5 years. Afterwards, the soil is exhausted of nutrients (due to harvesting, runoff and soil erosion), yield declines, forcing the tribals to move to new forest sites. In the abandoned crop fields secondary succession sets in leading to colonization by forest species and recovery of biotic regulation of nutrient cycle. However, due to lower resilience the attainment of the original forest, or even any stage near to it, may require long periods, perhaps measured in centuries.

Due to high population density the tribals, unable to find new undisturbed forest sites, often return to abandoned sites within few decades or even less. This has resulted in conversion of most forests to intermediate successional stages having rather "leaky" nutrient cycles. Continued nutrient depletion due to shortening of forest-crop rotation lowers the site quality. In Indian conditions the nutrient cycles in shifting cultivation need careful assessment to suggest optimum rotation period and soil conservation methods. In several south-east Asian countries, where population density is lower and rotation is longer, shifting cultivation seems to work well without significant permanent deterioration of the site quality.

Permanent Agriculture in Tropics

The natural vegetation in tropics is generally dominated by woody species, mostly trees; therefore, all croplands represent conversion stages. The tropical forest ecosystems have evolved nutrient conservation mechanisms, through intensive biotic regulation, in a climate that supports round-the-year biological activity. These mechanisms include nutrient accumulation in long lived structures (e.g. stems), mycorrhizal linkage between decomposing organic matter and roots, withdrawal of nutrients from leaves before leaffall, etc. The replacement of these ecosystems with croplands, lacking such conserving mechanisms, on nutrient poor soils, imparts high ecosystem unstability needing huge energy and subsidy for sustenance. Various practices employed in intensive agriculture like multiple cropping, legume improvement and soil-water management, all involving energy cost, essentially regulate the cycles. In subsistence agriculture, however, the nutrient cycle remains more open. Particularly, in seasonally dry regions, where multiple cropping is not feasible, the control of nutrient cycles becomes difficult. Exessive irrigation generated salinity in such regions manifests the mis-directed pathway in cycling of certain elements.

CONSEQUENCES OF DEFORESTATION IN TROPICS

Besides the environmental values and the unfathomed gene potential, whose undoubted benefits are difficult to quantify through the present day methods in economics, tropical forest deforestation is causing acute wood scarcity, particularly that of the fuelwood. One-third of the wood removed from the world's forests for human use comes from the tropics, more than one billion cubic meter per year (FAO, 1979); and some 80 per cent of tropical wood is used for fuel, mainly to meet household cooking needs of a large majority of population (Eckholm,1979). While tropical forest area is decreasing continuously, the fuelwood need is rising in proportion to the population increase. Not only the high timber cost impedes housing development programmes, the replacement of timber with steel promotes pollution load.

Following forest removal, and after the abondonment of cropping, the accelerated soil erosion and increased surface temperatures often retard or deflect the forest recovery processes. Some authorities, therefore, believe-contrary to the common contention-that many tropical forests are non-renewable resources because their original states may never be regained once lost.

Forest clearings in uplands is generally recognised to cause increased floods downhill and rapid siltation of reservoirs, as observed in several south east Asian countries in the recent past. Greater surface water flow may lead to lesser infiltration in soil and consequently to reduced supply of water in the watershed throughout the year.

Largescale tropical deforestation effects include changes in the local climate; such as, widening of diurnal temperature range, and alteration in seasonal distribution, and possibly total amount, of rainfall.

Concerns have been expressed more recently that deforestation in tropics may affect global climate. Some scientists argue that carbon dioxide released from the removal and burning of tropical forest wood, and that from increased decomposition in subsequently cropped soil, will increase the atmospheric carbon dioxide concentration, leading to an increase in the air temperature due to 'Greenhouse effect'. The atmospheric carbon dioxide concentration is indeed rising. How much of it is due to tropical deforestation alone has not yet been precisely determined; nevertheless, the risk exhibits because over 500 tonnes of carbon may be accumulated in each hectare of a rainforest.

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Table 1. Distribution of Forest Area (million ha) Under Major Forest Formations (Data Source World-Persson 1974; India-Kaul and Sharma 1971)

Formation	World Area	World % total	India Area	India % total
Tropical				
Wet evergreen	560	20	6.3*	8.4
Moist deciduous	308	11	23.9	31.8
Dry deciduous	588	21	34.4**	45.8
Total	1456	52	64.6	86.0
Sub-tropical	234	8	4.2	5.6
Temperate	448	16	4.5	6.0
Boreal/alpine	672	24	1.8	2.4
Grand total	2800	100	75.1	100

* includes semi-evergreen, 1.8 million ha.

** includes thorn forest, 5.2 million ha.

Table 2, Certain Climo-Vegetational Features of Tropical Forests in India (from Singh & Singh, 1988).

	Wet evergreen	Semi-evergreen	Moist deciduous	Dry deciduous	Thorn forest
Climate					
Mean annual temp (°C)	23-27	23-27	20-29	20-29	24-29
Mean January temp. (°C)	15-21	17-25	12-26	16-25	13-26
Annual rainfall (mm)	2400	1800-3000	1200-3000	750-1400	250-900
No. dry months	3-5	4-6	4-8	5-8	7-10
Vegetation					
Evergreenness	Entirely or nearly so	Dominants include some deciduous elements but evergreens predominate	Dominants predominantly deciduous; subcanopy evergreen	Entirely deciduous or nearly so	Entirely deciduous
Species richness	Extremely rich	Rich	Rich	Poor	Extremely poor
Canopy height (m)	40	25	25	8-20	10
No. ligneous layers	4-6	?	3	2	1
Basal area ($m^2\ ha^{-1}$)	40-55	?	35-50	15-20	5
Phytomass ($t\ ha^{-1}$)	400-600	?	300-350	50-200	10
Net production ($t\ ha^{-1}\ yr^{-1}$)	?	?	15-20	10-15	1-4
Shannon-Wiener Index	3.5-4.1	?	?	0.5-1.5	?

Table 3. Forest Area (Million ha) Changes in India

(Data Source: NRSA 1983)

Category	1972-75		1980-82		% Change
	Area	% geographic	Area	% geographic	
Closed forest	46.42	14.12	36.02	10.96	- 22.4
Open forest	8.76	2.67	10.04	3.06	+ 14.7
Mangrove forest	0.32	0.009	0.26	0.081	- 18.7
Total	55.5	16.89	46.33	14.10	- 16.5

Total geographical area = 328.779 million ha.

LEGEND

Fig.1. A simplified nutrient cycling model of a forest ecosystem. The forest consists of six nutrient pools with internal (thick arrows) and external (thin arrows) transfers. Generally the internal circulation exceeds the external transfers.

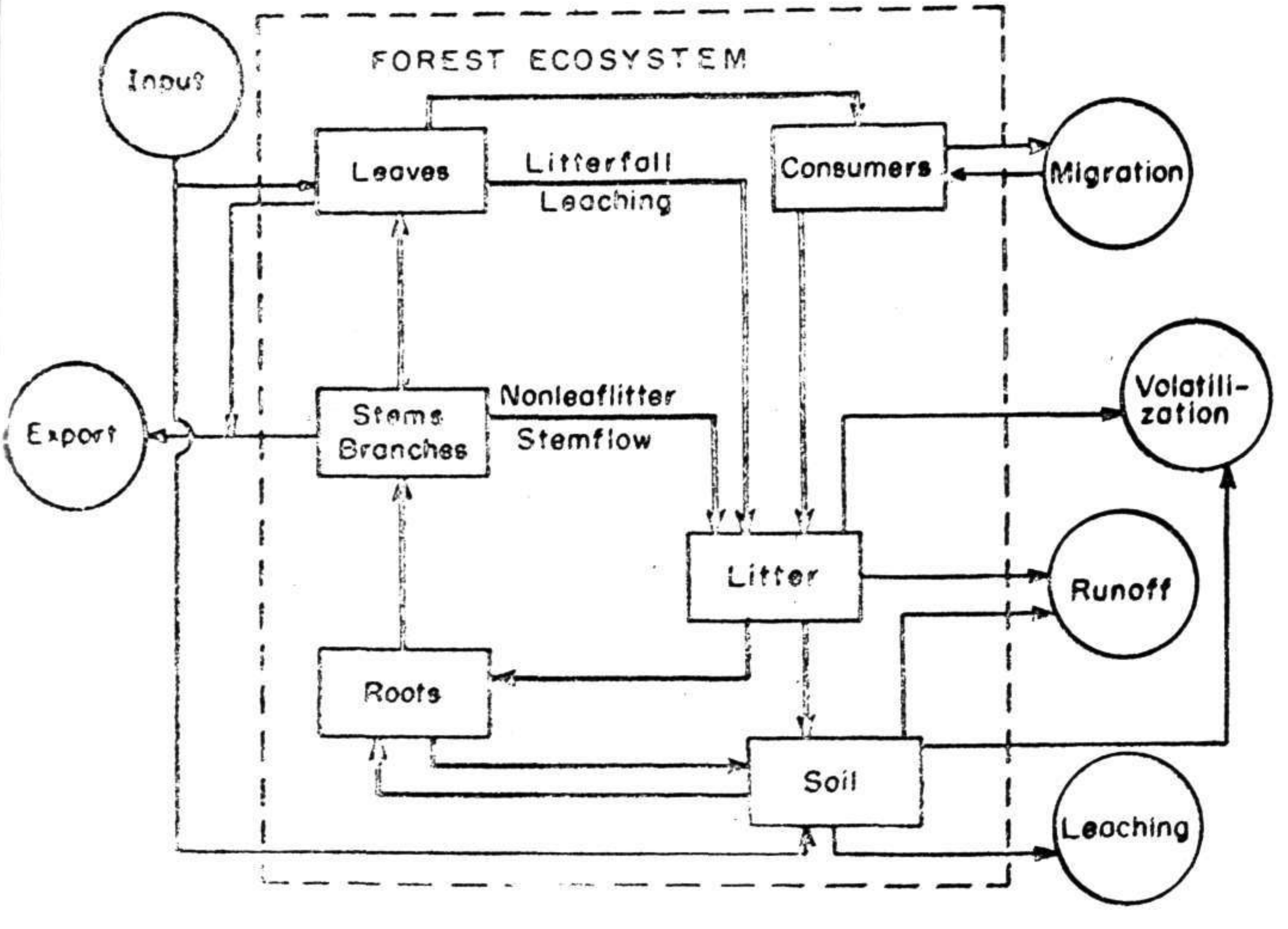
FOREST ECOSYSTEM
Input
Leaves
Litterfall
Leaching
Consumers
Migration
Export
Stems
Branches
Nonleaflitter
Stemflow
Volatili-
zation
Litter
Runoff
Roots
Soil
Leaching

Fig 1