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Review articles

Ecological Studies of Tropical Seasonally Dry Forest in Continental Southeast Asia: A Review using Thailand as a Case Study

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ABSTRACT

Tropical seasonally dry forest in Continental Southeast Asia has a prominent and similar importance to the region as does tropical rain forest. As there is broad encouragement to protect tropical forest to maintain global biodiversity and remedy global warming, major parts of this forest type are included in the protection system of all countries in Continental Southeast Asia. However, it has been less studied, particularly by ecologists, compared to the tropical wet forest type especially in this region compared to those forests in South and Central America. Ecological studies covering its past and present natural distribution, area cover, nomenclature, and some important aspects were examined using Thailand as a case study as representative of the Continental Southeast Asian region. The history of Thai-Japanese collaborative ecological studies in seasonally dry forests in Thailand is also described briefly. This broad forest community type in Thailand consists of seasonally dry forests of Mixed Deciduous or Monsoon Forest and Dry Evergreen or Seasonal Evergreen Rain Forest with variants occurring in small valleys and along stream banks called Gallery Forest and Dry Dipterocarp or Deciduous Dipterocarp Forest.

About 35 topics were found to have been intensively studied and published in scientific papers for these three forest community types in various locations in Thailand. Some of these studies are likely to have not fully covered all ecological aspects and all the details of each approach. Future research needs to fill knowledge gaps and to cover all interesting ecological as well as other related aspects that this study has identified to stimulate interested researchers in this region as well as other scientists to pay more attention to this forest type in the tropics, particularly in Thailand. Trans-boundary studies in neighboring Continental Southeast Asian countries are also encouraged.

Keywords: Continental Southeast Asia, Ecological studies, Thailand, Tropical seasonally dry forest

INTRODUCTION

Tropical seasonally dry forest has been less paid attention than humid or wet tropical forest although its distribution covers many parts of the world. It has served humans in various ways since ancient times. Ecological studies of tropical seasonally dry forest have been reviewed by Murphy and Lugo (1986) and Mooney *et al*. (1995). Emphasis on the danger of the disappearance of tropical dry forest has also been pointed out by Janzen (1988). There has been enormous scientific and public attention toward the effects of destruction of wet forests on soil, water, atmospheric, and global changes rather than on tropical seasonally dry forest. Degradation and conversion of tropical seasonally dry forest is far more advanced than that of wet tropical forest and only a small portion remains intact though it still contributes a great deal to the world ecosystems and to human wellbeing. It has also been less studied in Southeast Asia compared to the tropical seasonally dry forests in South and Central America or even in the African savanna.

About 105 books and 8,000 scientific articles on tropical rain forest are available but there is only one book that deals with the tropical seasonally dry forest (see Mooney *et al*., 1995). In this book, only one article was published on the tropical seasonally dry forest in Southeast Asia, especially on seasonally dry forests of Thailand (see Rundel and Boonpragob, 1995). While the recorded information in this article has proved to be generally useful and comprehensive, some important points particularly in relation to the ecological studies in Thai forests are not up to date and especially there is no categorization of the ecological research but rather general information has been given with practically no suggestions on future research needs. The information compiled before the appearance of that article did not fully cover all available information in published papers and those after 1995 have not yet been included. Then, 16 years later, Bunyavejchewin *et al*. (2011) published a paper on seasonally dry forest in Continental Southeast Asia but the contents were not complete; rather, they placed emphasis on the structure, species composition, and dynamics of several forest types throughout Thailand and included no study on ecological function especially on productivity and nutrient cycling, which are considered to be more important information guiding the future management and conservation of those forests. The author presented a view point to stimulate study on this forest formation through a short communication and a presentation at an international symposium in 2004 and 2005, respectively (Sahunalu, 2004c, 2005) though subsequent new publications have not yet been issued. It appears afterward that the results of ecological studies on these forest formations were newly added but were not exhaustive and further studies on various aspects are still required to formulate precise sustainable management and conservation strategies.

This forest type deserves priority research in order to preserve it as a part of maintaining world biodiversity and as insurance

against global change, while also avoiding direct exploitation. This paper aimed to review the existing information related to this important forest ecological study, particularly in Continental Southeast Asian countries by using seasonally dry forest in Thailand as an example.

Distribution of Tropical Seasonally Dry Forest

Tropical seasonally dry forest on the global scale is distributed across three continents, particularly in South and Central America, Africa, and Asia. Broad identification of the world's biome indicates that there are two major forest biomes in the tropics: tropical forest including seasonal forest and tropical savanna grassland. It is widely accepted that 40% of the Earth's tropical and subtropical landmass is dominated by open or closed forest (Murphy and Lugo, 1986). This area is further subdivided into dry forest (40%), moist forest (33%), and wet or rain forest (25%). These figures are approximate as the exact original and potential distributions of dry forest are uncertain because the existing savanna, scrub, and thorn woodlands are thought to have been derived from dry forest disturbance from time to time.

Tropical Seasonally Dry Forest Definitions

According to the life zone classification proposed by Holdridge (1967), tropical seasonally dry forest is found in frost-free areas with a mean annual bio-temperature of about 17^{O}C, the annual rainfall ranges from 250 to 2000 mm, and the ratio of potential evapo-transpiration (PET) to precipitation (P) or PET/P is greater than 1 to a maximum of 2. Different nomenclatures included in Holdridge's dry forest are: dry or sub-humid forest, seasonal drought forest, semi-evergreen, semi-deciduous and deciduous forest. Earlier, Beard (1955) classified tropical American vegetation types as: seasonal formation series which included: evergreen seasonal forest, cactus scrub, semi-evergreen seasonal forest, deciduous seasonal forest, thorn woodland; and as a dry evergreen formation series including: dry rain forest, dry evergreen forest, dry evergreen woodland, dry evergreen thicket and evergreen bushland. Later Hartshorn (1988) classified the North American terrestrial vegetation into major forest vegetation types as: lowland sub-humid forest which included tropical dry forest and subtropical dry forest, subtropical thorn forest and low mountain subhumid forest which was further classified into subtropical thorn woodland, subtropical dry forest, subtropical lower montane, subtropical dry forest, and subtropical lower montane dry forest. Nevertheless, all these classification and terminologies were not popularly adopted for tropical dry forest elements on the Asian continent.

Nomenclature of Seasonally Dry Forest in Continental Southeast Asia

Continental Southeast Asians countries consist of Myanmar, Thailand, Laos, Cambodia, and Vietnam. Tropical seasonally dry forest in Continental Southeast Asia was first defined by

Stamp (1925) and terminologies were adopted for Thailand, Myanmar, and India (Samapuddhi 1957, Ogawa *et al*., 1961, Champion and Seth, 1968) while those for Laos, Cambodia, and Vietnam were recognized by Vidal (1960). These terminologies are still used today and are well-known among the regional foresters as they reflect the physiognomy as well as the dominant tree species element clearly (Table 1). An additional terminology for the forest occurring along river courses or in depressions at lowland altitudes was added gallery forest (Ogawa *et al*., 1961) and the extremely open deciduous dipterocarp type was called savanna by most geographers.

Tropical Seasonally Dry Forest Distribution in Continental Southeast Asia

Based on the definitions and terminologies adopted for the region, there is no complete map of each forest type available for every country in Continental Southeast Asia. Each country might have published its complete set of vegetation map separately, for example, Thailand (RFD, 1962) and Myanmar (Gyi and Tint, 1998). For some particular forest type, such as deciduous dipterocarp forest, a map showing its distribution in Thailand, Laos, Vietnam, and Cambodia has been published but excluding Myanmar (see Blasco, 1983). The recent article of Vidal (2000) on Indochinese vegetation, with the exception of Myanmar, has substantially shown a map indicating various forest types. However, these were classified under broad categories as lowland mixed deciduous, lowland dry deciduous dipterocarp and highland more or less open forest that seem to be relevant to the tropical seasonally dry forest but the scale of each forest type was not precisely indicated to realize the true area extent.

The most up-to-date and probably the most useful information on tropical seasonally dry forest in Continental Southeast Asia was compiled by the World Conservation Monitoring Center and CIFOR (Iremonger *et al*., 1997) which included forest types, ecological zones, total forest area cover, protected area distribution, and population data of each country. It clearly shows that the dry forests in all countries in Continental Southeast Asia are predominated by and have been identified as deciduous/semi-deciduous broadleaf forest or as semi-evergreen moist broadleaf forest, with other forest types being less abundant. Among the nine ecological zones in the region, the lowland sub-dry zone covers much of the area with the dry zone being the next most common. The forest area cover as well as the protected area in each country vary and are largest in Myanmar and least in Vietnam. Laos and Cambodia have almost identical forest area cover. The protected forest area is largest in Thailand, followed by Cambodia, while it is least in Myanmar (Table 2). In the whole region, the protected forest area 11 % for deciduous and semi-deciduous forest and 19 % for semi-evergreen moist broadleaf forest. As the population in each country greatly affects forest utilization and conservation, the ratio of forest area cover to population reflects an important indicator for conservation planning.

Table 1 Nomenclature of seasonally dry forests in Continental Southeast Asia.

Thailand[1,2]	Myanmar[3]	Laos[4]	India and Myanmar[5]
Dry evergreen or seasonal evergreen rain forest or gallery forest[6]	Pyinkado/semi-evergreen forest	Dense humide semi-décidue forêt	Tropical semi-evergreen forest
Mixed deciduous forest or Monsoon forest	Moist teak, dry teak, dry deciduous without teak forest	Mixte décidue forêt	Tropical moist deciduous forest
Deciduous dipterocarp or dry dipterocarp forest (with exception of a savanna named by geographer)	Indaing forest	Claire á Dipterocarpacées forêt	Tropical dry deciduous forest

Notes: [1]Samapuddhi (1957). [2]Ogawa *et al*. (1961). [3]Stamp (1925). [4] Vidal (1960). [5]Champion and Seth. (1968). [6]Occurrence of this forest type along the river course or on the depression area is called gallery forest (*sensu* Ogawa *et al*., 1961). Note that India is not included in Continental Southeast Asian countries.

Table 2 Forest area cover and population in Continental Southeast Asia[1].

Country	Forest area (Million ha)	Population (x1,000 people)	Forest area: population ratio (ha/10 people)	Protected forest area (Million ha)	% of protected area
Thailand	17.11	59,414	2.88	5.13	30
Laos	12.97	5,020	25.81	1.78	14
Myanmar	45.95	47,513	9.67	0.56	1.2
Cambodia	11.64	10,530	11.05	2.99	26
Vietnam	5.01	76,161	0.66	0.50	10
Total	92.67	198,641	-	10.96	11.82[2]

Notes: [1]Modified from Iremonger *et al*. (1997). Data are as at 1996.
[2]Percentage of total forest area of all countries in the region and represent 11 % of deciduous and semi-deciduous broadleaf forest and 19 % of semi-evergreen moist broadleaf forest.

Protected forest area in Thailand includes national park, wildlife sanctuary, forest park, botanic garden, arboretum, and other specially assigned areas such as biosphere reserves and some archeological sites scattered throughout the country. As most areas are seasonally dry forest, the percentage of protected area in this forest type is considerably high. However, all forest area in Continental Southeast Asia is classified by WCMC (1994) as one under the 25 hot spots of global biodiversity that is very species rich and very sensitive to human disturbance.

Factors Affecting the Occurrence of Seasonally Dry Forest in Continental Southeast Asia

Climatic conditions:

- Under the Monsoon climatic regime. Being classified as Tropical savanna climate of Köppen (Aw).
- High total rainfall but erratic monthly rainfall.
- Having definite wet and dry season.

Edaphic condition:

- Lithosols and latosols which are poor in fertility status.
- Low water holding capacity.
- Shallow horizon of soil profile.

Physiographic location:

- Above the 5º N latitude to approximately 20ºN latitude but still within the northern belt of the tropical region.
- Most mountain ranges run in a north-south direction providing three major drainage systems: the Irrawaddy River in Myanmar, the Chao Phraya River in Thailand, and the Mekong River bordering Thailand, Laos, Vietnam, and Cambodia.

As stated above, based on these climatic regimes together with edaphic conditions and physiographic location, Thailand's seasonally dry forest has been identified into three main forest types (Table 1). The recent published information on the Myanmar and Cambodian forest classifications has not used the same nomenclature as Thailand. The distribution of the seasonally dry forest in Thailand is clearly in the upper latitudes beyond the southern peninsula where it is the main landmass of the country and represents approximately three-quarters of the country's total land area and is of considerable importance to the livelihood of a majority of the Thai population. These three main forest types are composed of many valuable tree species, with all of these having contributed a great deal to the economic development of this country for centuries. Some important tree species are listed in Table 3. For example teak (*Tectona grandis* L.f.) was a major export timber from Thailand during the last century and also for Myanmar. However, the distribution of teak-bearing forest is largest in India. It is also an endemic tree species found particularly in mixed deciduous forest in countries in the region while teak growing in Indonesia are thought to be non endemic and were probably introduced there during the Hindu period (Gyi and Tint, 1998).

Table 3 Major tree species in Seasonally Dry Forests of Thailand[1].

Forest type	Species	Family
Deciduous dipterocarp forest	*Aporosa villosa*	Euphorbiaceae
	Dipterocarpus intricatus	Dipterocarpaceae
	D. tuberculatus	”
	D.obtusifolius	”
	Shorea obtusa	”
	S.siamensis	”
	S.roxburghii	”
	Pterocarpus macrocarpus	Papilionoideae
	Sindora siamensis	Caesalpinoideae
	Quercus kerrii	Fagaceae
	Mitragyna rotundifolia	Rubiaceae
	Morinda coreia	,,
	Xylia xylocarpa	Mimosoideae
Seasonal evergreen rain forest	*Afzelia xylocarpa*	Caesalpinoideae
	Hopea ferrea	Dipterocarpaceae
	H.odorata	,,
	Shorea henryana	,,
	Hydnocarpus ilicifolius	Flacourtiaceae
	Memecylon ovatum	Melastomaceae
	Lagerstroemia calyculata	Lythraceae
	Parkia streptocarpa	Mimosaceae
	Walsura trichostemon	Meliaceae
Mixed deciduous forest	*Tectona grandis*	Labiateae
	Pterocarpus macrocarpus	Papilionoideae
	Terminalia mucronata	Combretaceae
	Lagerstroemia calyculata	Lythraceae
	Xylia xylocarpa	Mimosoideae

Note: [1]Summarized from Smitinand (1977, 1980).

Present Status of Seasonally Dry Forest in Thailand

The most up-to-date statistics on the forest area in Thailand have been published by the Royal Forest Department, Ministry of Agriculture and Cooperatives (Table 4). Although the seasonally evergreen forest type was not separately classified from the tropical evergreen forest type, the two main seasonally dry forest types (mixed deciduous and deciduous dipterocarp forest) are clearly shown and have remarkably high percentages as the former type dominates the northern and the latter the northeastern region.

Thailand is at the center of three plant distributional zones; Himalayan, Indochinese, and Malaysian elements. Plant species components range from those called mangrove species growing on mud flats in estuaries or along the coastal zone of both sides of the Thai peninsula to the sub-tropical and alpine plants on high altitude mountains in the northern region (Santisuk,

1988). Thailand is therefore considered to be rich in plant species resources and having high biodiversity. However, not all plant species in mangrove forest grow in the seasonally dry forest. Furthermore, although whole plant species components in the seasonally dry forest of Thailand have not yet been completely identified, there are several notable landscape diversity and numerous plant association types in each forest type of seasonally dry forest. Tree species composition is also diverse and constitutes a mixture of various plant life forms that result in relatively high species diversity. Many species are endemic, native, and some are rare and probably extremely rare species deserving careful study and strict conservation. Many species play important roles in different functions associated with environmental stabilization and human wellbeing.

Tropical Seasonally Dry Forest and People

- Site of human settlement since ancient times.
- Source of wood, food, fuel, fiber, medicinal plants, and non-wood forest products.
- The habitat for wildlife feeding on the ground and as shelter.
- Site for domesticated cattle.
- Major component of watersheds and other protected or reserved forests such as national parks, wildlife sanctuaries and various recreational sites.
- Site of numerous endemic and rare plant species, and the genetic pool of several plant species.
- Source of most valuable timbers, such as teak (*Tectona grandis* L.f.), *Dipterocarpus alatus, Hopea ferrea, H. odorata, Pterocarpus macrocarpus, Xylia xylocarpa* var. *kerrii* in India, Myanmar, Thailand, and Laos.
- Similar ecological significance as the wet or humid forest type, particularly in countries with seasonal climatic conditions.

Tropical Seasonally Dry Forest Utilization

Studies to date on the utilization of the forest have emphasized direct forest products that have numerous uses, for example, timber and wood products. Less study has been focused on non-forest products and in particular, information on utilization by the local people is scarce. Among the few studies, a thorough investigation was conducted by Prachaiyo (2000) and presented a very interesting topic emphasizing the utilization of the tropical seasonally dry forests by the local people in Northeast Thailand, whose local knowledge was comprehensive. Interested researchers on this aspect can refer to this informative article.

Table 4 Thailand forest area distribution by region[1].

Forest type	N		NE		C		E		S		Total M ha	% of total country forest area
	M ha	%	M ha	%	M ha	%	M ha	%	M ha	%		
Mixed deciduous	3.23	44.22	0.71	33.78	0.47	29.28	0.08	10.61	-	-	4.49	34.42
Tropical evergreen[2]	2.12	24.02	0.63	29.97	0.74	46.11	0.64	84.88	1.07	83.59	5.20	39.87
Deciduous dipterocarp	1.79	24.50	0.74	35.20	0.13	8.10	0.02	2.65	-	-	2.68	20.55
Swamp	-	-	0.02	0.95	-	-	-	-	0.06	4.69	0.08	0.61
Scrub	0.0002	0.003	-	-	-	-	-	-	-	-	0.0002	0.002
Pine	0.16	2.22	0.002	0.10	-		-	-	-	-	0.162	1.24
Bamboo	0.003	0.04	-	-	0.26	16.20	0.001	0.07	-	-	0.264	2.024
Mangrove	-	-	-	-	0.005	0.31	0.013	1.72	0.15	11.72	0.17	1.29
Total	7.305	100	2.102	100	1.605	100	0.754	100	1.280	100	13.044	100
% of total country forest area[3]	55.98		16.11		12.30		5.78		9.81			

Notes: [1]Modified from RFD (2000). Para rubber plantation is excluded.
[2]Dry evergreen or seasonal evergreen rain forest and montane or hill evergreen forest are included in this forest type.
[3]Total forest area as at 1998 was 13.044 M ha and 25.42 % of total country land area.

Ecological Studies on Tropical Seasonally Dry Forest: A Case Study in Thailand

Ecological studies on seasonally dry forest in Thailand substantially appeared in the scientific literature during the 1960s being pioneered by the work of Ogawa *et al*. (1961) in which quantitative community analysis focused on all the dominant forest types in Thailand. Before then, there had been numerous studies on Thai plants by some renowned Thai as well as overseas botanists that contributed to the species composition of each forest type being well known in other fields of forest science and helpful for past and present day ecological studies. Most studies in that period were directly for forest management purposes and were oriented toward timber exploitation. Subsequently from 1964 onward, Japanese ecologists and Thai collaborators published several ecological studies on Thai forests (Ogawa *et al*., 1965a; 1965b, Ogino *et al*., 1964, Kira *et al.*, 1967, Yoda, 1967). These studies expanded the horizon for Thai forest ecological research as well as representing the earliest and most significant Thai-Japanese cooperative research projects. In particular, these studies set the fundamental research methodologies for ecosystem studies so far carried out in this region. Later Thai investigators and some overseas researchers have undertaken their own studies independently as well as collaboratively and these studies have

expanded to cover various aspects. Examples of Thai research initiatives in ecological research in seasonally dry forests include the 52 stands of deciduous dipterocarp and 34 stands of mixed deciduous forests subjected to extensive studies throughout Thailand in 1975-1976 (Sukwong *et al*., 1976; 1977). One Thai-Japanese collaborative ecological study carried out during 1976 that included some seasonally dry forest stands scattered in North and Northeast Thailand apart from those carried out collaboratively between Japanese and Indonesian ecologists was published in 1989 (Yamakura *et al*., 1989). The author independently studied the dynamics of seasonal evergreen rain forest by setting up a single, 1 ha square plot and in deciduous dipterocarp forest setting up four, 1 ha square plots in the Sakaerat Biosphere Reserve, Northeastern Thailand since 1982 and 1984 that have been continuously monitored for 19 and 17 years, respectively (Sahunalu and Dhanmanonda, 1995, Sahunalu, 2001a, b, Sahunalu, 2004a, b, Sahunalu, 2009a, b, c, d, 2010 a, b, c, d). These studies represent the longest term study in large scale plots ever undertaken in Thailand as there were no other studies carried out in permanent plots larger than 1 ha in Thailand and elsewhere during that period. Later Kanzaki *et al*. (1995) established a substantially larger plot as a 2. 6 ha belt in the seasonal evergreen forest in the same area and this continues to be monitored today. However, the author's studies did not include the mixed deciduous forest as research on this forest type was claimed to have been undertaken by some foresters working in RFD at that time (Sakulmeerit, personal communication). The large scale and long term study plots in other forest types were subsequently enlarged to cover a wider area, for example in Huay Kha Kaeng Wildlife Sanctuary and in Doi Inthanon National Park in which 50 and 15 ha plots were set up in seasonally dry forest and montane forest, respectively, and these studies are ongoing, though the details of these studies are beyond the scope of this paper.

A recently published paper representing a long-term Thai-Japanese collaborative ecological study, particularly in MDF of western Thailand was initiated in 1992 (Marod *et al*., 1999). This study included the roles of bamboo undergrowth and fire on the structural dynamics of that forest and examined the effects of drought on the phonological events of some major tree species (Marod *et al*., 2002).These studies demonstrated a good example of a long-term, large-scale plot (4 ha) manipulated as an elaborate, educational venture between two counterparts in TSDF of CSEA. Nevertheless, there were other similar joint research activities undertaken in other forest types outside the TSDF in Thailand such as those in mangrove, swamp, and montane or hill evergreen forest.

Deforestation in the form of slash and burn farming was investigated in another Thai-Japanese collaborative study, particularly in the mixed deciduous and seasonal evergreen rain forest ecotone in the Namphrom area, Northeast Thailand (Kyuma and Pairintra, 1983) where a group of forest ecologists carried out

a detailed study on the forest, felling, burning, and regeneration as a part of research project (Tsutsumi *et al*., 1983). Prior to this study, Sahunalu *et al*. (1979) had made an extensive study of three forest types in the area where seasonally dry forest widely predominated and was found to be seriously disturbed by the slash and burn farming of the local inhabitants. These were all major contributions by the Thai-Japanese collaborative research on seasonally dry forest ecosystem in Thailand during the past four decades. There has been some other collaborative research activity but not entirely carried out in the seasonally dry forest of this country; for instance, wasteland rehabilitation that involved several kinds of degraded forest resulting from some deforestation practices, with sites scattered in South, West, Northeast, and North Thailand (Yoda and Sahunalu, 1991). These studies are not dealt with here although they are important examples of ecological research collaboration between the two countries' counterparts.

In this paper, only the topics of each category of ecological studies are pointed out and listed for each forest type and location in Thailand. Interested investigators can examine more detail on each subject from the literature cited and listed in this paper. The current investigations and ongoing research topics as well as unpublished post-graduate theses and other forest science researches are not dealt with here. Attempts have been made to identify each topic into three main categories: ecosystem analysis, ecosystem function, and miscellaneous aspects. Each category is sorted into the various topics so far investigated in the three main forest types and locations in Thailand and considered to be related to ecological research (Table 5). Some articles that have been omitted or are not sufficiently listed here can be referred to at least in the two papers presented by Rundel and Boonpragob (1995) and Bunyavejchewin *et al*. (2011).

It has been clearly demonstrated that there is insufficient detail in each category and the gaps in knowledge are relatively numerous. Each particular topic also has some more detail to be elucidated if the contents of these published research results are closely overviewed. The opportunity for further research is therefore wide open for all researchers who have a keen interest in ecological study in tropical seasonally dry forests, particularly in Thailand.

Table 5 Ecological studies on tropical seasonally dry forests: Case studies in Thailand.

Category/topic	Forest type/location		
	Mixed deciduous forest	**Seasonal evergreen rain forest**	**Deciduous dipterocarp forest**
A. Community analysis			
1. Structure and floristic or species composition	Pingkong[1] Namphrom[2] Doi Inthanon[3] -	Namphrom[2] Sakaerat[4] - -	Pingkong[1] Namphrom[2] Doi Inthanon[3] Sakaerat[5]
2. Mosaic structure	-	Sakaerat[6]	-
3. Vegetation pattern	-	Sakaerat[7]	-
4. Community dynamics	Maeklong WS[32]	-	Sakaerat[5,8]
5. Species diversity	Namphrom[2] Doi Inthanon[3]	Namphrom[2] Sakaerat[4]	Namphrom[2] Sakaerat[5,9]
B. Ecosystem function			
1. Biomass production	Pingkong[1] -	Namphrom[10] Sakaerat[11]	Pingkong[1] Sakaerat[11] 52 stands[12]
2. Litter production	Lampang[13] -	Namphrom[10] Sakaerat[14,15,16]	Sakaerat[17] Nongteng[18]
3. Biomass increment	- -	Namphrom[10] Sakaerat[11]	Sakaerat[11] -
4. Net primary production	- -	Namphrom[10] Sakaerat[11]	Sakaerat[11] 52 stands[12]
5. Community respiration	Pingkong[19] -	- -	Pingkong[19] 52 stands[12]
6. Gross primary production	-	-	52 stands[12]
7. Nutrient cycling	-	Namphrom[10]	Sakaerat[20]
C. Miscellaneous			
1. Nutrient use efficiency	-	Sakaerat[21]	-
2. Soil properties	Doi Chiangdao[22]	Sakaerat[23]	Sakaerat[23]
3. Forest fire	- - -	- - -	Sakaerat[24] Khao Nangram[24] Ban Huad[24]
4. Relative illuminance	-	Sakaerat[25]	-
5. Variation in flora along the transect	-	Sakaerat[26]	Sakaerat[26]
6. Phenology	Maeklong WS[33]	-	Sakaerat[27]
7.Growth of tree species	-	-	Sakaerat[28]
8. Species distribution on limestone hill	Lampang[29]	-	-

Table 5 (Content)

Category/topic	Forest type/location		
	Mixed deciduous forest	**Seasonal evergreen rain forest**	**Deciduous dipterocarp forest**
9. Leguminosae trees species in deciduous dipterocarp forest	-	-	Sakaerat[30] & various other locations
10. Soil and plant relationships	-	-	Sakaerat[31]

Notes: Figures above each location refer to list of references below.
[1]Ogawa *et al*. (1965a, b). [2]Sahunalu *et al*. (1979).[3]Teejuntuk *et al*. (2002).[4]Sahunalu (2001a) and Visarat *et al*. (1984a). [5]Sahunalu (2009a,b,c,d,2010a,b,c,d) and Dhanmanonda and Sahunalu (1988).[6]Kanzaki *et al*. (1995).[7]Bunyavejchewin (1986). [8]Sahunalu and Dhanmanonda. (1995). [9]Sahunalu (1995, 1996, 1998, 1999a, b). [10]Tsutsumi *et al*. (1983) and Prachaiyo *et al*. (1980).[11]Ogino *et al*. (1964, 1967). [12]Sahunalu and Jamroenpruksa. (1980) and Sahunalu (1994a). [13]Thaiutsa *et al*. (1978). [14]Sahunalu (2004a, b). [15]Chinsukjaiprasert *et al*. (1984) and Bunyavejchewin (1997). [16]Chunkao and Boonyawat. (1980). [17]Paovongsa (1976). [18]Wacharinrat (2000). [19]Yoda (1967). [20]Sahunalu and Jamroenpruksa (1980) and Sahunalu (1994). [21] Sahunalu (2004b, c). [22]Khemnark et *al*. (1972). [23]Sakurai *et al*. (1998). [24] Stott (1986). [25]Yoda *et al*. (1983) and Visarat *et al*. (1984b). [26]Sabhasri *et* al. (1968). [27]Sukwong *et al*. (1975). [28]Sukwong (1982). [29] Sukwong and Kaitpraneet. (1975). [30]Sahunalu (1994b, 1997a, b, 1999a, b). [31]Sahunalu *et al*. (1980, 1991, 1993). [32]Marod *et al*. (1999). [33]Marod *et al*. (2002). Only two post-graduate theses were referred to here.

Future Prospects and Research Needs in Tropical Seasonally Dry Forest

Tropical seasonally dry forest still remains important as does wet or tropical rain forest and will be attractive for future research. In particular, it serves as a valuable natural resource for a large number of people in Continental Southeast Asia. It has equal importance for conservation as for research through the exploration and gaining of deep knowledge on future exploitation and the formulation of the conservation strategy. It is especially crucial for maintaining and restoring species diversity in this important forest type. The management of protected areas in the 21st and successive centuries will not only involve the forest area under current control but also management of the forest ecosystem in which all components of the ecosystem in the protected areas and their surroundings must be fully and intensively studied as a whole. This needs to be recognized widely and demands urgent attention. Some important points of interest and for which there is still a lack of comprehensive information have emerged from the author's viewpoint, especially in the three main seasonally dry forests of Thailand and these are outlined as follows:

Community structure and species composition:

- Undergrowth or forest floor vegetation including vines and climber vegetation
- Variation in plant life-forms distribution and contribution to species diversity

Community productivity:

- Belowground or root biomass estimation
- Net primary production of various community types

- Litter production of various community types
- Community carbon sequestration, circulation, and preservation of three forest types

Community nutrient cycling:

- Nutrient cycling of various community types
- Decomposition rate of dead plant parts and litter of various community types
- Soil respiration, fine root distribution, and dynamics in the three forest types

Miscellaneous and related subjects:

- Phenology: flowering, fruiting, seed production, seed dispersal, seed bank, leafing, and growth of tree species
- Soil fauna in the three forest types
- Fire effects on the three forest types
- Human impacts: shifting cultivation, grazing, exploitation, and land-use
- Secondary forest studies, and regeneration and succession processes
- Rehabilitation and restoration of the degraded forests in the three forest types
- Ecophysiological studies: drought response, seedling establishment under adverse condition, water use, and water use efficiency of the three forest types
- Plant-animal-microorganism interactions: micorrhizae, rhizobia, herbivories, pollinators etc. in the three forest types
- Ethnobotany and local indigenous knowledge
- Paleobiology and palaeoecology
- Minor and non-wood forest products
- Commonness, rarity, and endemism in the three forest types

All these proposed aspects of future research have been derived from the author's thorough examination of the contents of the references discussed and are thought to have been ignored or included in such little detail and so need to be elucidated to gain more knowledge on seasonally dry forest ecology, especially in Thailand. All researchers in this academic society are sincerely welcomed and all protected forests in Thailand have facilities that are relatively comfortable and there are accessible educational and research sites in every region throughout the country. Moreover, trans-boundary research projects among neighboring countries using Thailand as a center are also encouraged to gain more collaborative academic activities, sharing, and exchanging of experiences and information as well as creating comparative studies on the regional seasonally dry forests. As five countries are on the Continental Southeast Asia region and presently enjoying close cooperation under the ASEAN Economic Community (AEC) agreement, academic collaboration in this field of study can provide mutual benefit among them all.

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