Nat. Hist. Bull. Siam. Soc. 57: 35–55, 2011

THE MO SINGTO FOREST DYNAMICS PLOT, KHAO YAI NATIONAL PARK, THAILAND

Warren Y. Brockelman[1, 2], Anuttara Nathalang[1] and George A. Gale[3]

ABSTRACT

A permanent biodiversity research and monitoring plot has been established in the center of Khao Yai National Park, east-central Thailand. It is located in broad-leaved, seasonal evergreen forest (725–815 m altitude) in the Mo Singto area which has been a study site for white-handed gibbons (*Hylobates lar*) since 1979. The plot is 30 ha in area and has been surveyed into 20-m squares and mapped with ArcGIS. Every woody stem ≥ 1 cm in diameter at 1.3 m height was measured, mapped and identified during 2004–2005. There were a total of 262 species of trees and shrubs ≥ 1 cm in diameter and 204 species ≥ 10 cm in diameter. Approximately 120 species of woody climbers ≥ 3 cm in diameter have been identified and counted. The plot is used for the study of the diversity and dynamics of tree populations and plant-animal interactions. Of particular interest has been the role of mammals and birds in the dispersal of seeds, their germination, and the survival of seedlings. Gibbons continue to be a focus of research, and their diet, foraging behavior and importance to fruiting trees and lianas are the subjects of long-term study. Bird populations and their breeding behavior and ecology are also being studied. The plot has played a vital role in the training of graduate students pursuing master's and doctoral degrees in biology and environmental science. The Mo Singto Plot is now part of the global forest dynamics plot network of the Center for Tropical Forest Science (CTFS), Smithsonian Tropical Research Institute.

Keywords: biodiversity monitoring, forest biodiversity, forest dynamics plot, Khao Yai National Park

INTRODUCTION

A forest dynamics plot (FDP) has been established in the Mo Singto area of Khao Yai National Park in Central Thailand, an area of active research on gibbons since 1979. Survey of the plot into 20×20 m squares ("quadrats") began in 1994 and was completed in 1998. A preliminary census of trees ≥ 10 cm in dbh (diameter at breast height, or 1.3 m above the ground) was completed in 1999. The first complete census of all stems of trees and shrubs ≥ 1 cm was carried out during the dry season of 2004–2005. A second complete census will be completed in early 2011. The plot has become the site of intensive research on plant-animal

[1] Ecology Laboratory, BIOTEC Central Research Unit, 113 Thailand Science Park, Paholyothin Road, Klong 1, Klongluang, Pathum Thani 12120, Thailand. E-mail: wybrock@cscoms.com
[2] Institute of Molecular Biosciences, Mahidol University Salaya, Phutthamonthon 4 Road, Nakhon Pathom 73170, Thailand.
[3] Conservation Ecology Program, School of Bioresources & Technology, King Mongkut's University of Technology Thonburi, 83 Moo. 8 Thakham, Bangkhuntien, Bangkok 10150, Thailand. E-mail: george.and@kmutt.ac.th
Recieved 20 October 2010; accepted 22 April 2011.

relations, gibbon foraging, bird ecology and forest dynamics. It has, most especially, promoted research by many university graduate students both in Thailand and from abroad, and many master's and doctoral thesis research projects have been carried out at Mo Singto. The purpose of this article is to introduce the plot and briefly describe its environment, fauna and flora, and some of the research that has been carried out there, for the benefit of prospective researchers and persons interested in research in the national park in general. We will also describe our methods and provide tips for prospective developers of large plots. The methodology of large plots is by now reasonably well developed and standardized, but there are still common recurring problems and pitfalls that researchers need to be aware of.

The survey and tree census methods employed on the Mo Singto Plot have followed the protocols of the Center for Tropical Forest Science (CTFS), Smithsonian Tropical Research Institute, Smithsonian Institution, Washington D.C. (MANOKARAN *ET AL*., 1990; CONDIT, 1998). In 2009 the plot became associated with the world-wide CTFS Network. Several other large FDPs have already been established in Thailand with CTFS support, for example in Huai Kha Khaeng and Khao Banthat Wildlife Sanctuaries and Doi Inthanon National Park. Information about all CTFS plots is found on their website: http://www.ctfs.si.edu.

The Mo Singto FDP is managed by the Ecology Laboratory of the National Center for Genetic Engineering and Biotechnology (BIOTEC), part of the National Science and Technology Development Agency (NSTDA). The databases and plot herbarium collections (part of BBH) are also located at the BIOTEC Central Research Unit in Pathumthani Province. Requests for data from the FDP, as well as for permission to carry out research on the plot, should be directed to the Ecology Laboratory of BIOTEC. CTFS maintains the tree census databases of all plots in its network on its website, but permission to access these must be granted by the local management authorities in the countries where they are located. The CTFS has been instrumental in fostering international collaborative research on its worldwide network of plots. Permission to carry out research anywhere in the national park must also be obtained from the Department of National Parks, Wildlife and Plant Conservation.

LOCATION

The plot is located in the center of Khao Yai National Park near the park headquarters (Fig. 1). The park is at the western extremity of the Phanom Dongrak mountain range which runs along the southern edge of Northeast Thailand. Geographic coordinates of the plot are roughly 101˚22´E, 14˚26´N. The park is about 3 hours' drive from Bangkok and lies south of the Mitraparp highway which connects the provincial capitols of Saraburi and Nakhon Ratchisima. The park can also be entered from the south via Nakhon Nayok and Prachinburi. From park headquarters, the plot is reached by a footpath (formerly an elephant trail) extending 600 m from the bend in the Takhong River near the road crossing; vehicles cannot reach the plot.

A survey reference marker using GPS was placed in the plot in 2000, in order to obtain a more accurate elevation reading than the 1:50,000 topographic maps and non-referenced GPS receivers can provide. It was placed by an engineering company (Asian Engineering Consultants Corp., Ltd.) using the nearest Royal Thai Survey Dept. point located near the town of Pak Chong to the north as reference. Relevant data for the reference point (labeled "MS PLOT 2000") in the plot are:

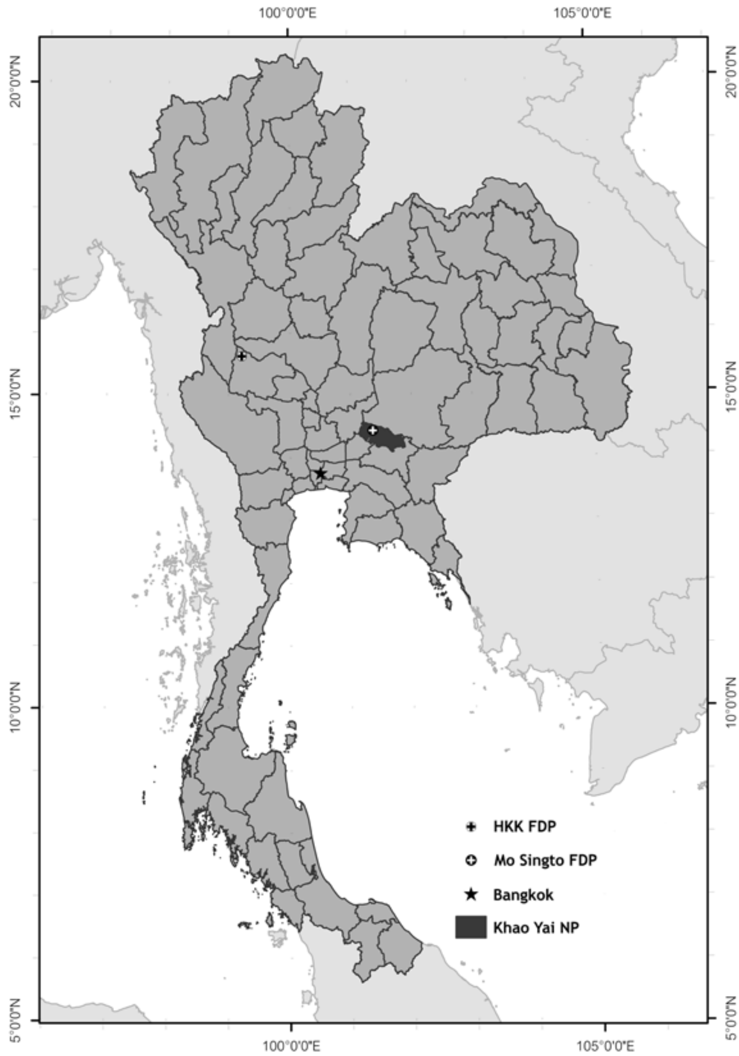

Figure 1. Map of Thailand showing the location of Khao Yai National Park and Mo Singto Forest Dynamics Plot. as well as the Huai Kha Khaeng Forest Dynamics Plot (Hkk FDP) in western Thailand.

Grid zone	UTM 47
Datum	Indian 1975
Easting	755,096.018
Northing	1,597,113.039
Elevation	795.604 m

The reference point marker is located on the CR Trail in quadrat 2902 about 2.2 m and 221˚ from the quadrat NE stake (Fig. 2).

GEOLOGY, TOPOGRAPHY AND CLIMATE

The headquarters area of Khao Yai Park lies within a region of Permian rhyolite, andesite, tuff and agglomerate, but Jurassic sandstone and siltstone rocks of the Khorat Group, many of them large boulders, lie strewn over the hillsides and in the ravines. These rocks evidently derive from weathering of thick Jurassic sandstone and siltstone beds still lying intact at higher elevations (1,000–1,300 m) on Khao Rom and Khao Khieo mountains a few km east of the plot (GEOLOGICAL SURVEY DIVISION, DEPARTMENT OF MINERAL RESOURCES, 1983).

Soils of the plot are mostly well-drained brown or gray-brown, fine-sandy or silty-clay-loam; derived from residuum or colluvium of shale or sandstone. They are classified as "Isohypertermic Ultic Haplustalfs" (Division of Soil Analysis, Land Development Department, Department of Agriculture, Bangkok).

The terrain of the plot is hilly with elevations above msl from 725 to 815 m (Fig. 2). The plot has a low area near the eastern edge, several ridges, and two valleys with wet-weather brooks and two permanent springs. The springs are in the south branch of the brook that drains the plot in the east; there are clear pools of water in this brook all year round. The plot streams drain into the Takhong River about 200 m away, which is part of the Mun/Mekong

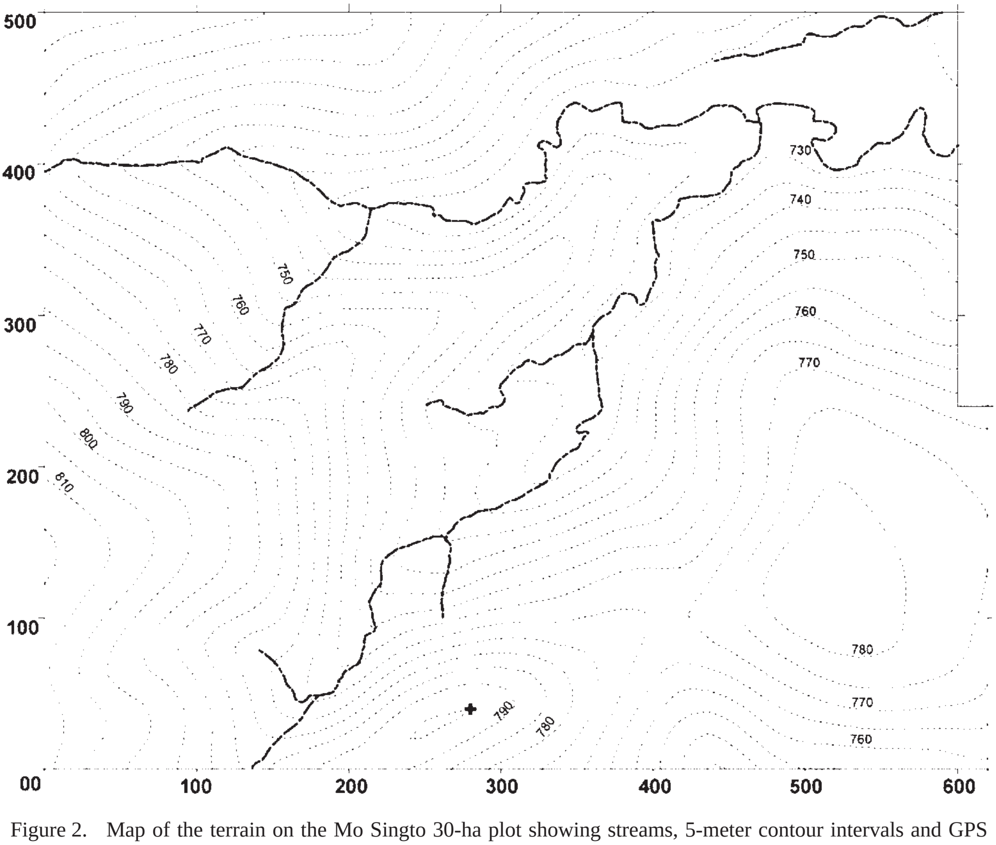

Figure 2. Map of the terrain on the Mo Singto 30-ha plot showing streams, 5-meter contour intervals and GPS reference point (cross near lower edge). Distances on the axes are in meters.

River drainage. Variation in terrain certainly affects the distribution of tree species, and both ridge and ravine specialists can be seen even without detailed analysis.

The annual rainfall in the park is sometimes quoted to be as high as 3,000 or even 4,000 mm (SMITINAND, 1968, 1977), but a 13-year (1994–2007) record of rainfall of the national park, whose gauge is located within 1 km of the plot at about 750 m msl, shows that 3,000 mm is close to the maximum annual rainfall. Average annual rainfall has been approximately 2,200 mm. Higher rainfall is expected at higher elevations. The rainy season is from May to October, the remaining months being relatively dry. Both April and October can be either dry (< 100 mm) or wet, making the length of the dry season quite variable. During the el Niño years of 1997–1998 the dry season lasted more than 7 months (BROCKELMAN, 2011). The mean monthly temperature varies between about 19˚ and 29˚C, and mean annual temperature is around 22–23˚C. Due to faulty equipment temperature records of the national park for some past years are not reliable, and records kept by researchers have been sporadic.

VEGETATION

The vegetation in the mid-elevations of Khao Yai Park may be considered to be part of the Southeastern seasonal evergreen forest of continental Asia (ASHTON, 1990). Seasonal evergreen forests have become endangered in many places because of their susceptibility to fire when logged or degraded. HOLDRIDGE *ET AL*. (1971) classified it as Subtropical Wet, and with such seasonal rainfall it would qualify as a dry atmospheric association. The plot is embedded in a large area of old-growth forest with scattered patches of regenerating successional forest and (along roads) fields, the result of old farming before 1960. The tree flora of the Mo Singto Plot is approximately 21 percent deciduous (37 out of 179 species > 10 cm in dbh that are not very rare and nonreproducing).

The 2004–2005 census of all trees and shrubs on the plot yielded the following results:

Number of families	67
Number of genera	167
Number of species ≥ 1 cm dbh	262
Number of species ≥ 10 cm dbh	204
Number of species ≥ 100 cm dbh	16
Total number of individuals ≥ 1 cm dbh	131,009
(per ha)	4,295
Total number of individuals ≥ 10 cm dbh	15,676
(per ha)	514.0
Basal area (m^2) per ha	31.78

The old-growth seasonal evergreen forest on the plot is dominated by Families Lauraceae, Rubiaceae, Moraceae and Euphorbiaceae in terms of numbers of species (Table 1). In terms of basal area, however, the leading families are Lauraceae, Dipterocarpaceae, Elaeocarpaceae, Anacardiaceae and Annonaceae.

The most abundant species is an understory evergreen treelet, *Polyalthia* sp., which is apparently still unnamed (Table 2). It shows affinity with *P. evecta*. It contributes 22.5 percent of the stems on the plot; the next most abundant species, *Knema elegans*, also an understory species, contributes only 5.76 percent of stems. The dominant dipterocarp species on the plot is *Diptercarpus gracilis*, the 8th most numerous species on the plot, and the first in basal area. Several individuals of this species exceed 100 cm in dbh and 50 m in height. Other species that reach relatively large size and emerge above the canopy are *Eugenia cerasoides* (also known as *Cleistocalyx operculatus*), *Altingia excelsa*, *Schima wallichii, Cinnamomum ilicioides, Ficus altissima, F. stricta, F. kurzii, Prunus javanica*, *Canarium euphyllum, Podocarpus imbricatus* and *Platymitra macrocarpa*.

Species of Podocarpaceae, Fagaceae, and Lauraceae typical of higher elevations (>1000 m msl) (SMITINAND, 1968, 1977) are common in upper parts of the plot. The abundance of Lauraceae on the plot (Table 1) suggests its montane affinities. The canopy is generally 20–40 m high but highly discontinuous, with occasional emergents reaching 50–55 m. Using a point-intercept method, BROCKELMAN (1998) determined mean height of the upper canopy surface in one favorable 1-ha site in the plot to be 25.5 m.

There is no sign of human disturbance of the forest except for the presence of an old field of 3–4 ha, now regenerated into secondary forest about 25 years old on the north side of the plot. The secondary forest overlaps the north edge of the plot, and covers about 0.32 ha of its area. However, there is evidence that most of the forest on the plot is not in a climax state, but is in a late stage of succession. Several species of trees are represented on the plot by large individuals nearly 100 cm in dbh but have unimodal size distributions, indicating a lack of recruitment. These appear to be pioneers that have persisted into late stages of succession. The most obvious and best studied of these is *Choerospondias axillaris* (BRODIE *ET AL.*, 2009; CHANTHORN & BROCKELMAN, 2008), discussed further below.

The ground vegetation, creepers and some epiphytes have been enumerated and will be discussed by J. F. MAXWELL in a book in preparation by NATHALANG *ET AL.* This book will also include lianas on the plot and secondary forest species, as well as a complete list of reference herbarium specimens. The total list of vascular plant species on the plot now numbers about 700.

PLOT ESTABLISHMENT

Selection and Survey

As stated above, site selection was based on the presence of the main gibbon study group which has been observed regularly since 1980. The plot is approximately 700 m west of the park visitor center restaurant, in the middle of Mo Singto gibbon study area (BROCKELMAN *ET AL.*, 1998) which is about 2 km^2 in area. This area includes the territories of about 10 gibbon groups, one of which is included almost entirely inside the plot.

Survey of the plot and tagging and mapping of trees were initiated with hired student and volunteer help in 1994, but were speeded up after more adequate grant support was received from Thai government agencies in 1996. The procedures of plot establishment are similar to those used on the 50-ha plots already established in Barro Colorado Island (BCI) in Panama (CONDIT, 1998), Pasoh Forest Reserve in Malaysia (MANOKARAN *ET AL.*, 1990), and Lambir Rain Forest in Sarawak, East Malaysia (LEE *ET AL.*, 1995). Survey of the plot into 20-m-square quadrats was completed in early 1998 by using an electronic digital theodolite (DT-20B, Topcon) and measurement tapes to obtain accurate vertical angles and distances.

All distances on the plot represent horizontal distances. In order to establish a point at

Table 1. List of tree families represented on the Mo Singto plot that have three or more species, with percent of individuals and percent of basal area of the whole plot.

No.	Family	No. of species	Percent of individuals	Percent of basal area
1	Lauraceae	22	11.25	10.13
2	Rubiaceae	21	4.55	2.55
3	Moraceae	18	0.27	3.32
4	Euphorbiaceae	16	2.23	2.72
5	Meliaceae	14	7.34	4.60
6	Phyllanthaceae	11	1.55	0.75
7	Clusiaceae	8	0.57	0.61
8	Myrtaceae	7	3.00	5.00
9	Fabaceae	7	0.07	0.87
10	Annonaceae	6	25.99	5.23
11	Melastomataceae	6	2.68	0.47
12	Rutaceae	6	2.15	0.36
13	Malvaceae	6	0.14	0.57
14	Fagaceae	5	1.94	4.75
15	Elaeocarpaceae	5	1.51	7.27
16	Anacardiaceae	5	0.45	5.52
17	Myrsinaceae	4	4.21	0.60
18	Dipterocarpaceae	4	2.47	8.04
19	Sapindaceae	4	1.99	3.56
20	Pentaphylacaceae	4	1.50	0.60
21	Arecaceae	4	0.91	0.13
22	Oleaceae	4	0.39	0.16
23	Celastraceae	4	0.04	0.15
24	Bignoniaceae	4	0.02	0.07
25	Cannabaceae	3	1.02	3.91
26	Icacinaceae	3	0.37	1.22
27	Sapotaceae	3	0.35	1.22
28	Rosaceae	3	0.18	1.67
29	Lamiaceae	3	0.02	0.02
30	Achariaceae	3	0.005	0.02

Table 2. List of most abundant tree species on the Mo Singto plot, which each contribute at least 1% of the total number (N) of individuals, along with maximum diameter (DBH) in cm, and percent of basal area (BA) of all trees on plot.

No.	Botanical name	Family	N	%N	Max. DBH	BA (m^2)	%BA
1	*Polyalthia* aff. *evecta* Finet & Gagnep. var. *evecta*	Annonaceae	29,476	22.18	13.3	7.61	3.12
2	*Knema elegans* Warb.	Myristicaceae	7,691	5.79	39.2	3.26	1.34
3	*Cinnamomum subavenium* Miq.	Lauraceae	6,560	4.94	76.7	6.89	2.83
4	*Gonocaryum lobbianum* (Miers) Kurz	Cardiopteridaceae	4,737	3.56	49.9	3.99	1.64
5	*Ardisia sanguinolenta* Blume var. *sanguinolenta*	Myrsinaceae	4,047	3.05	14.2	0.95	0.39
6	*Aglaia elaeagnoidea* Benth.	Meliaceae	3,574	2.69	27.2	1.86	0.76
7	*Symplocos cochinchinensis* (Lour.) S. Moore subsp. *laurina* (Retz.) Noot.	Symplocaceae	3,346	2.52	55.8	8.07	3.31
8	*Dipterocarpus gracilis* Blume	Dipterocarpaceae	3,229	2.43	135.2	18.99	7.79
9	*Walsura robusta* Roxb.	Meliaceae	2,919	2.20	44.5	2.39	0.98
10	*Mastixia pentandra* Blume subsp. *chinensis* (Merr.) K.M.Matthew	Nyssaceae	2,704	2.03	64.6	9.25	3.79
11	*Ilex chevalieri* Tardieu	Aquifoliaceae	2,661	2.00	62.3	9.77	4.01
12	*Polyalthia simiarum* (Buch.-Ham. ex Hook.f. & Thomson) Hook.f. & Thomson	Annonaceae	2,417	1.82	41.3	2.31	0.95
13	*Beilschmiedia glauca* S. K. Lee. & L. F. Lau (sp.1)	Lauraceae	2,121	1.60	58.5	2.61	1.07
14	*Memecylon lilacinum* Zoll. & Moritzi	Melastomataceae	2,018	1.52	47.0	0.69	0.28
15	*Aquilaria crassna* Pierre ex Lecomte	Thymelaeaceae	1,924	1.45	76.0	3.70	1.52
16	*Eurya nitida* Korth. var. *siamensis* (Craib) H. Keng	Pentaphylacaceae	1,824	1.37	18.9	1.16	0.48
17	*Nephelium melliferum* Gagnep.	Sapindaceae	1,782	1.34	70.5	8.12	3.33
18	*Sloanea sigun* (Blume) K. Schum.	Elaeocarpaceae	1,739	1.31	82.1	16.35	6.71
19	*Melicope pteleifolia* (Champ. ex Benth.) T. G. Hartley	Rutaceae	1,714	1.29	13.4	0.32	0.13
20	*Eugenia cerasoides* Roxb.	Myrtaceae	1,688	1.27	124.0	7.92	3.25
21	*Aphanamixis polystachya* (Wall.) R. Parker	Meliaceae	1,627	1.22	35.4	1.21	0.50
22	*Saprosma longifolia* Pit.	Rubiaceae	1,561	1.17	6.1	0.08	0.03
23	*Ardisia nervosa* H.R.Fletcher	Myrsinaceae	1,459	1.10	27.6	0.49	0.20
24	*Gironniera nervosa* Planch.	Cannabaceae	1,369	1.03	84.0	9.36	3.84

20-m horizontal distance, the vertical angle to a point at the approximate distance away from the theodolite is determined, and then the ground distance is calculated from the formula $d = x/\cos\theta$, where x is the horizontal width of the quadrat, here 20 m. This distance is then measured by tape through the air parallel to the ground, and a nail is placed in the ground at that point. The vertical angle is then remeasured and the ground distance recalculated if necessary. The nail is later replaced by an 18-inch orange plastic stake (Forestry Suppliers, Inc., Jackson, Mississippi) with column and row numbers punched on its head. Plastic stakes, of course, cannot be used on plots that are fire-prone. We know of no record of fire in the plot during the last 30 years since we have observed the area. Fire once did burn the old swidden fields on the north edge of the plot, but these have grown into secondary forest (the forest does not return if burned each year in the dry season, as very few trees in the evergreen forest are fire resistant).

The numbering of quadrats follows the pattern originally used at Barro Colorado, and is designed to reduce the number of digits required. While some large plots start with numbering one-hectare areas, our system first numbers all columns and rows of stakes (Fig. 3). The first column of stakes was labeled 15 because it was anticipated that the plot might expanded by 15 columns on the uphill (west) side at some time in the future to convert it into a 50-ha plot, like other large tropical plots in the CTFS network. This was not done, however, and the plot remains at 30 ha with columns 16 to 46. Each quadrat receives the number of its northeast stake, so that the southwestern-most quadrat at the origin is 1601. While Figure 1 shows the distances along each axis in meters, Figure 2 shows the column and row numbers. As each quadrat is 20×20 m in dimensions, there are 25 quadrats per hectare.

The area of the plot was brought up to 30.5 ha in the first census in 2000 (Fig. 3). The 12 quadrats of column 46 were added because gibbon group A occasionally went off the plot in the east. The total number of quadrats is now 762. These 12 quadrats in column 46 may be seen to compensate for the eight quadrats in row 25 at the north edge which lie in the secondary forest. The secondary–old growth forest boundary is very sharp, and lies almost exactly on the boundary between rows 24 and 25, between columns 30 and 38 (Fig. 3). A few species, most notably *Eurya nitida*, and *Schima wallichii*, occur primarily in the secondary forest, and many species, most dramatically *Polyalthia* aff. *evecta*, are common in old growth forest but do not occur in the secondary forest.

Tree Census and Mapping

The first census of trees ≥ 10 cm dbh was completed during 2000–2001, of which there were about 16,000. The second census was carried out during 2004–2005 and included all trees and shrubs ≥ 1 cm.

Tree tagging

All trees were tagged with locally purchased and cut aluminum tags about 50×20 mm in size, with numbers punched by hand with dies. These tags were cut by a local shop from 4×6-ft. aluminum sheets 1 mm thick. Nail-holes were drilled by hand with an electric drill. Aluminum-magnesium alloy 2¼-inch nails were purchased from Forestry Suppliers, Jackson MS (such nails are not made in Thailand). All trees > ca. 6 cm dbh have tags attached with nails at about 1.5 m height. Smaller trees have tags attached with a loop of copper wire tied

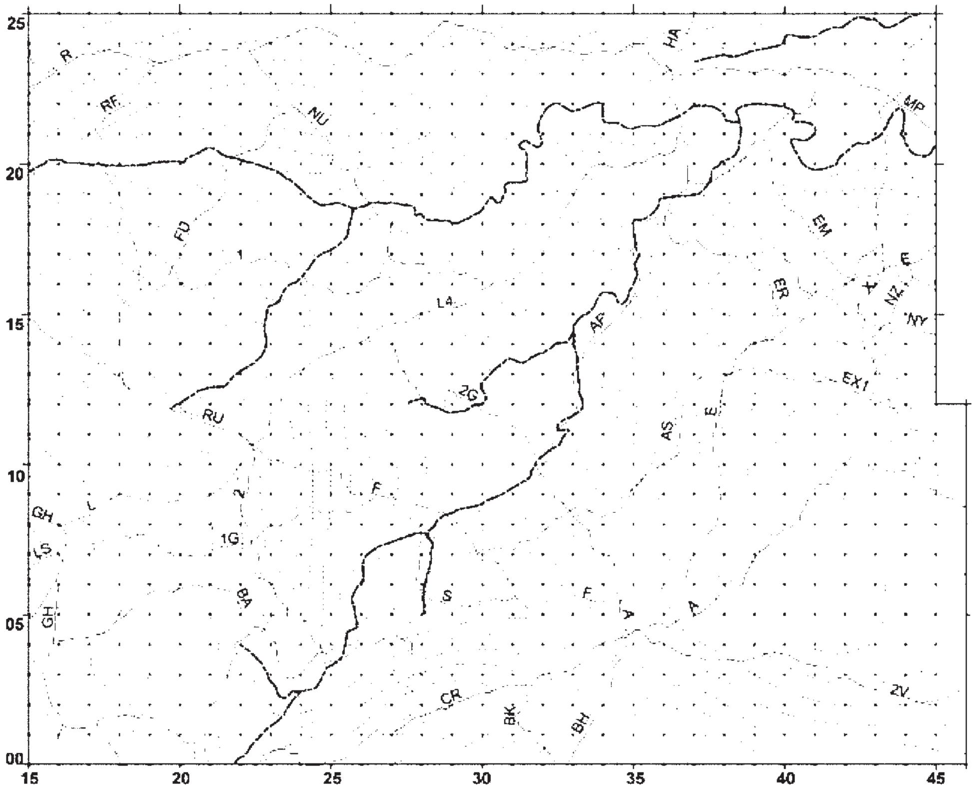

Figure 3. Map of the Mo Singto plot showing the 20-meter survey points and trails. Column and row numbers are shown on the axes.

loosely around the base. The nails cause some swelling in the trees but we have seen no serious injuries or deaths. The tree tags are considerably cheaper than pre-numbered tags imported from the U.S., but their production is labor-intensive. All nailed tags will eventually be "eaten up" as the trees expand in diameter, and nearly all will have to be reattached in the next census. Nails about 3 inches long are thus recommended, so that they stick out about 2 inches.

Each tree has a 5 or 6-digit number, the first two being the column number of the quadrat and the last three or four being the tree number within the column. Tagging within each column is begun in the first quadrat and proceeds north to the 25th. For all trees ≥ 10 cm we have also punched the row number below the column number on the tag, so that the quadrat number can be read off any tree above this size (the 3 or 4-digit tree number does not indicate the row). This greatly facilitates locating one's position on the plot without having to search for a corner stake.

Tree measurement

The main purposes of measuring trees are to study their size distributions and to measure their growth rates. The latter purpose requires that trees be measured accurately and repeatedly at exactly the same location. We strive for a precision of 1 mm in tree diameter measurement. The point of measurement (POM) is painted on the tree with red paint. The diameter of the tree is measured with a special forestry tape that measures circumference but is calibrated on one side to read diameter directly (circumference/π), making the assumption that the cross-section of the trunk is perfectly circular.

Many problems are encountered in selecting the POM; standard conventions are given in MANOKARAN *ET AL*. (1990) and CONDIT (1998). For trees on slopes the height of the POM is measured on the up-hill side, and for leaning trees from the lower side parallel with the stem. If trunks branch below 1.3 m, both branches are measured. For trunks with swellings or nodules at 1.3 m the POM should be moved upward or downward to avoid the swelling. All trees with buttresses or basal swellings must be measured above the enlargements. This means that for many large buttressed trees the POM may be as high as 5 m above the ground, and a ladder must be available. Beyond these guidelines, however, it does not matter a great deal exactly where the POM is marked, as long as it is in the same place for each measurement. Failure to establish and mark an appropriate POM on all trees in the early days of plot establishment caused serious problems in measuring growth rates.

Mapping

The mapping of trees is one of the most time-consuming jobs in the establishment of a large plot. The sides of each quadrat are marked at 5-m intervals and plastic strings are stretched across it to form a grid of 16 5×5-m subquadrats. Locations of trees are mapped by measuring with a metal carpenter's rule perpendicularly to the nearest x and y boundaries. The data are recorded in a notebook or directly into a hand-held computer with a Microsoft Excel program. A number of alternative methods of mapping trees have been tried that do not require subdivision into 5×5-m subquadrats, such as triangulating on stems from the quadrat corner posts, or measuring distances from two posts with lasers, or an angle and a distance (e.g. DALLMEIER, 1992). These methods are not so accurate under field conditions, especially in dense evergreen forest and on sloping terrain, and require the processing of increased amounts of data. Dallmeier's method was designed only for measuring trees ≥ 10 cm dbh on a 1-ha plot. On a large plot (≥ 16 ha) where all trees down to 1 cm in dbh need to be processed, one faces a severe time constraint, and so methods need to be simple and efficient.

Future refinements should help automate the process of entering data into the computer in the forest. Back in the laboratory the data are downloaded into a Microsoft Access database. Measuring, recording, and transcribing data in the forest allow several opportunities for mistakes. Experience has shown that error rates are typically on the order of 2 percent which, with many hundreds of thousands of pieces of data, results in many thousands of wrong tree locations or sizes in the database. The error rate can be reduced by enforcing better communication methods such as repeating measurements called out in the field. The final step is to correct as many errors as possible by printing our maps from the database by quadrat, and field-checking to see if trees are recognizable and in their approximate locations; most errors are in fact visibly obvious.

Plot database

Storage and analysis of the data are major tasks in the establishment of a large plot. Study of large FDPs with several hundred thousand trees became convenient only after the development of databases on desktop computers. Each plot census is a list of individual trees with the following information: date of quadrat census, tree id. number, quadrat no., plot *x* and *y* coordinates, species name, family name, stem diameter, extra stem diameters (in any), stem shape or status. The plot census database is now kept in Microsoft Access, and can be transferred to other programs for analysis such as Microsoft Excel, R, or ArcGIS. Other tables in the database may store information on the environment (usually by quadrat), species, other individual tree characteristics, family, other organisms on the plot, etc. The Mo Singto database is interfaced with ArcView GIS which allows the printing of maps of any type.

Plant Identification

Because there has been no complete enumeration of the flora of Khao Yai Park, we have endeavored to make a complete reference collection of all species of plants on the plot. Specimens are prepared and a collection is maintained in the herbarium (BBH) of Biotec Central Research Unit, National Science and Technology Development Agency, located in Science Park, Pathum Thani. A complete set of specimens is sent to the Royal Forest Department Herbarium (BKF; now part of the Department of National Parks, Wildlife and Plant Conservation). Sets of duplicates are also stored in the Biology Department of Chiang Mai University (CMU), and are distributed to Arnold Arboretum Herbarium at Harvard University (A) and the National Herbarium of the Netherlands, Leiden (L). These large herbaria have extensive collections of Southeast Asian flora. Collection of voucher specimens is such an important activity that all regular field personnel are trained in specimen collection and preparation of labels of international standard. The Ecology Laboratory of Biotec maintains a database of all herbarium specimens collected from the Mo Singto plot and from other plots it has established, which also prints out the labels that accompany all specimens.

Once the species present on a plot are reasonably well known (which takes several years of study), field workers must be trained to identify all species from vegetative characters (leaves, bark, trunk shape) as well as flowering or fruiting material, in the forest. Identification of plants in the initial quadrats should be supervised by the plot botanical authority until assistants can identify all the common species from vegetative characters. When new species or morphotypes are encountered, samples of leaves are collected and given provisional names, which are later replaced after being identified by the botanist. It is important for the botanist to check a sample of quadrats after all the trees have been mapped and identified, to correct misidentifications. The “misidentification” rate, which also includes transcription errors, has been estimated by rechecking a random selection of quadrats and is approximately 2 percent. This rate will be reduced during the next census, to be carried out during 2009–2010. Species of particular importance or undergoing special study are verified by rechecking all stems.

FAUNA OF MO SINGTO

One of the great assets of the Mo Singto plot is the diversity of animals that occur in the surrounding forest, many of which are important as frugivores, herbivores and predators. Most plots in the CTFS network were selected for ease of access, condition of the forest and security, and were placed in areas where the animal community has been greatly reduced or eliminated. Khao Yai is known for its virtually intact natural fauna, although the Huai Kha

Khaeng FDP in western Thailand is also an exception and has a higher diversity of fauna than does Mo Singto.

A list of 36 mammals seen on the plot or in the forest around it is given in Table 3. Primate nomenclature follows BRANDON-JONES *ET AL.* (2004). Bats are not listed except for one fruit bat that roosts under palm leaves in the forest. The pig-tailed macaque is the only monkey in the park but it is common, sometimes seen in groups of over 100 individuals. Why there are no langurs in the park has long puzzled zoologists, as they occur or once occurred in forests to the north, west and south of the park. Both muntjac and sambar are common in the forest and take large numbers of fallen fruits on the ground. Tiger and clouded leopard have been seen on the plot, but tigers are now becoming very scarce in the park and may already be extirpated. Golden cat and marbled cat are rarely seen in Khao Yai. Elephants are common and visit the plot several times a year. There are several guides to mammals which occur in Khao Yai (FRANCIS, 2001; LYNAM *ET AL.*, 2006; PARR, 2003; SRIKOSAMATARA & HANSEL, 2000), but there is no complete inventory of small mammals.

Although tigers, for unknown reasons, have virtually been extirpated from the park, the Asian wild dog, or dhole, is thriving. An interesting predation event involving a muntjac, a reticulated python and a pack of dholes was witnessed and photographed by NETTELBECK (1995) near what would become the southern edge of the plot.

The birds of Khao Yai are better known than any other animal group. The total list for the park stands at about 358 species (LYNAM *ET AL.*, 2006; ROUND *ET AL.*, 2009), of which 168 have been recorded on the Mo Singto Plot. The 113 resident species that breed at Mo Singto are augmented by 48 winter visitors, and during the migration seasons 7 passage migrants. A current list of species in and near the plot is provided in ROUND *ET AL.* (2011) in this issue of the *Natural History Bulletin.*

There is no published list of reptiles or amphibians in Khao Yai Park, but visitors may be interested in knowing that the following snakes occur on the plot (COX *ET AL.*, 1998):

Python reticulatus, reticulated python	common
Python curtus, blood python	uncommon
Python molurus, Burmese python	uncommon
Trimeresurus sp., green tree viper (resembles *T. popeiorum*, but species uncertain)	very common
Ophiophagus hannah, king cobra	uncommon
Naja siamensis, Indo-Chinese spitting cobra	fairly common

The blood python is not supposed to occur in central Thailand (COX *ET AL.*, 1998) so its finding in Khao Yai Park raises the possibility (although it seems unlikely) that it had been released from captivity.

HUMAN USE AND DISTURBANCE

It is important, while doing research, to minimize visitation to the plot and disturbance of plants and animals that are the objects of study. There are approximately 3 km of footpaths on the plot which disturbs less than 0.5% of the area. About half of the trails are elephant trails that have probably been present for millennia. Gibbon and bird researchers follow the trails as much as possible for easier movement about the plot and to avoid excess disturbance

Table 3. Medium and large sized mammals in the forest of Mo Singto. Some have been seen in forest within a few km of the plot but not on the plot.

Lorisidae
- *Nycticebus bengalensis*, slow loris

Cercopithicidae
- *Macaca leonina*, northern pig-tailed macaque

Hylobatidae
- *Hylobates lar*, white-handed gibbon (everywhere on and around the plot)
- *Hylobates pileatus*, pileated gibbon (one individual south of the plot)

Pteropodidae
- *Cynopterus sphinx*, greater short-nosed fruit bat

Sciuridae
- *Ratufa bicolor*, black giant squirrel
- *Callosciurus finlaysonii*, variable squirrel (the most common squirrel)
- *Callosciurus caniceps*, grey-bellied squirrel
- *Tamiops macclellandii*, Burmese striped squirrel
- *Menetes berdmorei*, Indochinese ground squirrel
- *Petaurista petaurista*, red giant flying squirrel
- *Hylopetes spadiceus*, red-cheeked flying squirrel

Hystricidae
- *Hystrix brachyura*, East Asian porcupine
- *Atherurus macrourus*, bush-tailed porcupine

Canidae
- *Cuon alpinus*, Asian wild dog

Ursidae
- *Ursus thibetanus*, Asiatic black bear
- *Ursus malayanus*, Malayan sun bear

Mustellidae
- *Martes flavigula*, yellow-throated marten
- *Arctonyx collaris*, hog badger

Viverridae
- *Viverricula indica*, small Indian civet
- *Viverra zibetha*, large Indian civet
- *Arctogalidia trivirgata*, three-striped palm civet
- *Paradoxurus hermaphroditus*, common palm civet
- *Arctictis binturong*, binturong

Herpestidae
- *Herpestes javanica*, Javan mongoose
- *Herpestes urva*, crab-eating mongoose

Felidae
- *Prionailurus bengalensis*, leopard cat
- *Catopuma temminckii*, Asian golden cat
- *Pardofelis marmorata*, marbled cat
- *Pardofelis nebulosa*, clouded leopard
- *Panthera tigris*, tiger

Elephantidae
- *Elephas maximus*, Asian elephant

Suidae
- *Sus scropha*, Eurasian wild pig

Tragulidae
- *Tragulus javanica*, lesser oriental chevrotain, or lesser mouse deer

Cervidae
- *Muntiacus muntjak*, red muntjac
- *Rusa unicolor*, sambar

of seedlings and other plants. There are seldom more than 3–4 researchers studying birds or gibbons on the plot at once. The most serious disturbance occurs in tree census years, when 8–10 persons work on the plot for many months, going through every quadrat. Tourists occasionally pass along the A–CR trails to the Mo Singto ridge (Fig. 3); this is a well-worn elephant trail. A small shelter 3×3 m in size with a tarpaulin roof is maintained on the plot mainly as a rain shelter, which disturbs an area of about 16 m^2.

Poachers of *Aquilaria crassna* trees, which produce the aromatic wood called *mai hom*, visit the plot several times per year to shave the sides of trees or to chop them down. The effect of harvest on the tree population has been studied by ZHANG *ET AL*. (2008). Poachers are seldom seen, and poaching pressure on the plot appears to be less than in much of the surrounding forest. Current patrolling by park guards is not effective in controlling poaching of this tree in the park.

The plot is not used for nature tourism and educational use of the plot by large groups is not encouraged. Habituated gibbon groups can be observed by visitors and nature lovers off the plot.

RESEARCH AT MO SINGTO

A brief history of research at Mo Singto might be of interest to prospective collaborators and others with an interest in the plot. As stated above, the plot was established in an existing active gibbon study area. The park has a history of gibbon research dating almost to its founding. Initial observations of gibbons in Khao Yai Park began with the early surveys of J. T. Marshall and collaborators, who in the 1960s established that two species, *Hylobates lar* and *H. pileatus*, both occur (MARSHALL *ET AL*., 1972; MARSHALL & BROCKELMAN, 1986; MARSHALL & SUGARDJITO, 1986). Later investigations documented the existence of a zone of overlap and hybridization between these species (BROCKELMAN & GITTINS, 1984; BROCKELMAN & SCHILLING, 1984). The Mo Singto site lies several km west of the zone of interspecies contact.

Initial observations of *H. lar* groups at Mo Singto were made by S. Srikosamatara in 1979. Since then, the area has been used for the study of many aspects of the behavior and ecology of white-handed gibbons, including vocal communication (RAEMAEKERS & RAEMAEKERS, 1984, 1985a, 1985b; RAEMAEKERS *ET AL*., 1984), diet and foraging (WHITINGTON, 1992; WHITINGTON & TREESUCON, 1991; BARTLETT, 2009), social relations (BROCKELMAN & SRIKOSAMATARA, 1984; BROCKELMAN *ET AL*., 1998; REICHARD, 1995; REICHARD & SOMMER, 1994; 1997; BARTLETT, 2003; SAVINI *ET AL*., 2008, 2009); predation (UHDE & SOMMER, 2002); inheritance of color phase (BROCKELMAN, 2004) and sexual behavior (BARELLI *ET AL*., 2007, 2008). The Mo Singto site is currently the most active and longest-running gibbon research site and results from observations there over the last 20 years have greatly increased our understanding of gibbon social biology.

Since the 1990s, the diet and foraging behavior of the gibbons (and other frugivores) have received increased attention. This research was hindered by the technical problems of identification of food species (the flora of Khao Yai has never been completely enumerated), and the accurate plotting of foraging path and home range without a very detailed map of the trees and the terrain. It was primarily these problems that led to the idea of establishing a permanent forest study plot on the site. The detailed map and knowledge of plant species gained would permit major advances in the study of diet, foraging strategy, and effects on seed dispersal of food species. Study of the effects of frugivores and seed predators would in turn permit a broader ecological approach to the study of forest regeneration and dynamics. The plot was in fact positioned to enclose the territory of the main gibbon study group, Group A, which had been known since 1979 and was well habituated.

The plot has also become an active research site for bird behavior and ecology. A major research effort in the Mo Singto and surrounding areas of the park has concentrated on the ecology and behavior of hornbills, of which there are four species (CHUAILUA *ET AL.*, 1998; POONSWAD, 1995; POONSWAD & TSUJI,1994; POONSWAD *ET AL.*, 1986, 1998a, b). Hornbills also rely on a high diversity of fruit trees for their food supply. The larger species in the park (the Great Hornbill *Buceros bicornis*), and Wreathed Hornbill (*Aceros undulatus*) exist at lower densities than do gibbons, apparently limited by the availability of suitable nesting holes in large trees. A nest tree of the Great Hornbill lies near the southern edge of the plot.

Recent studies of songbird ecology and behavior have made use of the plot's grid in mapping and monitoring ranges. The tree database has helped in the study of food species. Foraging studies have been carried out on racket-tailed drongos (*Dicrurus paradiseus* and *D. remifer*) by DHANASARNPAIBOON & ROUND (2004), and on the breeding biology of Abbott's Babbler (*Malacocincla abbotti*) (PIERCE *ET AL.*, 2004; SANGKAMETHAWEE *ET AL.*, in press), Puff-throated Bulbul (*Alophoixus pallidus*) (PIERCE *ET AL.*, 2004, 2007; and several studies in progress). Nesting success and nest predation have been studied by PIERCE & POBPRASERT (2007), and TOKUE (2008). GALE *ET AL.* (2009) have made use of the plot to test some standard census methods on several understory bird species whose densities are exactly known. NIMNUAN *ET AL.* (2004) examined the structure and composition of mixed-species feeding flocks.

An additional project has been initiated on the ecology of pheasants in the Mo Singto area around the plot (SUKUMAL & SAVINI, 2009). Pheasants have received attention recently because two species common in Khao Yai, Silver Pheasant (*Lophura nycthemera*) and Siamese Fireback (*L. dairdi*), appear to be changing their distribution by moving upward in elevation (ROUND & GALE, 2008). The lowland species, the Siamese Fireback, has become the commoner species in the Mo Singto area where the Silver Pheasant used to be more common. It is hypothesized that the warming climate around the park is responsible for this shift upward. The study of the effects of climate change will likely become the major impetus for research on populations at Mo Singto. Climate change research requires the special combination of long term monitoring and quantitative measurements, for which long-term forest dynamics plots are ideally suited.

There will be increasing use of the plot for its main intended purpose: the study of the dynamics of plant populations and the plant community, and other species such as seed dispersers that interact with plants. Initial studies have focused on the trees *Choerospondias axillaris* (BRODIE *ET AL.*, 2009a, b; CHANTHORN & BROCKELMAN, 2008), *Aquilaria crassna* (ZHANG *ET AL.*, 2008), and dispersal of the tree *Prunus javanica* (MCCONKEY & BROCKELMAN, 2011).

ZHANG *ET AL.* (2008) found that *A. crassna* is still common and recruiting well on the plot but the size distribution of trees has been shifted downward, with very few large trees surviving. If the harvest of *mai hom* by felling of reproductive trees continues, fruit production and recruitment of young trees will be adversely affected.

The tree *C. axillaris* is an interesting case study. It produces large numbers of fruits during July to November that have a tendency to fall to the ground when ripe and be consumed by deer, which appear to be the most important seed dispersal agents. The fruit is also critical for gibbons which harvest it on the tree during months when few other fruits are available.

Despite being well-dispersed, the tree is declining in abundance on the plot because of lack of recruitment of saplings (Chanthorn & Brockelman, 2008). *C. axillaris* appears to be a pioneer species that must have large sun-lit clearings in which to regenerate, and is persisting in old-growth forest without being able to regenerate there.

Studies have also begun on the ecology of lianas (Lertpanich & Brockelman, 2003; Wongsiriphuek, in preparation) which have also been enumerated on the plot. Work on seed dispersal and populations of several other species of trees important to gibbons, including *Nephelium melliferum* and *Garcinia benthamii*, are in progress.

The studies reviewed above reflect the breadth of research being carried out at Mo Singto, but hardly begin to cover the amount of ongoing research and planned future research.

FUTURE RESEARCH

We plan a complete tree census on the plot every 5 years, a standard practice for CTFS plots. The next census is planned for 2010 and will be completed in early 2011. Census of individual species under intensive study is carried out more often. Issues of particular interest are the regeneration of species on the plot, the history of natural disturbance on the plot, ecological succession from old fields, the role of animals in seed dispersal and tree recruitment, and the role and effects of lianas on the forest. Bird researchers will continue to test census methods and study foraging behavior, nesting biology, bird diets, predation on birds and population changes in species of interest. The study of gibbon foraging and diet will continue, and we will try to answer questions concerning how gibbons deal with seasonal and supra-annual variation in fruiting, whether or not food is limiting, and the role of territorial defense. Gibbon group formation, social behavior and demography continue to be studied in the whole Mo Singto area surrounding the plot.

A lot of animal, plant, and microbe groups have not been studied at Mo Singto and we welcome serious attempts to inventory poorly known groups and study their roles in the forest ecosystem. Biotec has studied the insect pathogenic fungi on the plot and many other places. Several types of macroscopic fungi are pathogenic on trees and research on them is anticipated.

Permanent plots such as Mo Singto are ideally suited to study biomass storage and carbon sequestration, especially in the pioneer and successional forest in and near the plot. Such studies are being planned but have not begun.

Persons interested in starting any kind of research on the Mo Singto plot should contact one of the authors. We welcome collaborative and integrative research, provided that it is coordinated with existing research. Prospective researchers must follow national park regulations and are responsible for obtaining the necessary permissions.

ACKNOWLEDGEMENTS

This project has been supported by grants from the Biodiversity Research and Training Program (BRT 239001, BRT 242001, BRT R_346005; BRT R_349009) and the National Center for Genetic Engineering and Biotechnology (Biotec BT-B-06-XA-14-4301 and Biotec CO-B-11-22-14-301) under Biotec/National Science and Technology Development Agency

(NSTDA) and the Thailand Research Fund. Support by the Institute for Science and Technology for Research and Development (now the Institute of Molecular Biosciences), Mahidol University, is gratefully acknowledged. It is being carried out with collaboration from the National Park Division, Royal Forest Department. We are grateful to Mr. Pairat Tarnchai, Dr. Chumpon Suckaseum, Mr. Prawat Wohandee, and Mr. Narong Mahunnop, former chiefs of Khao Yai National Park, and Mr. Amnuay Intarak, head of the Training and Research Center of Khao Yai Park, Department of National Parks, Wildlife and Plant Conservation, for their support. We also thank the National Research Council of Thailand for permissions to carry out research in Thailand.

We thank the following persons for their field assistance in the early stages of plot establishment: Amnart Boonkongchart, Atsadang Bhudhipap, Panarat Charoenchai, Wisanu Chongko, Saiwaroon Chongko, Sumonta Korkaew, Vudhikorn Kumcharoen, Somsak Pumpoung, Mark Read, Ulrich Reichard, Viboonsak Sairat, Direk Songserm, Nicola Uhde, and also Achaya Leksuntorn, Wararat Kusiriwanichkorn, Sudarat Zangkarn and Oraya Sutibutr for their administrative support. More recently, we are grateful to the following field assistants for their continuing and dedicated help: Umaporn Martmoon, Onuma Petmitr, Jantima Saentorn and Ratasart Somnuek. We thank many former and present students for their interest and cooperation, especially Thad Bartlett, Wirong Chantorn, Chuti-On Kanwattanakid, Kanok Lertpanich, Nalinee Pisuthiporn, Wangworn Sankamethawee, Udomlux Suwanvecho, Supreeda Tangprasertsri, Ranida Touranant, Yingluk Ratanapongsai, Tommaso Savini, Chanpen Wongsriphuek, and Petchprakai Wongsorn. Chen Nan's efforts in designing and managing our initial database are much appreciated. We also thank Stuart Davies and Jim LaFrankie for their useful advice and help in database management and other matters. We thank Phillip Round, Andy Pierce and Ted Webb for their useful comments on the manuscript.

We are greatly indebted to the botanists who helped us identify the flora of the plot, starting with the late Dr. Tem Smitinand, then Dr. Thawatchai Santisuk, and finally Mr. J. F. Maxwell who helped establish our herbarium and train our assistants, and continues to support us. We thank Stuart Davies and Jim LaFrankie for their advice and help regarding data storage. Drs. Morakot Tanticharoen and Kanyawim Kiratikara, former and current directors of Biotec Central Research Unit, have given our project constant enthusiastic support. Finally, our spouses Prof. Chariya, Mr. Ben and Dr. Kanyawim have been patient and supportive throughout.

REFERENCES

ASHTON, P. S. 1990. Thailand: Biodiversity center for the tropics of Indo-Burma. *J. Science Soc. Thailand*, 16: 107–116.

BARELLI, C., M. HEISTERMANN, C. BOESCH, AND U. H. REICHARD. 2007. Sexual swellings in wild white-handed gibbon females (*Hylobates lar*) indicate the probability of ovulation. *Hormones and Behavior* 51: 221–230.

BARELLI, C., M. HEISTERMANN, C. BOESCH, AND U. H. REICHARD. 2008. Mating patterns and sexual swellings in pair-living and multimale groups of wild white-handed gibbons, *Hylobates lar*. *Anim. Behav*. 75: 991–1001.

BARTLETT, T. Q. 2003. Intragroup and intergroup social interactions in white-handed gibbons. *Intl. J. Primatol*. 24: 239–259.

BARTLETT, T. Q. 2009. *The Gibbons of Khao Yai: Seasonal Behavior and Ecology*. Pearson Prentice Hall, Upper Saddle River, New Jersey, U.S.A. 192 pp.

BRANDON-JONES, D., A. A. EUDEY, T. GEISSMANN, C. P. GROVES, D. J. MELNICK, J. C. MORALES, M. SHEKELLE, AND C.-B. STEWART. 2004. Asian primate classification. *Intl. J. Primatol*. 25: 97–164.

Brockelman, W. Y. 1998. Study of tropical forest canopy height and cover using a point-intercept method. Pages 521–531 *in* F. Dallmeier and J. A. Comiskey (eds.), *Forest Biodiversity Research, Monitoring and Modeling: Conceptual Background and Old World Case Studies, Man and the Biosphere Series Edition. Volume 20.* UNESCO, Paris.

Brockelman, W. Y. 2004. Inheritance and selective effects of color phase in white-handed gibbons (*Hylobates lar*) in central Thailand. *Mammal. Biol.* 69: 73–80.

Brockelman, W.Y. 2011. Rainfall patterns and unpredictable fruit production in seasonally dry evergreen forest, and their effects on gibbons. *in* W. J. McShea, S. Davies, and N. Phumpakphan (eds.), *The Unique Ecology and Conservation of Tropical Dry Forests in Asia*. Smithsonian Institution Scholarly Press, Washington, D.C.

Brockelman, W. Y., P. Charoenchai, and J. F. Maxwell. 2002. A new tree species (Sapotaceae) and a new species record for Thailand (Flacourtiaceae) from Khao Yai National Park. *Nat. Hist. Bull. Siam Soc*. 50: 89–97.

Brockelman, W. Y., and D. Schilling. 1984. Inheritance of stereotyped gibbon calls. *Nature* 312: 634–636.

Brockelman, W. Y., U. Reichard, U. Treesucon, and J. J. Raemaekers. 1998. Dispersal, pair formation and social structure in gibbons (*Hylobates lar*). *Behav. Ecol. Sociobiol*. 42: 329–339.

Brockelman, W. Y., and S. Srikosamatara. 1984. Maintenance and evolution of social structure in gibbons. Pages 298–323 *in* H. Preuschoft, D. J. Chivers, W. Y. Brockelman and N. Creel, editors. *The Lesser Apes: Evolutionary and Behavioural Biology*. Edinburgh Univ. Press, Edinburgh.

Brodie, J. F., O. E. Helmy, W. Y. Brockelman, and J. L. Maron. 2009. Functional differences within a guild of tropical mammalian frugivores. *Ecology* 90: 688–698.

Brodie, J. F., O. E. Helmy, W. Y. Brockelman, and J. L. Maron. 2009. Bushmeat poaching reduces the seed dispersal and population growth rate of a mammal-dispersed tree. *Ecol. Appl.* 9(4): 854–863.

Chanthorn, W., and W. Y. Brockelman. 2008. Seed dispersal and seedling recruitment in the light-demanding tree *Choerospondias axillaris* (Anacardiaceae) in old-growth forest of Thailand. *ScienceAsia* 34: 129–135

Chuailua, P., K. Plongmai, and P. Poonswad. 1988. Status of nest cavities of hornbills in Khao Yai National Park, Thailand. Pages 219–226 *in* P. Poonswad (ed.), *Thai Studies in Biodiversity, No. 2: The Asian Hornbills: Ecology and Conservation.* White Lotus, Bangkok.

Condit, R. 1998. *Tropical Forest Census Plots: Methods and Results from Barro Colorado Island, Panama and a Comparison with Other Plots.* Springer-Verlag, Berlin, Heidelberg. 211 pp.

Cox, M. J., P. P. van Dijk, and K. Thirakupt. 1998. *A Photographic Guide to Snakes and other Reptiles of Thailand and Southeast Asia*. Asia Books, Bangkok. 144 pp.

Dallmeier, F. (ed.). 1992. L*ong-term Monitoring of Biological Diversity in Tropical Forest Areas: Methods for Establishment and Inventory of Permanent Plots.* MAB Digest 11, UNESCO, Paris. 72 pp.

Dhanasarnpaiboon, S., and P. D. Round. 2004. Foraging of Greater Racket-tailed Drongo (*Dicrurus paradiseus*) and Lesser Racket-tailed Drongo (*D. remifer*) in Khao Yai National Park. *Nat. Hist. Bull. Siam Soc*. 52(1): 115–117.

Francis, C. M. 2001. *A Photographic Guide to Mammals of Thailand & South-East Asia.* Asia Books, Bangkok.

Gale, G. A., P. D. Round, A. J. Pierce, S. Nimnuan, A. Pattanavibool., and W. Y. Brockelman. 2009. A field test of distance sampling methods for a tropical forest bird community. *Auk* 126: 439–448.

Geological Survey Division, Department of Mineral Resources. 1983. *Geological Map of Thailand 1:500,000*. Royal Thai Survey Department, Bangkok.

Holdridge, L. R., W. C. Grenke, W. H. Hathaway, T. Liang, and J. A. Tosi, Jr. 1971. *Forest Environments in Tropical Life Zones: A Pilot Study.* Oxford: Pergamon Press. 780 pp.

Lee, H. S., P. S. Ashton, and K. Ogino (eds.). 1995. *Reports of a New Program for Promotion of Basic Sciences Studies of Global Environment Change with Special Reference to Asia and Pacific Region, Vol. II-3: Long Term Ecological Research of Tropical Rain Forest in Sarawak.* Ehime University, Matsuyama.

Lertpanich, K., and W. Y. Brockelman. 2003. Lianas and environmental factors in the Mo Singto biodiversity research plot, Khao Yai National Park, Thailand. *Nat. Hist. J. Chulalongkorn Univ*. 3: 7–17.

Lynam, A. J., P. D. Round, and W. Y. Brockelman, 2006. *Status of Birds and Large Mammals in Thailand's Dong Phayayen—Khao Yai Forest Complex.* Biodiversity Research and Training Program and Wildlife Conservation Society International Programs, Bangkok.

Manokaran, N., J. V. LaFrankie, K. M. Kochummen, E. S. Quah, J. E. Klahn, P. S. Ashton, and S. P. Hubbell. 1990. *Methodology for the Fifty Hectare Research Plot at Pasoh Forest Reserve.* Forest Research Institute Malaysia, Research Pamphlet No.104, Kepong, Malaysia.

Marshall, J. T., and W. Y. Brockelman. 1986. Pelage of hybrid gibbons (*Hylobates lar* × *H. pileatus*) observed in Khao Yai National Park. *Nat. Hist. Bull. Siam Soc*. 34: 145–157.

Marshall, J. T., B. A. Ross, and S. Chantharojvong. 1972. The species of gibbons in Thailand. *J. Mammal*. 53: 479–486.

Marshall, J., and S. Sugardjito. 1986. Gibbon systematics. Pages 137–185 *in* D. Swindler (ed.), *Comparative Primate Biology, Vol. 1*: Systematics, Evolution, and Anatomy. Alan R. Liss, New York.

McConkey, K. R., and W.Y. Brockelman. 2011.Nonredundancy in the dispersal network of a generalist tropical tree. *Ecology* 92: 1492–1502

Nettelbeck, A. R. 1995. Predation on barking deer by reticulated python and dholes in Khao Yai National Park. *Nat. Hist. Bull. Siam Soc*. 43: 369–373

Nimnuan, S., P. D. Round, and G. A. Gale. 2004. Structure and composition of mixed-species insectivorous bird flocks in Khao Yai National Park. *Nat. Hist. Bull. Siam Soc*. 52(1): 71–79.

Parr, J. W. K. 2003. *A Guide to the Large Mammals of Thailand*. Sarakadee Press, Bangkok. 206 pp.

Pierce, A. J., Tokue, K., Pobprasert, and P. D. Round. 2004. Observations on the breeding of the Puff-throated Bulbul *Alophoixus pallidus* in north-east Thailand. *Forktail* 20: 101–102.

Pierce, A. J., and K. Pobprasert. 2007. A portable system for continuous monitoring of bird nests using digital video recorders. *J. Field Ornithol*. 78: 322–328.

Pierce, A. J., K. Pobprasert, and G. A. Gale. 2004 Breeding ecology and nesting success of Abbott's Babbler *Malacocincla abbotti*. *Wilson Bull*. 116: 274–276.

Pierce, A., K. Tokue, K. Pobprasert, and W. Sankamethawee. 2007. Cooperative breeding in the Puff-throated Bulbul *Alophoixus pallidus* in Thailand. *Raffles Bull. Zool*. 55(1): 187–189.

Poonswad, P., 1995. Nest site characteristics of four sympatric species of hornbills in Khao Yai National Park, Thailand. *Ibis* 137 (2): 183–191.

Poonswad, P., P. Chuailua, K. Plongmai, and S. Nakkuntod. 1998a. Phenology of some *Ficus* species and utilization of *Ficus* sources in Khao Yai National Park, Thailand. Pages 227–252 *in* P. Poonswad (ed.), *Thai Studies in Biodiversity, No. 2: The Asian Hornbills: Ecology and Conservation.* White Lotus, Bangkok.

Poonswad, P., and A. Tsuji, 1994. Ranges of males of the great Hornbill *Buceros bicornis*, Brown Hornbill *Ptilolaemus tickelli* and Wreathed Hornbill *Rhyticeros undulatus* in Khao Yai National Park, Thailand. *Ibis* 136 (1): 79–86.

Poonswad, P., A. Tsuji, N. Jirawatkavi, and V. Chimchome. 1998b. Some aspects of food and feeding ecology of sympatric hornbill species in Khao Yai National Park, Thailand. Pages 137–157 *in* P. Poonswad (ed.), *Thai Studies in Biodiversity, No. 2: The Asian Hornbills: Ecology and Conservation.* White Lotus, Bangkok.

Poonswad, P., A. Tsuji, and C. Ngampongsai. 1986. A study of the breeding biology of hornbills (Bucerotidae) in Thailand. *Natur und Museum* 115(5): 129–144.

Raemaekers, J. J., and P. M. Raemaekers. 1984. Vocal interactions between two male gibbons, *Hylobates lar*. *Nat. Hist. Bull. Siam Soc*. 32: 95–106.

Raemaekers, J. J., and P. M. Raemaekers. 1985a. Field playback of loud calls to gibbons (*Hylobates lar*): territorial, sex-specific and species-specific responses. *Anim. Behav*. 53: 481–493.

Raemaekers, J. J., and P. M. Raemaekers. 1985b. Long-range vocal interactions between groups of gibbons (*Hylobates lar*). *Behaviour* 95: 26–44.

Raemaekers, J. J., P. M. Raemaekers, and E. H. Haimoff. 1984. Loud calls of the gibbon (*Hylobates lar*): repertoire, organization and context. *Behaviour* 91: 146–189.

Reichard, U. 1995. Extra-pair copulations in a monogamous gibbon (*Hylobates lar*). *Ethology* 100: 99–112.

Reichard, U., and V. Sommer. 1994. Grooming site preferences in wild white-handed gibbons (*Hylobates lar*). *Primates* 35: 369–374.

Reichard, U., and V. Sommer. 1997. Group encounters in wild gibbons (*Hylobates lar*): Agonism, affiliation, and the concept of infanticide. *Behaviour* 34: 1135–1174.

Round, P. D., and G. A. Gale. 2008. Changes in the status of *Lophura* pheasants in Khao Yai National Park, Thailand: A response to warming climate? *Biotropica* 42(2): 225–230.

Sangkamethawee, W., G. Gale, and B. Hardesty 2009. Post-fledging survival of the cooperatively breeding Puff-throated Bulbul (*Alophoixus pallidus*). *Condor* 111: 675–683.

Savini, T., C. Boesch, and U. H. Reichard. 2008. Home-range characteristics and the influence of seasonality on female reproduction in white-handed gibbons (*Hylobates lar*) at Khao Yai National Park, Thailand. *Am. J. Phys. Anthropol*. 135: 1–12.

Savini, T., C. Boesch, and U. H. Reichard. 2009. Varying ecological quality influences the probability of polyandry in white-handed gibbons (*Hylobates lar*) in Thailand. *Biotropica* 41: 503–513.

Sukumal, N., and T. Savini. 2009. Home range analysis of Siamese Fireback *Lophura diardi* and Silver Pheasant *L. nycthemera*, Khao Yai National Park, Thailand. *Intl J. Galliforme Conservation* 1: 18–22.

Smitinand, T. 1968. Vegetation of Khao Yai National Park. *Nat. Hist. Bull. Siam Soc*. 22: 289–303.

Smitinand, T. (ed.). 1977. *Plants of Khao Yai National Park*. Friends of Khao Yai National Park Association, Bangkok.

Srikosamatara, S., and T. Hansel. 2000. *Mammals of Khao Yai National Park* (2nd ed.). Green World Foundation, Bangkok.

Tokue, K. 2008. Predation by pig-tailed macaque *Macaca nemestrina* on bulbuls in Khao Yai National Park, Thailand. *Nat. Hist. Bull. Siam Soc*. 56:

Uhde, N., and V. Sommer. 2002. Antipredatory behavior in gibbons (*Hylobates lar*, Khao Yai Thailand). Pages 268–291 in L.E. Miller (ed.), *Eat or be Eaten: Predator Sensitive Foraging Behavior among Primates*. Cambridge Univ. Press, Cambridge, U.K.

Whitington, C. L. 1992. Interactions between lar gibbons and pig-tailed macaques at fruit sources. *Am. J. Primatol*. 26: 61–64.

Whitington, C. L., and U. Treesucon. 1991. Selection and treatment of food plants by white-handed gibbons (*Hylobates lar*) in Khao Yai National Park, Thailand. *Nat. Hist. Bull. Siam Soc*. 39: 111–122.

Zhang, Lixin, W. Y. Brockelman, and M. A. Allen. 2008. Matrix analysis to evaluate sustainability: the tropical tree *Aquilaria crassna*, a heavily poached source of agarwood. *Biol. Cons.* 141: 1676–1686.