# Phenology and Distribution of *Elateriospermum tapos* (Euphorbiaceae) at Khao Nan, a Tropical Rain Forest in the South of Thailand

**Wacharapong Srisang**

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy in Computational Science
Walailak University

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ชื่อวิทยานิพนธ์ ชีพลักษณ์ และการกระจายตัวของ *Elateriospermum tapos* (Euphorbiaceae) ณ เขานัน, ป่าฝนเขตร้อนในภาคใต้ของประเทศไทย
ผู้เขียน นายวัชรพงศ์ ศรีแสง
สาขาวิชา วิทยาศาสตร์เชิงคำนวณ
ปีการศึกษา 2551

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# บทคัดย่อ

การศึกษานี้มุ่งศึกษาชีพลักษณ์ของต้นประ (*Elateriospermum tapos*) และศึกษาว่าข้อมูลภูมิอากาศส่งผลกระทบต่อการแตกตายอดและการแตกตาดอกของต้นประอย่างไร ขั้นแรกเราทดสอบแบบจำลองที่ใช้สำหรับสร้างแบบจำลองการกระจายตัวของสิ่งมีชีวิตชื่อ Ecological Niche Factor Analysis (ENFA) เราสร้างสิ่งมีชีวิตเสมือนขึ้นจากข้อมูลสิ่งแวดล้อมจริง เราศึกษา 3 กรณีศึกษาคือ (1) สิ่งมีชีวิตกำลังกระจายตัวเข้าสู่พื้นที่ (2) สิ่งมีชีวิตอยู่ในสถานะสมดุล (3) สิ่งมีชีวิตอยู่ในสถานะหนาแน่น เราสุ่มเลือกสิ่งมีชีวิตเสมือนในแต่ละกรณีศึกษา มาเป็นข้อมูลนำเข้า เพื่อสร้างแบบจำลองการกระจายตัวของสิ่งมีชีวิต พบว่าเมื่อทดสอบด้วยสิ่งมีชีวิตอยู่ในสถานะสมดุล จะได้แบบจำลองที่ดีทั้งในด้านคุณภาพและปริมาณ แบบจำลองที่สร้างขึ้นโดยใช้ ENFA จะได้รับอิทธิพลจากกรณีศึกษา แต่ไม่ได้รับอิทธิพลจากขนาดของกลุ่มตัวอย่าง ขั้นที่สองเราสร้างแบบจำลองศักยภาพการกระจายตัวและการบ่งชี้ลักษณะที่เป็นผลมาจากวิวัฒนาการของต้นประ เราเก็บข้อมูลการกระจายตัวของต้นประสองวิธีได้แก่การสำรวจในภาคสนามและการบินสำรวจโดยใช้เฮลิคอปเตอร์ เราเก็บข้อมูลอากาศจากจุดศึกษาจำนวน 8 จุดศึกษารอบอุทยานแห่งชาติเขานัน เราใช้ ENFA ในการสร้างแบบจำลองการกระจายตัวของต้นประ เราพบว่าการสำรวจโดยเฮลิคอปเตอร์และการสำรวจภาคสนามให้ผลตรงกัน ซึ่งเป็นการบ่งชี้ว่าเราสามารถใช้การสำรวจโดยเฮลิคอปเอตร์เพื่อประมาณการกระจายตัวของพืชชนิดนี้ได้ ขนาดลำต้นของต้นประมีการกระจายตัวเป็น แบบอักษร J-กลับ ป่าประที่บ้านหุกภูมีการเติบโตทดแทนน้อย และอาจอยู่ในสถานะเสี่ยงต่อการถูกทำลาย ในการสร้างแบบจำลองการกระจายตัวของต้นประ เราศึกษาปัจจัยทางกายภาพหกปัจจัยได้แก่ ความสูงจากระดับน้ำทะเล ค่าความเบี่ยงเบนมาตรฐานของความสูงจากระดับน้ำทะเล ความลาดเอียงของพื้นที่ในแนวตะวันออกตะวันตก ความลาดเอียงของ

พื้นที่ในแนวเหนือใต้ ความลาดเอียงของพื้นที่ และอุณหภูมิอากาศ ผลการศึกษาแสดงให้เห็นว่า ปัจจัยหลักที่สำคัญต่อการกระจายตัวของต้นประคือ ความสูงจากระดับน้ำทะเล และความลาดเอียงของพื้นที่ในแนวตะวันออกตะวันตก แบบจำลองที่สร้างขึ้นแสดงให้เห็นว่า ต้นประชอบจะขึ้นในบริเวณที่มีความสูงของพื้นที่ต่ำ และอยู่ทางด้านทิศตะวันตกของภูเขา อุณหภูมิไม่มีความสำคัญต่อการกระจายตัวของต้นประ แต่ช่วยทำให้โมเดลถูกต้องมากขึ้น ขั้นสุดท้ายเราศึกษาผลกระทบของปัจจัยภูมิอากาศต่อชีพลักษณ์ของการแตกตายอดและการออกดอกของต้นประ เราติดตั้งอุปกรณ์ตรวจวัดอากาศอัตโนมัติ ณ ป่าประเพื่อเก็บข้อมูลอากาศ 23 ปัจจัย เราพบว่ามีปัจจัยทางภูมิอากาศ ห้าตัวแปรที่ส่งผลกระทบต่อการแตกตายอดและการออกดอกของต้นประได้แก่ ลมในทิศตะวันออกและตะวันตก ค่าความเบี่ยงเบนมาตรฐานของความเร็วลม อุณหภูมิต่ำสุดในช่วงวัน ดัชนีรังสีอัลตราไวโอเล็ต และความชื้นสัมพัทธ์ต่ำสุด ตามลำดับ

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| Thesis Title | Phenology and Distribution of *Elateriospermum tapos* (Euphorbiaceae) at Khao Nan, a Tropical Rain Forest in the South of Thailand |
| Author | Wacharapong Srisang |
| Major Program | Computational Science |
| Academic Year | 2008 |

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# Abstract

This study aims at studying the phenology of the parah tree (*Elateriospermum tapos*) and how climatic data effect on budburst and flower bloom. Firstly, we examined a habitat-suitability assessment method namely the Ecological Niche Factor Analysis (ENFA). A virtual species was created and then dispatched in a geographic information system model of a real landscape in three historic scenarios: (1) spreading, (2) equilibrium, and (3) overabundance. In each scenario, the virtual species was sampled and these simulated data sets were used as inputs for the ENFA to reconstruct the habitat suitability model. The 'equilibrium' scenario gave the highest quantity and quality among three scenarios. ENFA was sensitive to the distribution scenarios but not sensitive to sample sizes. Secondly, we studied potential distribution modeling, niche characterization of the species. We collected species distribution data by both field survey and helicopter observation. We collected climatic data from eight study sites around Khao Nan National Park. We used ENFA to model Species Distribution Model. We found that both helicopter observation and field survey gave the same results for species distribution. It indicated that we can use helicopter observation to estimate a species distribution. parah tree at Khao Nan National Park had an inverse-j-shaped distribution. We found that parah trees at Ban Huk Phu had a low recruitment rate and possibly in great danger. For parah species distribution model, we put 6 factors in the model: elevation, SD of Elevation, Eastness, Northness, slope and temperature. Our results showed that elevation and Eastness were two main important factors for parah distribution model. The model predicted that parah trees preferred to grow at low elevation areas, especially on the west site of the hill. Though temperature was not an important factor for the parah distribution, temperature factor can help to improve the quality of the parah species distribution model. Finally, we studied the effect of climatic factor on bud burst and flower bloom phenology. We installed the automatic weather station at parah forest and collected 23 climatic factors. There were five climatic factors significantly affecting parah bud burst (i.e. total east-west wind run, standard deviation of wind speed, minimum temperature, total UV index, and minimum relative humidity, respectively).

# Acknowledgments

My dissertation was completed and finally got approved through my great effort and kind assistance from the following professors and colleagues to whom I would like to express my sincere thanks and appreciation.

My deep gratitude and esteem are extended specially to Asst. Prof. Dr. Krisanadej Jareonsutasinee and Asst. Prof. Dr. Mullica Jareonsutasinee my major advisor and co-advisor for their supervisions, guidance and encouragement. They kindly and closely gave me advice throughout my dissertation acting. Without their helps, this dissertation might have been inconceivable. I am grateful to the committee members, Dr. Piyawut Srichaikul and Asst. Prof. Dr. Teerakiat Kerdcharoen, for their affirmative suggestions and helpful comments.

We thank Asst. Prof. Dr. Pornpatsara Supakorn, Assoc. Prof. Dr. David Harding, Mr. David Weatherby, and anonymous referees for editing and commenting on previous versions of the manuscript of this dissertation. We thank Mr. Anun Charoensuk, Mr. Pattanabhorn Rintachak, Mr. Manob Kiawchad, Mr. Santichai Jomrit, and Khao Nan National Park rangers for kindly help during both field work and helicopter observation. I would like to thank my colleagues, Mr. Peerasak Sangarun, Mr. Wittaya Pheera, Mr. Sunthorn Suraban, Asst. Prof. Uthai Kuhapong, Miss Nutrapee Janchoy, Miss Sirilak Chumkiew, and my friends in Computational Science Graduate program for their helps, good comments and friendship.

This work was supported in part by PTT Pubic Company Limited, the TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT T_549002, BRT T_550005, Complex System Key University Research Unit of Excellence, the Institute of Research and Development, Walailak University, and DPST project, IPST, Thailand.

Finally, I would like to thank my dearest parents Mr. Sanga and Mrs. Thitibhorn for their loving, caring, supportive and thoughtful vision on encouraging me to study in the higher education level.

Wacharapong Srisang

# Disclaimer

I certify that the material contained in this dissertation is my own work and does not contain significant portions of unreferenced or unacknowledged material. I also warrant that the above statement applied to the implementation of the project and all associated documentation.

In the case of electronically submitted work, I also consent to this work being stored electronically and copied for assessment purposes, including the graduate office use of plagiarism detection systems in order to check the integrity of assessed work.

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Wacharapong Srisang

Date...........................

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# List of Symbols, Abbreviations and Technical Vocabulary

ANOVA = Analysis of Variance

CX-KURUE = Complex System Key University Research Unit of Excellence

DAB = Diameter At Base

DBH = Diameter at Breast Height

DEM = Digital Elevation Model

df = Degree of freedom

E = East

ENFA = the Ecological Niche-Factor Analysis

GIS = Geographical Information System

N = North

NE = North East

NEE = North East East

NEN = North East North

NOGAPS = Navy Operational Global Atmospheric Prediction System

NW = North West

NWN = North West North

NWW = North West West

PAR = Photosynthetically Active Radiation

PFD = Photon Flux Density

RH = Relative Humidity

S = South

SD = Standard Deviation

SE = South East

# List of Symbols, Abbreviations and Technical Vocabulary (Continued)

SE = Standard Error

SEE = South East East

SES = South East South

SW = South West

SWS = South West South

SWW = South West West

UV = Ultra Violet

W = West

# Chapter 1

# Introduction

## Origins and Significances

Phenology is the study of plant and animal life cycle events and how these are influenced by seasonal and inter-annual variations in climate. For plants, phenology studies include vegetative processes such as leaf flushing and shedding as well as reproductive events such as bud formation, flowering and production of fruit. Most phenology studies have worked on plant in temperate zones. An understanding of the plant phenology in tropical rain forests is still limited (Bendix, 2006). Aspects addressed in this respect are the incidence of rhythmic cycles (Mikich & Silva, 2001), the influence of climatic triggers and day-length as proximate factors, and the intra-specific and inter-specific synchronization of phenological events (Ims, 1990; Poulin et al., 1999; Borchert et al., 2005), these being ultimate factors that regulate plant life and plant-animal interactions (Frankie et al., 1974; Stiles, 1977; Opler et al., 1980; Wright et al., 1999; Lobo et al., 2003). A study of the complex relationships between plant structures, vegetative development and the incidence of flowering of selected tropical trees has been presented by Borchert (1983).

In contrast to habitats subjected to a regular cycle of dry and wet seasons (Daubenmire, 1972; Shukla & Ramakrishnan, 1982), the synchronization of phenological events may not a priori be expected in perhumid evergreen tropical rain forests lacking well-developed xeric periods, and, due to the high degree of species diversity, may also be difficult to examine. The proportion of trees and shrubs that show continuous flowering and fruiting appears to be small, as distinct peaks of flowering and fruiting are observed in the course of the year (Opler et al., 1980). A comprehensive 4-year study of the phenology of flowering and fruiting in a Philippine submontane rain forest found 34 tree species that reproduced once a year, 13 that reproduced continuously, 3 supra-annually and 7 irregularly (Hamann, 2004). In lowland Dipterocarp forest in Malaysia, Sakai et al. (1999) found that 35% of 257 species flowered only during mass flowering, 19% flowered supra-annually, 13% annually and only 5% more or less continuously.

With regard to climate as the triggering and synchronizing master control factor of phenological cycles, a thorough physiological or ecological understanding is still lacking, although even in the perhumid regions changes between less and more humid seasons occur regularly. Species that flower during the wet season will fruit during the subsequent drier months, which will favor seed dispersal, while germination can take advantage of the rainy season following. On the other hand, species flowering during the drier months will find a broad spectrum of pollinators, including wind, and may still be able to ripen their seeds before the peak of the following wet season. Various hypotheses have been presented over the last few decades addressing individual elements of the climate as proximate factors that trigger seasonality in the equatorial tropics. Cloudiness appears to play an important role because most of the meteorological cues that may have an impact on plant development, e.g. global radiation, UV-B intensity, rainfall and air temperature, are coupled with the occurrence and frequency of clouds. Higher doses of UV-B are known to affect flowering as well as the germination of pollen (Caldwell, 1968; Flint and Caldwell, 1984; Tevini & Teramura, 1989; Caldwell et al., 1998). Wright et al. (1999) attributed the seasonality of plant reproduction in the tropical forests of Panama to a shortage of assimilates during the rainy season when Photosynthetically Active Radiation (PAR) is low, and Hamann (2004) reported that nearly all canopy tree species in a submontane rain forest (Philippines) flowered during the peak of solar irradiance. Numata et al. (2003) showed that the flower induction of tropical canopy trees was triggered by prolonged drought, high solar radiation and abnormally low temperatures. They presumed that a drop in nocturnal air temperatures due to cloudlessness, and thus enhanced radiation emission, is the most plausible cue for a supra-annual synchronization of flowering. Considering changes in the light climate as the proximate factor that triggers periodicity in the aseasonal tropics, a differentiation must be made between direct and diffuse global radiation. The ratio of diffuse to direct global radiation increases under a cloudy sky (Graham et al., 2003). As a consequence, the light microclimate of sub-canopy trees improves, whereas that of canopy trees deteriorates as compared to clear sky conditions under which the proportion of direct radiation is higher (Endler, 1993). Another potential factor explaining phenological phases could be the state of the saturation deficit of air (Wright & Cornejo, 1990a). However, many of these observations still require confirmation, as claimed by Sakai (2002), because the link between climate and reproductive cycles can be modified by biotic factors, such as low pest pressure combined with a maximum activity of pollinating insects during times of maximum solar irradiance (Hamann, 2004), or competition for pollinators (Lobo et al., 2003).

## Role of Environmental Factors Effecting Phenology in the Tropical Forest

Wright (1996) grouped environmental factor effecting phenology in the tropical forest into four broad classes.

## Moisture Availability

In many tropical forests, low dry-season rainfall reduces moisture availability just as increases in atmospheric saturation deficits, irradiance, and leaf temperatures increase transpirational demand. The resultant moisture shortfalls are a primary determinant of tropical vegetation types.

Evergreen forests predominate where rainfall exceeds evapo-transpiration for 11 or 12 months (Köppen, 1936; Medina, 1983; Whitmore, 1984). Plant water deficits have been recorded in evergreen tropical forests both during unusual drought events and also as an adaptive response to high irradiance (Chiariello et al., 1987; Oberbauer et al., 1987). Predictable seasonal water deficits are absent from most tropical evergreen forests, however, moisture seasonality is unlikely to be an important factor influencing plant phenologies (Frankie et al., 1974; Newstrom et al., 1994).

Semideciduous tropical forests occur where rainfall exceeds evapo-transpiration for eight to 10 months (Köppen, 1936; Medina, 1983, Whitmore, 1984). Dry-season drought is predictable in semi-deciduous forests, and in some years, plant moisture stress can be severe (Leigh et al., 1990; Wright et al., 1992; Condit et al., 1995). Nonetheless, many plants maintain year-round growth. For example, 90% of the plant species are evergreen and 20% of the plant species flower, fill, and disperse fruit during the four-month dry season on Barro Colorado Island, Panama (Croat, 1975; 1978). Moisture seasonality is only likely to be an important factor influencing the phenologies of the drought-sensitive species in semi-deciduous forests (Reich & Borchert, 1984; Wright & Cornejo, 1990a, b; Wright et al., 1992).

In contrast, deciduous tropical forests predominate where evapo-transpiration exceeds rainfall for five or more months (Köppen, 1936; Medina, 1983; Whitmore, 1984). Dry-season water deficits are potentially severe, and the dominant phenological pattern is to avoid dry-season water stress by becoming deciduous during the dry season (Frankie et al., 1974; Lieberman & Lieberman, 1982; Bullock & Solis-Magallanes, 1990). Deciduous species may renew growth during the dry season, but constraints imposed by water deficits are again evident. For example, many deciduous species flower after a heavy dry-season rain (Opler et al., 1976). More perplexing are deciduous species that renew growth under continuous drought. Reich and Borchert (1982, 1984, 1988) hypothesized that these species experience water stress early in the dry season because senescent leaves have lost the ability to control transpiration. As a consequence, leaf abscission occurs before soil water is completely depleted, and the leafless tree is able to take up water and renew growth under continuous drought.

At this time, predictions of the relationship between phenology and water stress for deciduous and semi-deciduous forests depend on species-by-species information on adaptations for drought resistance (Reich & Bochert, 1984; Borchert, 1994). The possible adaptations are few in number (Jones et al., 1981). Transpirational water loss can be reduced through reductions in leaf area, cuticular conductance, and leaf temperatures via reductions in the amount of radiation absorbed. Water uptake can be maintained through deep, extensive root systems and low resistances to xylem water flow. Tissue tolerance to moisture stress can be enhanced through increases in tissue osmotic concentrations and the rigidity of cell walls. These mechanisms of drought resistance have all been observed among tropical forest plants (Medina, 1983). The critical question here is whether growth is possible during the drier season, as growth and cell expansion are among the first plant processes to be adversely affected by small water deficits and reductions in tissue turgor pressures (Bradford & Hsiao, 1982).

Most tropical deciduous forests include a few evergreen plants (Frankie et al., 1974; Lieberman & Lieberman, 1982; Bullock & Solis-Magallane, 1990). In contrast to their deciduous neighbors, evergreen species maintain positive leaf turgor potentials in the dry season (Sobrado, 1986; Fanjul & Barradas, 1987). Similar dry season reductions in osmotic potentials occur in both deciduous and evergreen species, however, evergreen species have deep root systems and inelastic cell walls relative to their deciduous neighbors (Sobrado & Cuenca, 1979; Sobrado, 1986; Funjul & Barradas, 1987). Deep root systems also characterize evergreen trees in tropical savannahs (Sarmiento et al., 1985). A few deciduous forest species may even reverse the normal pattern of leaf phenology. For example, the shrub *Jacquinia punpens* is deciduous in the wet season and foliated in the dry season in the deciduous forests of Mesoamerica (Janzen, 1972). The depth of the root system may again be critical. The deep tap root of *J. pungens* is exceptional for a deciduous forest shrub and allows the maintenance of high dry-season water potentials (Fanjul & Barradas, 1987; Janzen, 1972; Oberbauer, 1985). Recent data for trees from semideciduous and deciduous tropical forests suggest that analyses of hydraulic architecture and consequent dry-season water relations can predict phenologies (Borchert, 1994; Machado & Tyree, 1994).

## Light Availability

Most tropical forests experience substantial seasonal variation in irradiance. In the wet tropic, global radiation averages 50% greater in the highest month than in the lowest month (compiled for the 24 tropical sites with annual rainfall > 1000 mm in Müller (1982)). Seasonal changes in cloud cover, day length and solar elevation contribute to seasonal variation in irradiance (Chazdon & Fetcher, 1984). The importance of day length and solar elevation increase with latitude, and the month of maximum global radiation fall close to the summer solstice at higher latitudes within the tropics. The quantitative importance of cloud cover can be illustrated by a comparison of the equinoxes for a 17-year record from central Panama (Windsor, 1990). Global radiation averages 31% greater on the March equinox when dry-season conditions with negligible cloud cover prevail. Cloud cover increases toward the equator (Hastenrath, 1985), and within 10° of the equator, the month of maximum global radiation is less tightly constrained by solar elevation and reflects the local seasonality of cloud cover.

Predictable seasonal changes in light levels will be a potent selective agent on the phenologies of light limited plants. Light limits many tropical forest plants. Photosynthetically active radiation (PAR) in the shaded understory of tropical forests is as low as in any other habitat occupied by autotrophic plants (Björkman & Ludlow, 1972). The growth of understory plants increases dramatically in response to short sunflecks that pass through small openings in the canopy (Pearcy, 1983) and after treefalls open the canopy overhead (Brokaw 1985; Fisher et al., 1991).

Light may also limit taller plants. Radiant energy is extinguished exponentially with distance beneath forest canopies (Kira et al., 1969). Above-canopy PAR was reduced by 94% just 5 m into the canopy of a wet forest n Puerto Rico (Johnson & Atwood, 1970) and global radiation was reduced by 53% just 6 m into the canopy of a Malaysian rainforest (Yoda, 1974; Aoki et al., 1975). PAR is extinguished more rapidly than global radiation due to differential absorption by leaves. Limiting levels of PAR predominate directly below the uppermost leaves of tropical forests.

Correlations between plant performance and irradiance suggest that tropical forest trees are light limited. The radial growth of trees from evergreen forests increases with irradiance in Surinam and possibly Costa Rica (Schulz, 1960; Clark & Clark, 1994). Seed set increases with irradiance for several trees in Borneo (Wycherley, 1973), and the likelihood of a mast flowering increases with irradiance in peninsular Malaysia (van Schaik, 1986). These correlations are consistent with limitation by irradiance, but shifts in allocation and effects of co-varying environmental factors cannot be discounted.

Physiological measurements provide stronger evidence that light limits tropical trees. Light often limits photosynthesis by canopy leaves. Canopy leaves measured *in situ* become saturated with light at photosynthetic photon flux densities (PFD) of 450 to 600 μmol $m^{-2}$ $s^{-1}$ for trees from a wide variety of tropical forests (Oberbauer & Strain, 1986; Pearcy, 1987). Lower light levels will limit photosynthesis. PFD varied by three orders of magnitude and limited photosynthesis in most determinations made between 0800 and 1000 h for leaves from above 29 m in an Australian rainforest tree. PFD was less than 400 μmol $m^{-2}$ $s^{-1}$ in 71% of Diurnal course measurements for canopy leaves for *Petaclethra macoloba in* an evergreen forest in Costa Rica (Oberbauer & Strain, 1986). Low light levels associated with heavy cloud cover often limit photosynthesis by the emergent tree *Ceiba pentandra* during the wet season in central Panama. Self shading, lateral shading by neighbors, and shading by competing lianas affect all clouds affects all leaves. Thus, predictable, seasonal changes in irradiance may be an important selective agent on the phenologies of tropical forest plants.

## Biotic Interactions

Seasonal changes in the activities of interacting animals and microbes also influence tropical forest plant phenologies. Possibilities include selection to coincide with the seasonality of mutualisms, such as pollinators, and selection to avoid the seasonality of pests, such as seed predators and herbivores. Many tropical forest animals specialize on a particular host plant or on a small group of related host plants (Janzen, 1980; Frankie et al., 1983). It is well established that host specialists can cause strong selection on plant phenologies (Augspurger, 1981). However specialists must track the seasonality of their hosts, and stabilizing selection or directional selection for earlier or later production may result depending on the autecologies of the particular species involved (Wright, 1990; Van Schaik et al., 1993). Host specialists are unlikely to have consistent, predictable effects on plant phenology.

Consistent effects are more likely when a variety of host generalists share a common seasonality. For example, in seasonal tropical forests, many herbivorous insects are inactive or restricted to moist micro-sites during the drier season (Janzen, 1973; Wolda, 1978). This hared seasonality creates the potential for phenological selection.

This potential will be illustrated by a comparison of seasonal changes in leaf herbivory across three tropical forests with very different seasonalities. Tropical forest is near its distributional limit in the Accra Plains of Ghana where rainfall seasonality is extreme. Insect herbivory was largely restricted to the wet season at this site, and strong selection for dry-season leaf production resulted (Lieberman & Lieberman, 1982). The seasonal fluctuations of herbivorous insects decrease in tropical forests with milder dry seasons (Wolda, 1988). Relative to Accra, seasonal changes in herbivory were modest in the semi-deciduous forest of Varro Colorado Island, Panama, averaging 20-22% in the three driest months and 25-42% in the nine wetter months (Aide, 1988). Finally, seasonal changes in herbivory were absent for an understory shrub in the evergreen forests of La Selva, Costa Rica (Marquis, 1987). The potential for selection by seasonal insect populations increases with rainfall seasonality. Less is known about seasonal changes in tropical forest microbes, but a similar pattern is to be expected.

### Mineral Nutrients

Temporal variation in nutrient availability has been documented for several tropical forests. Pulses of high nitrogen and phosphate availability are often associated with rapid changes in moisture availability that cause lysis of soil and litter microbes (reviewed by Lodge et al., 1994). Microbial death simultaneously frees nutrients and reduces microbial competition for those nutrients. The type of change in moisture availability that induces microbe death varies among forest. Microbe death is caused by droughts in normally aseasonal, ever wet forests, and by the rapid increase in moisture availability at the beginning of the wet season in monsoonal and other seasonally dry forests.

There may also be long-term seasonal changes in nutrient availability that are unrelated to rapid changes in moisture availability. Magnesium and calcium availability increased steadily throughout the wet season, reached their annual peak in the final month of the wet season, and then crashed rapidly to low dry-season levels for three consecutive years on Barro Colorado Island. This seasonal pattern of availability may characterize nutrients whose concentrations remain high in recalcitrant liter fractions until final release from decayed litter (Cornejo et al., 1994). Other nutrients that are released more rapidly during decomposition had different seasonal patterns on Barro Colorado Island. Phosphate and ammonium increased in the dry season then decreased in the wet season, while potassium and sulfate did not vary seasonally. Likewise, phosphate and ammonium availabilities did not vary among months in the relatively aseasonal, evergreen forests of La Selva, Costa Rica (Vitousek & Denslow, 1986).

Predictable changes in nutrient availability, like those outlined above, may select for plant phenologies. Many wild plants are able to store and recycle nutrients effectively (Chapin, 1980); however, this would tend to minimize the impact of temporal variation in nutrient availabilities. Perhaps for this reason the potential effect of temporal variation in nutrient availability on plant phenologies has generally been overlooked.

## Climatic Factors Affecting on parah Phenology

Comprehensive studies of reproduction phenology in relation to climate have been performed in tropical lowland rain forests (Frankie et al., 1974; Croat, 1975; Opler et al., 1980; Newstrom et al., 1994; Hamann and Curio, 1999; Sakai et al., 1999; Schöngart et al., 2002; Hamann, 2004) and tropical mountain rain forests (e.g. Koptur et al., 1988). But there were little research in Thai tropical rain forest. This research studied parah tree (*Elateriospermum tapos*) which is native species of South-East Asia.

parah tree is a monoecious canopy species that found in South-East Asian tropical rain forests (Whitmore, 1972). This species was dominant in the Jengka Forest Reserve, Peninsular Malaysia (Ho et al., 1987), and in Belalong forest, Brunei (Cranbrook & Edwards, 1994). This species appeared well-suited to the very friable, relatively nutrient-rich soil of the Segamat series, which had lower soil water content in the dry period (Ho et al., 1987). Two hundred and twenty individuals larger than 1 cm in diameter at breast height (DBH) were found in a 50-ha permanent plot in the Pasoh Forest Reserve, and many were clumped on a hill (Manokaran et al., 1992). This species was thought to exchange its leaves annually (Medway, 1972; Whitmore, 1972; Cranbrook & Edwards, 1994), although Koriba (1958) reported that it produced leaves twice a year. The inflorescences develop with the young leaves (Whitmore 1972), thus the timing of flowering directly reflects leaf phenology in mature individuals.

This dissertation was divided into five chapters. The first chapter was about the general information on phenology and factors affecting phenology. In the second chapter, we examined the use of the Ecological Niche Factor Analysis (ENFA) model at Khao Nan area. In the third chapter, we investigated parah tree distribution around Khao Nan National Park. We use ENFA model to predict parah habitat suitability model and niche characterization of parah tree. In the fourth chapter, we investigated the phenology of the parah tree (*Elateriospermum tapos*) and how climatic data effecting on budburst and flower bloom of this tree. In the final chapter, we summarized and concluded our findings.

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# Chapter 2

# Assessing Habitat-Suitability Models with a Virtual Species at Khao Nan National Park, Thailand

## Publication

Srisang, W., Jaroensutasinee, K. and Jaroensutasinee, M. (2007). Assessing Habitat-Suitability Models with a Virtual Species at Khao Nan National Park, Thailand. *Enformatika Transactions on Engineering, Computing and Technology*, 19, 340-345.

## Abstract

This study examined a habitat-suitability assessment method namely the Ecological Niche Factor Analysis (ENFA). A virtual species was created and then dispatched in a geographic information system model of a real landscape in three historic scenarios: (1) spreading, (2) equilibrium, and (3) overabundance. In each scenario, the virtual species was sampled and these simulated data sets were used as inputs for the ENFA to reconstruct the habitat suitability model. The 'equilibrium' scenario gives the highest quantity and quality among three scenarios. ENFA was sensitive to the distribution scenarios but not sensitive to sample sizes. The use of a virtual species proved to be a very efficient method, allowing one to fully control the quality of the input data as well as to accurately evaluate the predictive power of the analyses.

## Introduction

Prediction of species distribution is an important element of conservation biology. Management for endangered species (Palma et al., 1999; Sanchez-Zapata & Calvo, 1999), ecosystem restoration (Mladenoff et al., 1997), species re-introductions (Breitenmoser et al., 1999), population viability analyses (Akçakaya et al., 1995; Akçakaya and Atwood, 1997), and human-wildlife conflicts (Le Lay et al., 2001) often rely on habitat-suitability modeling. Multivariate models are commonly used to define habitat suitability and combined with geographical information systems (GIS), allowing one to create potential distribution maps (Guisan & Zimmermann, 2000). Numerous multivariate analyses are developed for building habitat suitability or abundance models in the past decade (Lek et al., 1996; Manel et al., 1999; Özesmi and Özesmi, 1999).

Ecological niche factor analysis (ENFA) (Hirzel et al., 2002) is a heuristic modeling approach recently developed to predict potential species distribution from presence-only data. This approach, based on Hutchinson ecological niche theory (Hutchinson, 1957), creates habitat suitability maps that indirectly reveal potential species distribution (Hausser, 1995; Hirzel et al., 2002). ENFA is originally created to predict fauna distributions that are especially susceptible to erroneous or 'false' absences due to an animal's ability to disperse or hide during field surveys. Hirzel et al. (2002) suggest that inclusion of these types of 'false' absences in predictive modeling could substantially bias analysis. Therefore, ENFA is an alternative approach to model potential species distributions when there is no reliable absence data. Even though this approach does not incorporate species absence data, ENFA has potential for predicting plant species distributions from presence-only data sets.

ENFA compares the eco-geographical predictor distribution with a presence data set consisting of locations where the species had been detected with the predictor distribution of the whole area. Like the Principal Component Analysis, ENFA summarizes all predictors into a few uncorrelated factors retaining most of the information. But in this case, these factors have ecological meanings. The first factor is the 'marginality', and reflects the direction in which the species niche mostly differs from the available conditions in the global area. Subsequent factors represent the 'specialization'. They are extracted successively by computing the direction that maximizes the ratio of the variance of the global distribution to that of the species distribution. A large part of the information is accounted for by the first few factors. The species distribution base on these factors is used to compute a habitat suitability index for any set of descriptor values (Hirzel et al., 2002).

Modeling with ENFA is usually done by using the software *Biomapper* (Hirzel et al., 2002; Hirzel, 2004; Chefaoui et al., 2005). In this study, we rewrote the ENFA program with *Mathematica* (Wolfram, 2003), which is a mathematical and statistical package with visualization tools. We tested our ENFA program with virtual species data and real eco-geographical and climatic data at Khao Nan National Park, Southern Thailand.

## Mathematical Procedures of ENFA

Eco-geographical and climatic parameters are first normalized through the Box-Cox transformation (Sokal & Rohlf, 1981). Though multi-normality is theoretically needed for factor extraction through eigensystem computation (Legendre & Legendre, 1998), this method seems quite robust to deviate from normality (Glass and Hopkins, 1984). The parameters are then standardized by retrieving means and dividing by standard deviations:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{\sigma_{x_j}}$$

where $x_{ij}$ is the value of the variable $x_j$ in cell $i$, $\bar{x}_j$ is the mean of this variable over all cells, and $\sigma_{xj}$ is its standard deviation. Let $Z$ be the $N \times V$ matrix of standardized measurements $z_{ij}$. The $V \times V$ covariance matrix among standardized variables is then computed as

$$R_G = \frac{1}{N} Z^T Z$$

where $Z^T$ is the transposed matrix of $Z$. Because of standardization, $R_G$ is also a correlation matrix.

The $N_S$ lines of $Z$ corresponding to the $N_S$ cells where the focal species detected are then stored in a new $N_S \times V$ matrix (say $S$), from which the $V \times V$ species covariance matrix is calculated:

$$R_S = \frac{1}{N_S - 1} S^T S$$

Let $u$ be a normed vector of the eco-geographical and climatic spaces. The variance of the global distribution on this vector is $u^T R_G u$, while that of the species distribution is $u^T R_S u$. The first specialization factor should thus maximize the ratio $\Theta(u) = u^T R_G u / u^T R_S u$. However, this vector must also be orthogonal to the marginality factor $m$, given that the vector of means over $V$ columns of $S$:

$$m = \left\{ \frac{1}{N_S} \sum_{i=1}^{N_S} z_{ij} \right\}$$

The problem, therefore, becomes that of finding the vector $u$ that maximizes $\Theta(u)$ under the constraint $m^T u = 0$. This is equivalent to finding $u$, such that

$$\begin{cases} u^T R_S u = 1 \\ u^T m = 0 \\ u^T R_G u \ max \end{cases}$$

A change in variables allows us to rewrite the problem

$$\begin{cases} v^T v = 1 \\ v^T y = 0 \\ v^T W v \ max \end{cases}$$

where $v = R_s^{1/2} u, y = z / \sqrt{z^T z}$, and $z = R_s^{-1/2} m$, $W = R_s^{-1/2} R_G \ R_s^{-1/2}$ is a symmetric matrix. It can be shown that the solution is given by the first eigenvector of

$$H = (I_v - yy^T)W(I_v - yy^T)$$

where $I_v$ is a $V \times V$ identity matrix.

Indeed,

1) $y$ is an eigenvector of $H$ because $Hy = (I_v\text{-}yy^T)W(I_v\text{-}yy^T) = 0$;

2) $H$ is symmetrical and thus admits a base of orthonormed eigenvectors so that $Hv = \lambda v \Rightarrow v^T y = 0$; and,

3) $v^T Hv$ is maximum for the first eigenvector, which also maximizes $v^T Wv$ since $v^T y = 0 \Rightarrow v^T Hv = v^T (I_v\text{-}yy^T)W(I_v\text{-}yy^T)v = v^T Wv$

The $V$ eigenvectors of $H$ are then back transformed, and the new eigenvectors ($u = R_s^{-\frac{1}{2}}v$) are stored in a matrix $U$. These vectors are $R_s$-orthogonal (all $Su$ distributions have variance 1 and are uncorrelated). Furthermore, due to the constraint that $u$ be orthogonal to $m$, this system has one null eigenvalue. The corresponding eigenvector is thus deleted from $U$, and $m$ is substituted instead as the first column. It should be noted that, although all marginality is accounted for by the first factor, this factor is not ''pure,'' in that the niche of the focal species may also display some restriction on it, in addition to its departure from the mean. 'Marginality' ($m$) and 'specialization' ($U$) factors from this computation will be used to transform species distributions from an $N \times V$ matrix to an ecological niche factor value.

The suitability map for the focal species can be computed by building on a count of all cells from the species distribution that lays as far or farther apart from the median than the focal cell on a factor axis. This count is normalized in such a way that the suitability index ranges from zero to one. Practically, this is performed by dividing the species range on each selected factor into a series of classes, in such a way that the median would exactly separate into two classes (Figure 1). For every cell from the global distribution, we count the number of cells from the species distribution that are either in the same class or in any class farther apart from the median on the same side (Figure 1). Normalization is achieved by dividing twice this number by the total number of cells in the species distribution. Thus, a cell laying in one of the two classes directly adjacent to the median would score one, and a cell laying outside the species distribution would score zero.

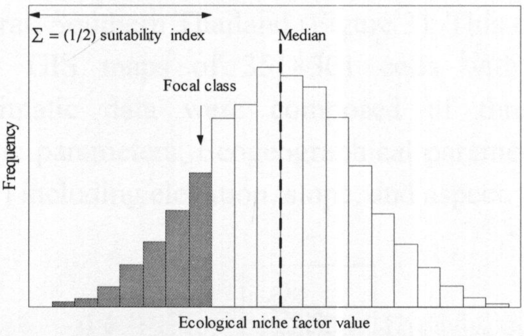


**Figure 1** **The suitability of any cell from the global distribution is calculated from its situation (arrow) relative to the species distribution (histogram) on all selected niche factors. Specifically, it is calculated as twice the dashed area (the sum of all cells from the species distribution that lies as far or farther from the median dashed vertical line) divided by the total number of cells from the species distribution (surface of the histogram).**

# Methods

This study generated a virtual species completely characterized by its ecological niche, which would be modeled by a 'true' habitat suitability map. Three data sets were then generated to simulate three different scenarios. These data sets, in conjunction with environmental variables, were fed into the ENFA analysis, which produced 'predicted' habitat suitability maps. Finally, resulting models were evaluated by statistically comparing each 'predicted' map with the 'true' map. These steps (Figure 2) will now be developed in full detail.

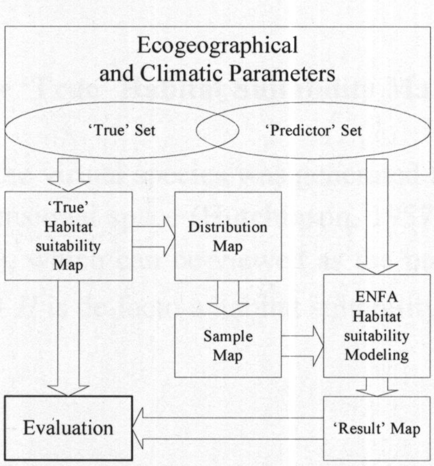


**Figure 2 Flow chart summarizing the steps involved in the study.**

## Ecogeographical and Climatic Parameters

Although a virtual species is used, ecogeographical and climatic data were collected from a rectangular region of 35.1×30.1 km$^2$ located in Khao Nan National

Park, Nakhon Si Thammarat, Southern Thailand (Figure 3). This rectangular region is numerically modeled by GIS maps of 351×301 cells with 0.1×0.1 $km^2$/cell. Ecogeographical and climatic data were composed of three ecogeographical parameters and six climatic parameters. Ecogeographical parameters were computed from military maps (DEM) including elevation, slope, and aspect.

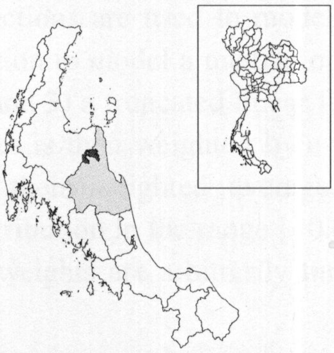


**Figure 3 Study area (35.1×30.1 $km^2$) at Khao Nan National Park (dark gray area), Nakhon Si Thammarat province, Thailand.**

We collected climatic data from eight study sites around Khao Nan National Park from April-May 2006 and uploaded this data to the Thailand National Biodiversity Database System (NBIDS) (NBIDS, 2006). These climatic parameters were composed of solar noon temperature, maximum temperature, minimum temperature, relative humidity, %cloud cover, and the amount of rainfall. The climatic data were then interpolated using invert distance weighted methods to generate our study area.

## Virtual Ecological Niche: the 'True' Habitat Suitability Map

On this spatial canvas, the virtual species was generated by creating a simulated ecological niche in an *n*-dimensional space (Hutchinson, 1957). It was modeled by a niche coefficient $H$ ($H \in [0,1]$), which can be viewed as the probability that each cell belongs to the niche; note that $H$ is de facto a habitat suitability index. This value was built as summarized in (8).

$$H = \frac{1}{\sum w_i} \sum w_i H_i + \varepsilon$$

where $H$ is the habitat suitability of the focal cell, $H_i$ is the value of the $i^{th}$ partial niche coefficient, $w_i$ is the weight assigned to the $i^{th}$ partial niche coefficient, and $\varepsilon$ is a random value.

Global habitat suitability is composed of a weighted average of partial niche coefficients ($H_i$) and a stochastic coefficient ($\varepsilon$). The partial niche coefficients are the habitat suitability engendered by each predictor value. They are computed from four predictors that are picked out of the nine available predictors by four niche functions (i.e. elevation with Gaussian function, aspect with Gaussian function, the amount of rainfall with truncated linear, and minimum air temperature with decreasing linear function). Three types of functions are used to model three types of environmental optimum: 1) a Gaussian function to model a median optimum, 2) a linear function to model an extreme optimum, and 3) a truncated linear function to model a buffer zone effect. Each of these $H_i$ values is then weighted by a $w_i$ factor and the global niche coefficient is calculated as their weighted average. Finally, a random term $\varepsilon$, generated from a uniform distribution in the range $[-0.05, 0.05]$, is added. The niche-function parameters and the weights are arbitrarily tuned in order to generate about 50% of cells with $H \geq 0.5$.

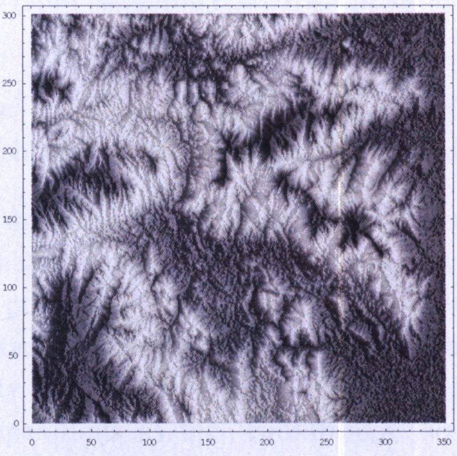


**Figure 4 The 'true' habitat suitability map generated to model the ecological niche of the virtual species. High suitability areas are indicated by white pixels.**

This produces the 'true' habitat suitability map (Figure 4), representing the 'real' intrinsic preferences of our virtual species. By 'true' map, we mean that it represents the kind of information usually unreachable by ecologists, the information they are trying to reveal through field sampling and statistical analysis. The 'true' map will be constantly used as a basis to generate data and as a reference to assess the accuracy of habitat suitability analyses.

## Distribution Map

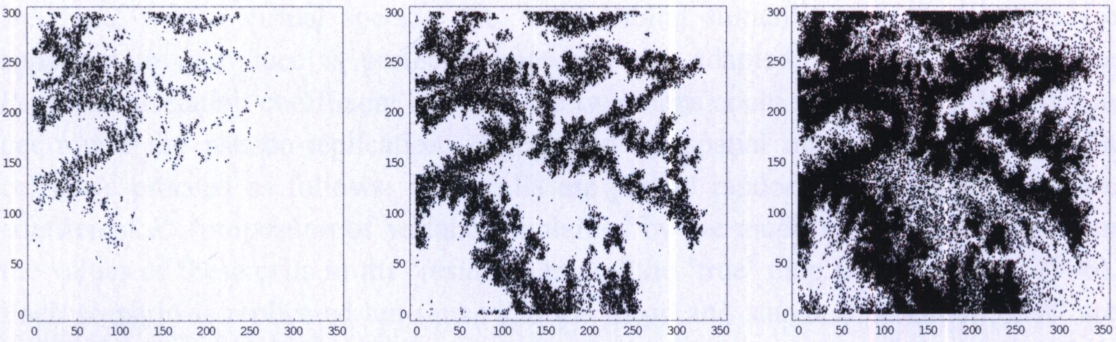
Distribution maps are computed on the basis of the 'true' map, the distribution maps give the 'true' presence/absence of the virtual species, information usually unavailable to field ecologists. Three distribution scenarios are addressed in order to determine the advantages and drawbacks of each habitat suitability analysis. They can be viewed as three historical phases of colonization—the fundamental niche does not change but the realized one does: 1) a 'spreading phase' showing a density gradient from the north-west corner of the map to the south-east corner, 2) an 'equilibrium phase' where the species are abundant enough to occupy all the available suitable areas, and 3) an 'overabundance phase' where the species are so numerous that it has to spread in less suitable areas (Figure 5).

The 'equilibrium' distribution map is computed as follows. To each cell of the 'true' habitat suitability map is added a random value taken in the range [−0.2, 0.2] (uniform distribution); this is made in order to introduce some stochasticity into the model. If the resulting habitat suitability coefficient is larger than 0.7, the cell is marked as occupied.

The 'overabundance' distribution map is computed in a similar way but with a 0.5 habitat suitability threshold to simulate the overflowing density.

The 'spreading' distribution needs an additional operation: each cell of the 'true' habitat suitability map is beforehand multiplied by a value decreasing in $1/d^2$, $d$ being the distance to a point arbitrarily placed north-westward to south-eastward corner of the map. This gradient function is tuned to produce values ranging from 0 to 1, 0.5 lying approximately in the middle of the map. This new gradient map is then submitted to the same operations as the 'equilibrium' scenario (habitat suitability threshold = 0.7).

This generating method allow us obtain distribution maps with a presence density correlated with area suitability.



(a) (b) (c)

**Figure 5** **Distribution maps of the virtual species for three colonization scenarios. Black points are the cells where the species are present and the white ones are those where the species are absent. Map (a) represents the 'spreading' scenario: the species entered the area from the northwest and is currently propagating in all directions, settling down in the most suitable areas. Map (b) represents the 'equilibrium' scenario in which the species occupies uniformly all the suitable areas. Map (c) represents the 'overabundance' scenario in which very high densities force the species to occupy less adequate areas.**

### Sample Maps

These distribution maps are then used to simulate 'field' sampling data usually resulting from the trapping, detecting or observation activities of field biologists. Since ENFA needs only presence data, ENFA data sets are generated by randomly sampling points in the distribution maps in order to obtain the targeted sample size.

### Result Habitat Suitability Maps

The simulated data sets are then submitted as dependent variables to the ENFA. The independent variables are a set of five predictors out of the nine available; four of them are arbitrarily taken among those used to generate the 'true' habitat suitability map and other is new. In order to evaluate quality and quantity of the three scenarios, sampling sizes of 250 to 5000 points are simulated ten times for all scenarios and analyses, except for the spreading scenario in which only 250 to 4000 points are simulated. This is because the spreading scenario has only 4000 occupied cells and therefore, it is impossible to get more than 4000 points sample size in this case

### Evaluation

The accuracy of the 'result' habitat suitability maps has finally to be assessed. With a real species, we would have used independent evaluation data and calculated various statistics to assess the accuracy of the classification (Fielding and Bell, 1997).

But here, with a virtual species, the 'true' habitat suitability that the models are supposed to reproduce is perfectly known. More adapted statistics based on the Pearson correlation coefficient between the two maps could thus be used. In order to get round the pseudo-replication, engendered by spatial auto-correlation between cells, we proceed as follows: 1000 cells are picked randomly and a determination coefficient $R^2$ (proportion of variance explained by the model) is computed between the values of these cells in the 'result' map and the 'true' map (Mesplé et al., 1996). Each scenario is replicated ten times and the mean and standard deviation of $R^2$ are computed. The mean $R^2$ ($<R^2>$) is used to assess the accuracy of the models. Their sensitivities to distribution scenario and sample size are also assessed with a Student *t*-test for each method. In order to compare results, two sampling sizes are addressed: 500 and 2000 points for all scenarios and analyses.

## Results and Discussions

$<R^2>$±S.D. of 'spreading', 'equilibrium', and 'overabundance' of 500 points scenarios are similar to 2000 points scenarios (Table 1). This result confirms the previous work of Hirzel et al. (2001). They showed that $<R^2>$ of 'spreading', 'equilibrium', and 'overabundance' of 300 and 1200 points scenarios were ranging from 0.55-0.60 with the SD of 0.03-0.05. Due to the stochasticity added in the process of building the 'true' habitat suitability map, it is impossible to obtain $R^2 = 1$. The best model would have been the map computed just before the addition of stochasticity and this one gives the maximum $R^2 = 0.59$. The 'equilibrium' scenario had the highest $<R^2>$ among three scenarios; there were no differences among 16 sample sizes and no interaction term between scenario and sample size (Two-way ANOVA: scenarios: $F_{2, 432} = 133.262$, $P<0.001$; sample size: $F_{15, 432} = 1.469$, NS; scenario x sample size interaction: $F_{30, 432} = 1.337$, NS, Figure 6). The 'equilibrium' scenario had the fewest S.D. among three scenarios (One-way ANOVA: $F_{2, 45} = 15.780$, $P<0.001$) and post-Hoc tests showed that the S.D. of the 'equilibrium' scenario was lower than both the 'spreading' scenario ($P<0.01$, Figure 6) and the 'overabundance' scenario ($P<0.001$, Figure 6). Our results suggest that the 'equilibrium' scenario had the highest quantity and quality among the three scenarios. Our results also indicate that ENFA was sensitive to the distribution scenarios but not sensitive to sample sizes (Table 2, Figure 6). The reason that the 'overabundance' scenario was not the best scenario was because most individuals in this species tend to occupy a low suitability area. This might lead to a low $R^2$. The 'Spreading' scenario was not the best scenario because if a species starts spreading from an area that has other uncorrelated parameters, then the 'spreading' scenario may interpret these uncorrelated parameters as essential parameters. Therefore, this also could cause a low $R^2$.

**Table 1 $\langle R^2 \rangle$and (S.D.) of the proportion of explained variance obtained by comparing 'result' map with 'true' map (The greater the value of $\langle R^2 \rangle$ shows the higher the predictive power of the 'result' map.)**

| Scenarios | $\langle R^2 \rangle$ | S.D. |
|---|---|---|
| Spreading, 500 points | 0.47 | 0.04 |
| Equilibrium, 500 points | 0.53 | 0.03 |
| Overabundance, 500 points | 0.46 | 0.05 |
| Spreading, 2000 points | 0.47 | 0.04 |
| Equilibrium, 2000 points | 0.55 | 0.02 |
| Overabundance, 2000 points | 0.49 | 0.03 |

**Table 2 Sensitivity analyses of the methods**

| | Spreading, 500 points | Equilibrium, 500 points | Overabundance, 500 points | Spreading, 2000 points | Equilibrium, 2000 points |
|---|---|---|---|---|---|
| Equilibrium, 500 points | * | | | | |
| Overabundance, 500 points | NS(0.67) | * | | | |
| Spreading, 2000 points | NS(0.95) | * | NS(0.62) | | |
| Equilibrium, 2000 points | ** | NS(0.07) | ** | ** | |
| Overabundance, 2000 points | NS(0.26) | * | NS(0.16) | NS(0.28) | ** |

**Significant results: NS non Significant, *$P<0.01$, ** $P<0.001$**

Our results suggest that 1) ENFA will be most suitable to model plants or native species that occur in an area for sometimes and might reach their equilibrium stage, 2) ENFA might not be the best model for invasive species and 3) since ENFA was not affected by the number of sample sizes in all three scenarios; therefore, ENFA may be suitable to model habitat-suitability for rare species.

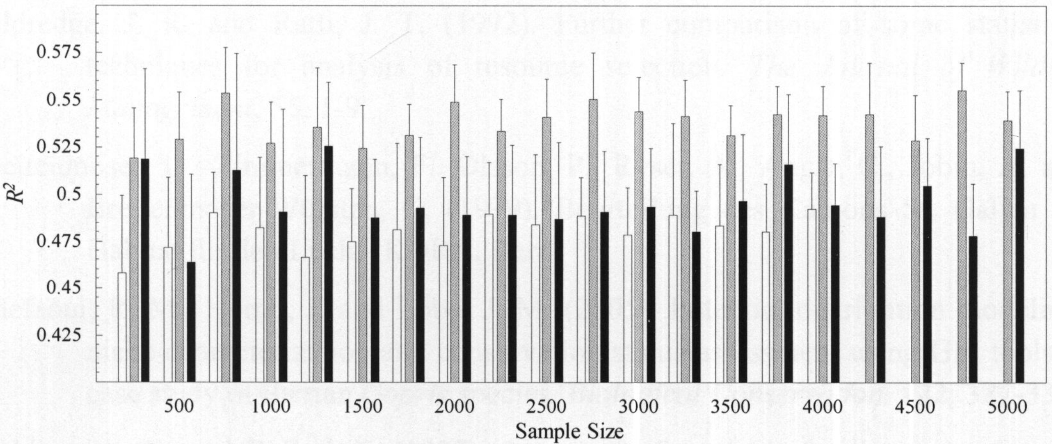


**Figure 6** **$<R^2>$±S.D. of three scenarios 'spreading' (white), 'equilibrium' (gray), and 'overabundance' (black).**

The virtual species approach proved to be the most serviceable. When comparing models on a real data basis, it is only possible to make assumptions about what is the true habitat suitability by using various expert and statistical evaluation methods. Many factors are out of reach and may introduce a bias that cannot be accurately assessed (Alldredge and Ratti, 1992; Manel et al., 1999; Guisan and Zimmermann, 2000; Hirzel et al., 2001). Therefore, real data are only a snapshot of a dynamical situation and can only give a partial and instantaneous comprehension of the fundamental ecological niche. By generating a virtual species, the 'true' is now completely reachable and resulting models can be accurately compared to it.

## Acknowledgments

We thank Assoc. Prof. Dr. David Harding, Mr. Anun Charoensuk, Mr. Pattanabhorn Rintachak, and Khao Nan National Park rangers for kindly help. This work was supported in part by PTT Pubic Company Limited, the TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT T_549002, Complex System research unit, the Institute of Research and Development, Walailak University, and DPST project, IPST, Thailand.

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# Chapter 3

# Potential distribution modeling, niche characterization using Geocomputing: A case study of *Elateriospermum tapos* Bl. (Euphorbiaceae) in Southern Thailand

## Abstract

In this study, we investigated the species distribution modeling of parah tree *Elateriospermum tapos* Bl. (Euphorbiaceae) in Southern Thailand rain forest. We studied parah tree distribution at Khao Nan National Park by field survey to get its distribution and status. We combined a helicopter observation with survey data to generate species distribution data for modeling. We used the ENFA model to predict species distribution model to examine parah niche characterization. Mean±SD of parah density around Khao Nan National Park were 0.0370±0.0114 plant/$m^2$ at Ban Najao, 0.0256±0.0114 plant/$m^2$ at Ban Hukphu, 0.0244±0.0194 plant/$m^2$ at Sunanta, and 0.0233±0.0114 plant/$m^2$ at Hui Lek. Mean±SD of DBH around Khao Nan National Park were 25.0±21.2 cm at Hui Lek, 28.8±21.0 cm at Ban Hukphu, 18.3±16.2 cm at Sunanta, and 25.5±18.1 cm at Ban Najao. The results from the model showed that parah trees preferred low elevation areas on the west side of the hill.

## Introduction

Biogeographical and conservation studies usually need species distribution modeling for pinpointing the areas where appropriate environmental conditions exist to sustain species. Species distribution modeling relates species records with a set of variables, building a mathematical function that can be interpolated or extrapolated to areas with absence of information on the focus species (Guisan & Zimmermann 2000). It allows identifying environmentally suitable regions still not colonized, or where the species has become extinct; then the contribution of unique historical or geographical factors to the shaping of the current distribution of a species can be judged. With regard to conservation, potential distribution area identification can help locate sites suitable for reintroduction programs, or faunistic corridors, favoring success in regional conservation planning. Species distribution modelings are being increasingly used in solving a variety of problems (see Peterson, 2006 for a review). They can be used to define the environmental adaptations of species (e.g. Chefaoui et al. 2005, the 'Grinnellian niche' according to Soberón, 2007), to locate new populations of rare and/or endangered taxa (e.g. Bourg et al., 2005; Peterson & Papeş, 2006; Jiménez-Valverde & Lobo, 2007) or to identify areas with the environmental requirements of the focus species where to direct future survey efforts (Raxworthy et al., 2003). Other uses in conservation include highlighting areas for translocations and application for reserve system design (Peterson, 2006).

In this study, we investigated the species distribution modeling of parah tree *Elateriospermum tapos* Bl. (Euphorbiaceae) in Southern Thailand rain forest. parah *(Elateriospermum tapos)* is the only plant in monotypic genus. It is native to Thailand, Malaysia, and Sumatra Island. parah trees were found at Jengka national forest in Malaysia (Osada et al., 2003), Belalong forest in Brunei (Cranbrook & Edwards, 1994) and Khao Nan National Park in Thailand (Chumkiew et al., 2007). parah trees at Khao Nan National Park tend to cluster in only some areas not spreading out around Khao Nan National Park. This indicates that parah trees might require some specific niche characteristics. This study examined the parah species distribution at Khao Nan National park. We combined helicopter observation with survey data to generate species distribution data for modeling. We used ENFA model to predict species distribution model to examine parah niche characterization.

## Materials and Methods

### Study Site

Khao Nan was located at 8° 22'- 8° 45' N, 99° 37'- 99° 51'E, southern Thailand (Figure 7a). The Park consists of complicated mountain range along the north and the south. The park was a part of Nakhon Si Thammarat Mountain Range. The altitude of the area was about 50 m to 1400 m above sea level; climate and forest type varied with elevations. From 0 m to about 1000 m there are tropical rainforest; above 1000 m there were cloud forest.

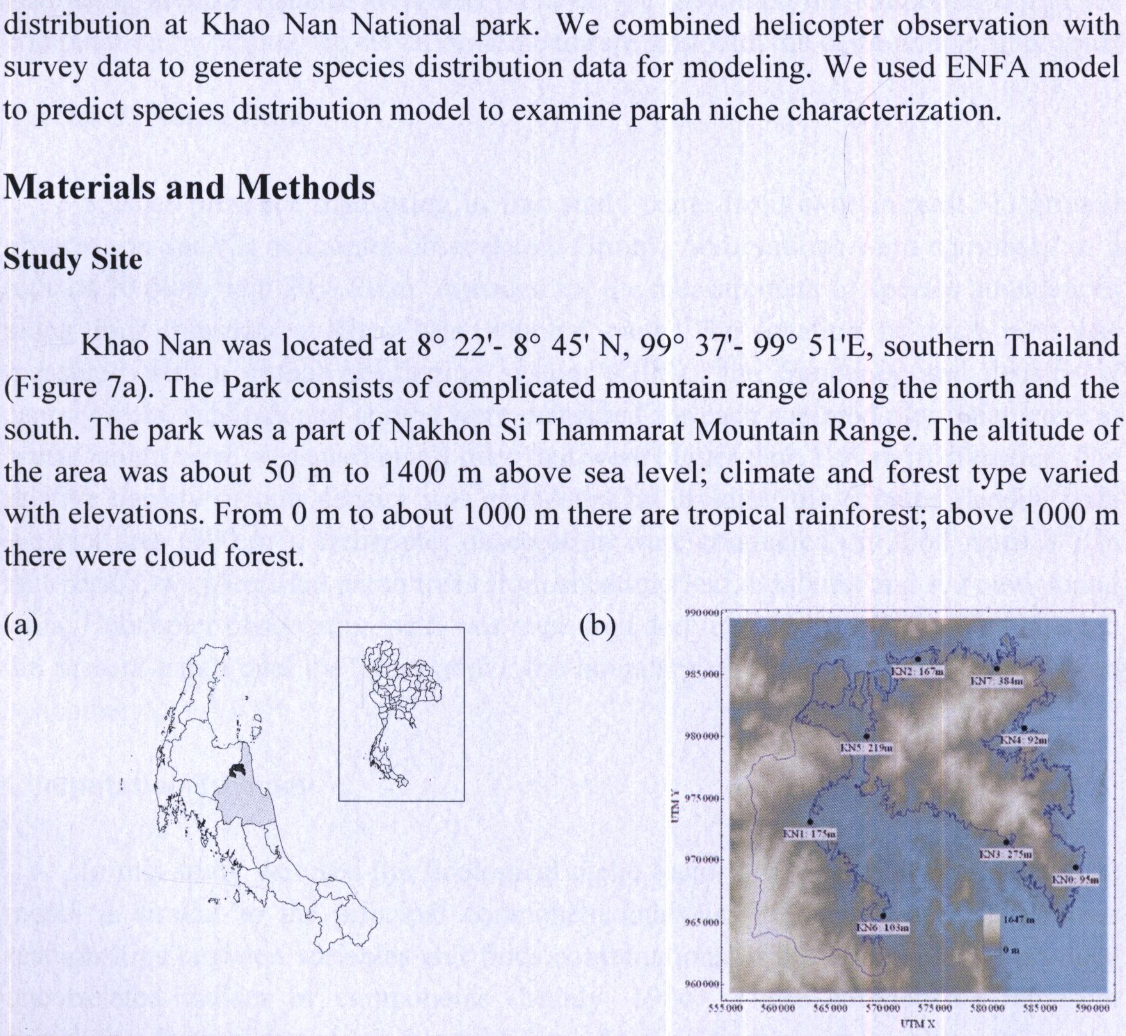

**Figure 7 (a) Khao Nan National Park Map and (b) eight park ranger stations**

## Geographical and Climatic Data

We used Digital Elevation Model (DEM) grid from Thailand military department to generate geological variable grid (e.g., elevation, slope, SD of elevation, Northness, and Eastness). We installed eight HOBO Pro V2 Temperature/RH Data logger at eigth park ranger stations around Khao Nan National Park (Figure 7b). All sensors were put in instrument shelter 150 cm above ground. Data were collected every 5 minutes since September 2007. We calculated the mean monthly temperature of each station. We used those means to generate temperature grid as a variable for the model. We calculated the linear regression model between elevations of stations and mean temperature of each stations. We applied the regression model to all grids to generate the elevation-temperature grid. We used the difference between actual temperature and modeled temperature of each station to generate delta-temperature grid (i.e., grid of temperature differences between the linear regression model and the measured data). We generated the delta-temperature grid using inverse distance weighted method. We generated the temperature grid for computation by adding the elevation-temperature grid with the delta-temperature grid.

## Species Presence Data

Species presence data using in this study came from two sources: (1) ground observation and (2) helicopter observation. Ground observations were composed of a total of 20 plots with $20 \times 20$ m$^2$ intended for the measurement of species abundances along four transects a Khao Nan national park. The location of each plot was measured with a global positioning system (GPS). The frequency and density of canopy trees, saplings and shrubs were measured for each sampled plot. Diameters at breast height were measured on all trees that were bigger than 1.5 cm in diameter. The relative density or unit density was calculated by dividing the counted density with the plot area (400 m$^2$). Helicopter observation were conducted on 2008 April 8$^{th}$. In that period, we identified parah trees from shedding leaf, budburst and red new young leafs. Helicopter observation path was measured and tracked by a GPS. We collected the present parah data by flying above the boundary of parah cluster observed from helicopter.

## Computational Model

In this study we used the Ecological niche factor analysis (ENFA) model. The model is similar to the principal component analysis (PCA) in that it determines relationships between variables and finds combinations of these variables to produce uncorrelated indices or components (Manly, 1986). These components represent composite factors that explain variability. In ENFA, however, unlike PCA, the components have direct ecological meaning. The first component is defined as the 'marginality' of the species' niche, which describes the mean of the species distribution in relation to the mean of the global (study) distribution. It is defined as 'the absolute difference between the global mean and the species mean' for each environmental variable (Hirzel et al., 2002) and is calculated as:

$$m_i = \frac{|m_{G_i} - m_{S_i}|}{1.96\sigma_{G_i}}$$

where $m_i$ is the marginality for a particular environmental variable, $m_{G_i}$ is the global mean of the variable, $m_{S_i}$ is the mean of the variable in species' range and $\sigma_{G_i}$ is the standard deviation of the global distribution for the variable. The first component in ENFA is chosen to account for 100% of the marginality of the species, as well as some proportion of specialization, with the remaining components maximizing the remaining amount of specialization of the species (Hirzel, 2001).

The remaining components explain progressively decreasing amounts of the 'niche specialization' of the species. Specialization indicates how restricted the species' niche is in relation to the study area and is defined as 'the ratio of variance in the global distribution to that in the species distribution' of the environmental variable (Hirzel et al., 2002; Reutter et al., 2003). It is calculated as:

$$\lambda_i = \frac{\sigma_{G_i}}{\sigma_{S_i}}$$

where $\lambda_i$ is the specialization for a particular environmental variable, $\sigma_{G_i}$ the standard deviation of the variable in the global range and $\sigma_{S_i}$ is the standard deviation of the variable in the species' range. Eigen values associated with specialization components can be larger than the values associated with the marginality values (Hirzel, 2001). The coefficients of each environmental factor indicate the magnitude of variance in HS that they explain. Along the marginality component, the signs of the coefficients indicate whether the suitable habitat is represented by above-average (positive coefficients) or below-average (negative coefficients) values of the environmental variable. The signs of the coefficients are meaningless along the specialization components as the analysis uses absolute values.

Combining the marginality of individual environmental variables, ENFA then computes an overall global marginality (Hirzel et al., 2002; Reutter et al., 2003) as:

$$M = \frac{\sqrt{\sum_{i=1}^{V} m_i^2}}{1.96}$$

where $V$ is the number of environmental variables. $M$ generally ranges between 0 and 1, with large values indicating that the species is not equally represented in all environments. Extreme conditions may force this value higher than 1. It also calculates a global specialization coefficient as:

$$S = \frac{\sqrt{\sum_{i=1}^{V} \lambda_i}}{1.96}$$

*S* ranges from 1 to ∞, with the niche becoming narrower as *S* increases. Tolerance, which is the inverse of specialization, ranges from 0 to 1, with a larger coefficient indicating a wider niche for a particular species (Reutter et al., 2003).

Environmental variable maps were transformed using the Box-Cox transformation, which optimizes the normality of the distributions (Sokal & Rohlf, 1981). Using the median algorithm, ENFA was used to obtain marginality and specialization values, which indicated those environmental parameters with the greatest influence (weight) on the distribution of parah tree. This algorithm assumes that the median value for the environmental variable in the species distribution is approximately the same as in the study area and makes no assumptions based on the density of observation points (Hirzel et al., 2002; Hirzel & Arlettaz, 2003).

### Model Running and Validation

ENFA was done using BIOMAPPER 3.0 software (Hirzel et al., 2002). We used 500×500 m grid size in our analysis. To assess the robustness and the predictive power of a HS model, ENFA uses the novel continuous Boyce index (Hirzel et al., 2006), a threshold independent modification of the Boyce index (Boyce et al., 2002) which measures the relation between the observed and expected number of validation points for different HS values. The continuous Boyce index yields a smooth curve and the Boyce value ranges between 0 and 1 (the closer to 1, the better the model). The maximum value of the Boyce curve (called the F-value) shows how much the model differs from a random model (Hirzel et al., 2006) and the F-value can be used to further discriminate between competing models. By applying a k-fold cross validation, k estimates of the continuous Boyce index are produced, allowing assessment of its central tendency and variance (Hirzel et al., 2006). We use build in function cross validation with Huberty's rule to define the optimal number of cross-validations for our dataset. We ran each model cross validation 10 times and then compare the Boyce's Index for comparing models. We ran model with data for a) a niche characterization of the species b) an assessment of the effect of climate to the model c) a Generation of the specie distribution maps.

# Results

## Species Distribution

Mean±SD of the parah density was 0.0370±0.0114 plant/m$^2$ at Ban Najao, 0.0256±0.0114 plant/m$^2$ at Ban Hukphu, 0.0244±0.0194 plant/m$^2$ at Sunanta, and 0.0233±0.0114 plant/m$^2$ at Hui Lek, respectively (Figure 8). Mean±SD of DBH was 25.0±21.2 cm at Hui Lek, 28.8±21.0 cm at Ban Hukphu, 18.3±16.2 cm at Sunanta, 25.5±18.1 cm at Ban Najao, respectively. The biggest parah tree was found at Hui Lek. With a 142.921 cm in DBH. parah clusters that were found both with the ground observation and Helicopter observation were at Hui Lek, Ban Najao, and Sunanta (Figure 8a-c). A parah cluster that was found only with ground observation was at Ban Hukphu (Figure 8d). We found one cluster of parah tree which had only been observed from helicopter. The cluster was located near Sunanta cluster (Figure 8e).

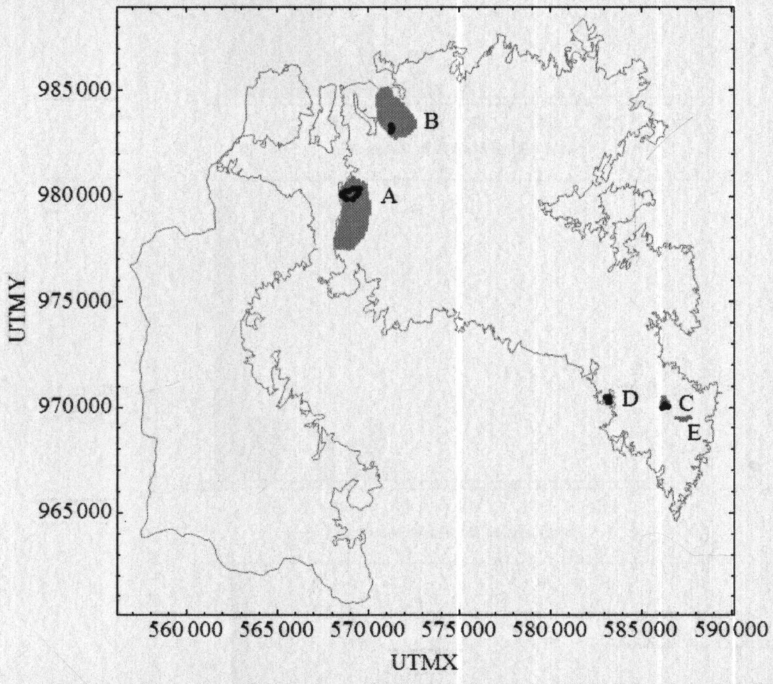

**Figure 8** **parah tree distribution found at Khao Nan, (a) Hui Lek, (b) Ban Najao, (c) Sunanta, (d) Ban Hukphu and (e) unnamed. Gray area showed observation by helicopter. Black points showed field surveys.**

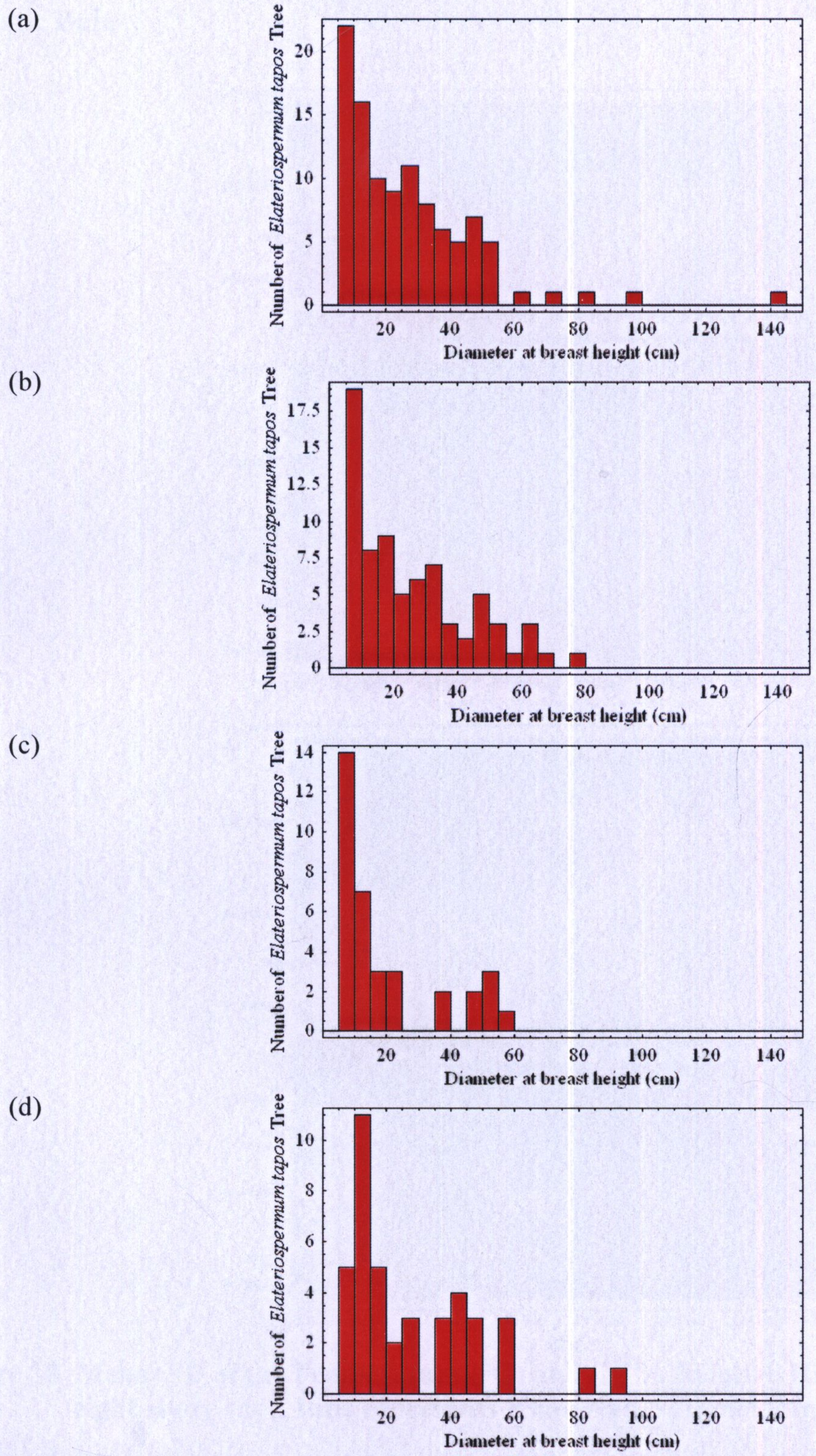

**Figure 9 Size distribution of parah tree at (a) Hui Lek, (b) Ban Najao, (c) Sunanta, and (d) Ban Hukphu.**

**Climatic Data**

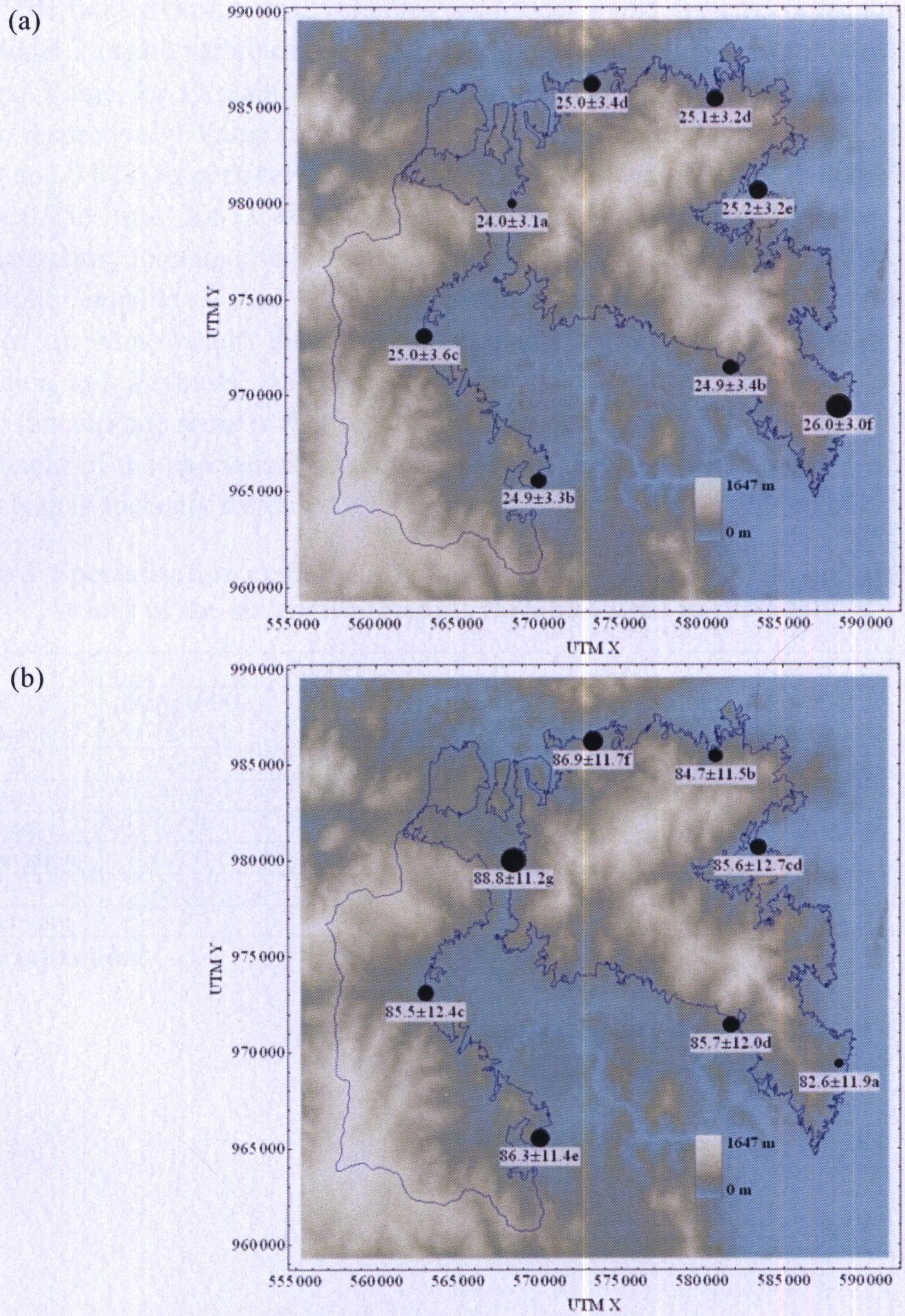

**Figure 10 Mean±SD of (a) Temperature (°C) and (b) % Relative Humidity of eight study sites. Line represents Khao Nan National Park boundary.**

Temperature levels varied at different study sites (one-way ANOVA, $F_{1,811744}$ = 3215.63, $P<0.01$). The percent of Relative humidity were different among different study sites (one-way ANOVA, $F_{1,811744}$ = 2449.15, $P<0.01$). At KN5 Hui Lek where was also the biggest cluster of parah tree was located had the lowest temperature and the highest percent relative humidity.

## Habitat Suitable Map

The five environmental variables for Model 1 and six environmental variables for Model 2 (same variables as model, but temperature added) were reduced to three factors. Value for Explained Information of Model 1 and Model 2 are 0.954 and 0.936, respectively. Value for Explained Specialization of Model 1 and Model 2 are 0.908 and 0.873, respectively. Mean±SD of Boyce index of Model 1 and Model 2 are 0.513±0.256 and 0.6733±0.115, respectively. The high values for Explained Specialization, Explained Information, and the Boyce index indicate that these models are highly reliable (Hirzel et al., 2006). The marginality factor of both analyses showed the same result; the higher coefficients or most important coefficients are Elevation and Eastness. As these coefficients are negative, species was shown to prefer low altitude areas in the west of hill. Elevation and Eastness also has the higher coefficient of the specialization factor, showing that the distribution of parah tree at Khao Nan is specially restricted by this variable too.

**Table 3 Specialization explained by factors extracted by ENFA, and coefficient values of the six environmental variables used in the analysis**

| | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| Eco-geovariable | Marginality (48.4%) | Spec.* 1 (26.5%) | Spec. 2 (15.9%) | Marginality (45.7%) | Spec. 1 (26.1%) | Spec. 2 (15.6%) |
| Eastness | -0.496 | -0.545 | 0.204 | -0.477 | -0.534 | 0.231 |
| Elevation | -0.693 | 0.709 | -0.128 | -0.666 | 0.726 | -0.212 |
| Northness | 0.129 | 0.002 | -0.505 | 0.124 | 0.000 | -0.457 |
| SD Elevation | 0.351 | 0.225 | 0.694 | 0.337 | 0.182 | 0.686 |
| Slope | -0.367 | -0.386 | 0.453 | -0.352 | -0.369 | 0.430 |
| Temperature | - | - | - | 0.277 | 0.134 | -0.194 |

***Specialization**

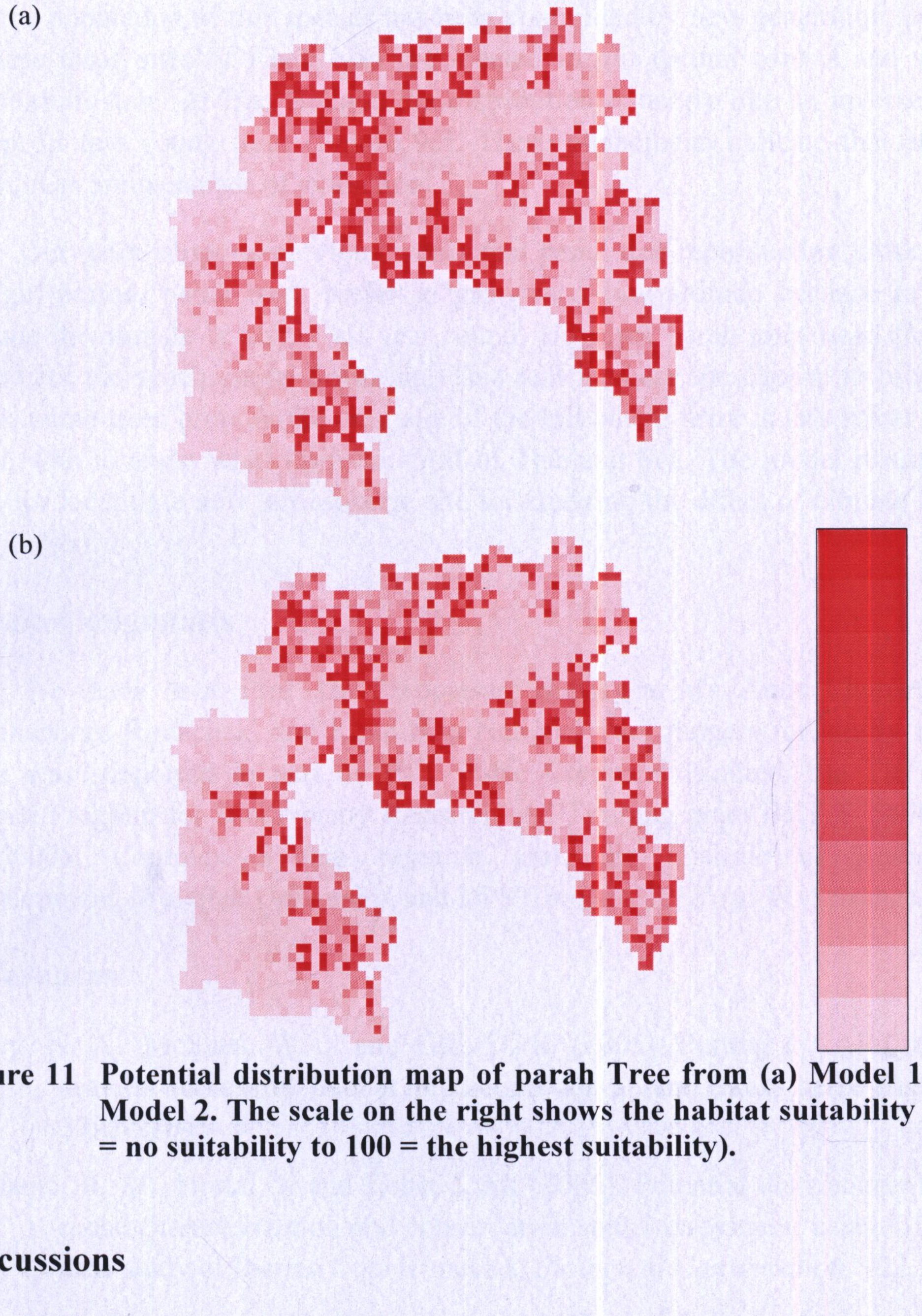

**Figure 11 Potential distribution map of parah Tree from (a) Model 1, and (b) Model 2. The scale on the right shows the habitat suitability values (0 = no suitability to 100 = the highest suitability).**

## Discussions

Helicopter and ground observations led to the same results. These indicate that the helicopter observation method might be a good method for studying parah trees. The helicopter observation did not cover Ban Hukphu forest where parah trees did not shed leafs and produce new leafs during the experiments. Also we were missing it. Those kinds of problem can be solved by expanding more observation time and periods. The advantage of helicopter observations is that we can collect tree cluster boundary in the lush rain forest.

The size distribution of parah tree at Hui Lek, Ban Najao, and Sunanta showed an inverse-J-shaped curve with many young and few old trees (Figure 9a-c). It meant that the population of this species has been commuted by new generation. parah trees at these three sites of Khao Nan are located in old natural forests and still in an equilibrium state. At Ban Hukphu the distribution is nearly like an inverse-J-shaped except in few young trees (Figure 9d). These phenomena indicate that at this site parah trees are in danger of extinction.

Our work supports previous works that parah tree reproduction induced by the drought period. parah trees prefer to grow in a low altitude because in a higher altitude the climate is humid all year round. However parah trees need the drought period for the synchronous flowering. This will increase the chance to produce new fruits. parah trees grow in the west site of the hill where there is less effect from east wind, with is moist wind from the Gulf of Thailand Sea. The model results may be used for locating a new atmospheric site for studying the effect of climate to species distribution.

## Acknowledgments

We thank Asst. Prof. Dr. Pornpatsara Supakorn, Mr. Anun Charoensuk, Mr. Pattanabhorn Rintachak, and Khao Nan National Park rangers for kindly help. This work was supported in part by PTT Pubic Company Limited, the TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT T_549002, BRT T_550005, Complex System research unit, the Institute of Research and Development, Walailak University, and DPST project, IPST (to W. Srisang).

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# Chapter 4

## Budburst and flowering phenology of a canopy species, *Elateriospermum tapos* (Euphorbiaceae), in Thai rain forest: climatic factors as proximate and ultimate causes

### Abstract

This work aims at studying the phenology of the parah tree (*Elateriospermum tapos*) and how climatic data might affect budburst and Flower bloom. We installed the Davis weather station model wireless Vantage Pro II plus at the parah park ranger station. We selected 30 parah trees and marked these parah trees by placing an individual tag on each tree and over a period of 2 years recorded the time that the first buds and the first flowering buds appeared. Discriminant function analysis using Wilks' $\lambda$ for the stepwise selection of the climatic variables was applied to assess the response of budburst to the climatic factors. We developed wind circle visualization for evaluation of the relationship between the wind and other climatic factors and the affect of wind on phenology. In 2007, budburst occurred from 13th February to 24th March with budburst duration of 40 days. Mean±S.D. of number of budbursts at the parah forest was 2.25±2.97 branches/day. Flower bloom occurred from 15th February to 30th March with flower bloom duration of 44 days. The mean number of flower bloom at the parah forest was 2.05±2.81 branches/day. In 2008, budburst and flower bloom occurred at the same time from 2nd January to 31st March with a bud and flower bloom duration of 90 days. The mean number of budburst and flower bloom was 1 branch/day. There were five factors significantly affecting budburst: total east-west wind run; SD of wind speed; minimum temperature; total UV index; and minimum relative humidity. These observations suggest that the wind plays a major role in parah budburst and flower bloom phenology.

### Introduction

Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and annual variations in climate. For plants, phenology studies include vegetative processes such as leaf flushing and shedding, as well as reproductive events such as bud formation, flowering and production of fruit. The timing of many of these events is likely to represent trade-offs between resource availability, pollinator availability and competition, abundant presence of herbivores, suitable conditions for seed germination and establishment, and phylogenetic constraints (e.g. Mosquin, 1971; Johnson, 1992; van Schaik et al., 1993; Murali & Sukumar, 1994; Wright & Calderón, 1995). In temperate regions, which are clearly seasonal, the abiotic factors most likely to affect phenological patterns are temperature and photoperiod (Ratheke & Lacey 1985; Badeck et al. 2004; Molau et al. 2005), but in tropical regions the understanding of the phenology of forest trees is still limited (Bendix et al., 2006). Aspects that have been addressed in this respect are the incidence of rhythmic cycles (Mikich and Silva, 2001), the influence of climatic triggers and day-length as proximate factors, and the intra- and inter-specific synchronization of phenological events (Ims, 1990; Poulin et al., 1999, Borchert et al., 2005), these being ultimate factors that regulate plant life and plant-animal interactions (Frankie et al., 1974; Stiles, 1977, Opler et al., 1980; Wright et al., 1999, Lobo et al., 2003). A study of the complex relationships between plant structures, vegetative development and the incidence of flowering of selected tropical trees has been presented by Borchert (1983).

Many comprehensive studies of reproduction phenology in relation to climate have been performed in tropical lowland rain forests (Frankie et al., 1974; Croat, 1975; Opler et al., 1980; Newstrom et al., 1994; Hamann and Curio, 1999; Sakai et al., 1999; Schöngart et al., 2002; Hamann, 2004) and tropical mountain rain forests (e.g. Koptur et al., 1988; Bendix et al. 2006).

This work presents the reproductive phenology in relation to climate of the special canopy tree called parah (*Elateriospermum tapos* Bl.). This species is interesting because it is a monoecious canopy species that is found in only Southeast Asian tropical rain forests (Whitmore 1972; Ho et al. 1987; Cranbrook & Edwards 1994).). This plant grows in the rainforest but shows amazing phenological behaviour like that of temperate plants as it exchanges its leaves annually (Medway, 1972; Whitmore, 1972; Cranbrook & Edwards, 1994) and shows synchronous budburst and flower bloom.

## Materials and Methods

### Study Site

Khao Nan is located at 8° 22'- 8° 45' N, 99° 37'- 99° 51'E, southern Thailand (Figure 12). The Park consists of a complicated mountain range oriented north and south. The Park is a part of the Nakhon Si Thammarat Mountain Range. Most of the area is productive rainforest which is the main source of the rivers in the area, and the habitat of many kinds of wildlife including valuable flora. parah trees were found growing in large clusters in the lower mountain rain forest at Khao Nan. The largest cluster in the Park was chosen as the study site.

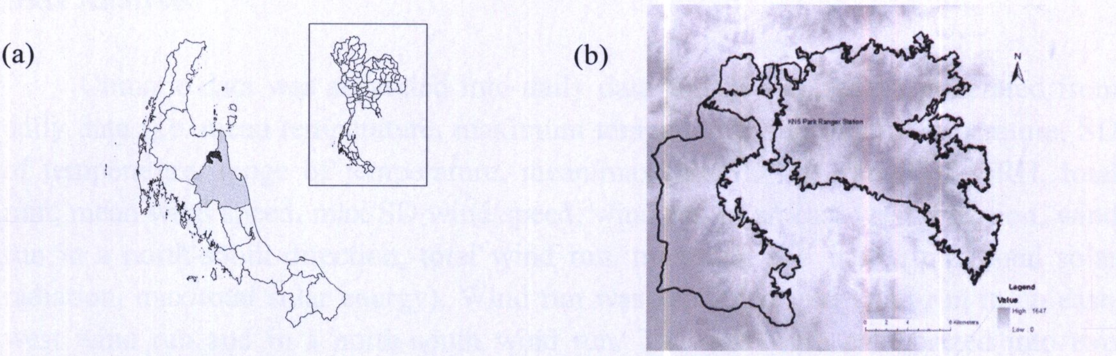

**Figure 12 Khao Nan National Park (a) location on map and (b) the study site; the largest parah forest in this protected area.**

### Phenology Data

For the phenology study, we selected 30 parah trees at the parah park ranger station. We marked these parah trees by placing an individual tag on each tree. We measured each tree the diameter at the base (DAB), the diameter at breast height (DBH), i.e. 130 cm, and tree height. We visited the parah trees once every two weeks until the first tree started to budburst, then visited trees daily, and recorded the time that the first buds and the first flowering buds appeared at the top, the middle and the base of the branches. We recorded the number of fruits produced by each tree by counting the young fruits. We then estimated that these constituted 1% of the fruits for each tree and counted them.

### Climatic Data

We installed the Davis weather station model wireless Vantage Pro II plus at the parah park ranger station (latitude 8.86543 °N and longitude 99.62230 °E, Figure 12) on the 21st November 2006. This weather station recorded the amount of rainfall, temperature, relative humidity, solar radiation, UV, wind speed and wind direction. The data were collected every 30 minutes.

The Navy Operational Global Atmospheric Prediction System (NOGAPS, Rosmond et al., 2002) 1st December 2007-31st August 2008, global coverage, 1° gridded, U and V horizontal wind speed data were compared with the measured wind data. U and V horizontal wind data was obtained at the study site by interpolation. U and V were combined to give wind vectors from 1°-360°. Wind speed data was transformed to wind run data by multiplying the wind speed by the time interval for each three-hourly reading. We separated the wind vectors for each month into 16 directions (N, E, S, W, NE, NW, SE, SW, NEN, NEE, NWN, NWW, SES, SEE, SWS, SWW) for comparison with the weather station wind directions.

### Data Analysis

Climatic data was separated into daily data and 23 parameters generated from daily data (i.e. mean temperature, maximum temperature, minimum temperature, SD of temperature, range of temperature, mean/max/min/SD and range of %RH, total rain, mean wind speed, max/SD wind speed, wind run in an east-west direction, wind run in a north-south direction, total wind run, max/total UV index, max/total solar radiation, max/total solar energy). Wind run was separated into wind run in an east-west wind run and in a north-south wind run. The data were categorized into two groups: data during budburst and flower bloom occurred and data during no a budburst and flower bloom occurred, the first group being the group of days in which budburst occurred and the second group the other days. Discriminant analysis was performed using the SPSS software package. The data populations were normalized using Z scores to avoid the size effect in the classification. Discriminant function analysis using Wilks' λ for the stepwise selection of the climatic variables was applied to assess the response of budburst to the climatic factors.

### Wind Circle Visualization

We developed wind circle visualization, which showed the relationship between the wind direction and other climatic factors, to better understand the relationship between the wind and other climatic factors and the affect of the wind on phenology. The wind circle visualization was composed of five rings (Figure 14). Each ring had 16 sectors representing the wind in 16 directions (e.g. N, E, S, W, NE, NW, SE, SW, NEN, NEE, NWN, NWW, SES, SEE, SWS, SWW). The upper, bottom, left, and right sectors represented north, south, east, and west directions, respectively. Each sector showed data when the wind blew from a certain direction. The inner red ring showed the NOGAPS Total Wind Run which was computed from the original NOGAPS wind speed data. The outer red ring showed the measured total wind run at the study site. The outer green ring showed the mean % Relative Humidity. The blue ring showed the total amount of rainfall. Data when there was no wind was not shown in the visualization.

## Results

### parah Phenology

parah trees had a mean±S.D. of DAB of 72.21±29.18 cm, DBH of 43.92±14.68 cm, and tree height of 31.03±9.41 m. In 2007, budburst occurred from 13th February to 24th March with a budburst duration of 40 days. Mean±S.D. of number of budburst at the parah forest was 2.25±2.97 branches/day. The maximum number of budbursts/day occurred on 1st March 2007 with a total of 17 branches (Figure 13a). Flower bloom occurred from 15th February to 30th March with a flower bloom duration of 44 days (Figure 13a). The mean number of flower blooms at the parah forest was 2.05±2.81 branches/day (Figure 13a). The maximum number of flower bloom/day occurred on 8th March 2007 with a total of 12 branches (Figure 13a). This indicates that budburst occurred 2 days prior to flower bloom. There were two-day time lags between budburst and flower bloom in the parah trees at parah park ranger station, Khao Nan National Park.

In 2008, budburst and flower bloom occurred at the same time from 2nd January to 31st March with a budburst and flower bloom duration of 90 days (Figure 13a). The mean number of budburst and flower blooms was 1 branch/day (Figure13a). The maximum number of budburst and flower blooms/day occurred on 4th March 2008 with a total of 12 branches (Figure 13a).

In 2007, the mean±S.D. number of fruits per tree was 756±761.87. There were 26 fruiting trees having fruits and 4 trees not having fruits. In 2008, none of the observed trees fruited.

### Climatic Data

The mean±S.D. of temperature climatic factors at the parah forest during budburst and flower bloom from January to March 2007 were 23.51±3.47 °C with a relative humidity of 89.23±13.05 % and a total rainfall of 271.33 mm. From January to March 2008 the figures were 23.48±9.34 °C with a relative humidity of 90.43±9.34 % and a total rainfall of 295.05 mm (Figure 13)

### Climatic Data Affecting parah Phenology

Stepwise discriminant analysis results showed that there were five factors significantly affecting budburst: total east-west wind run; SD of wind speed; minimum temperature; total UV index; and minimum relative humidity. Total east-west wind run was the most important factor because it was the first component added in the model. In the month of budburst (Feb-Mar 2007, Jan -Mar 2008), the wind direction was North West (Figure 14a-c). From first discriminant analysis function, there were 80.8% overall correct classification, 69.9 % correctly classified when budburst occurred and 83.6 % correctly classified when budburst did not occur (Table 4). Second discriminant analysis function was made by removing SD of wind speed which had some correlation to the Total East West wind run. The result of the second analysis showed that there were 78.5% overall correctly classified, 70.7 % correctly classified when budburst occurred and 80.5% correctly classified when budburst did not occur (Table 4).

**Table 4 Summary of Analysis 1 and 2**

| | Analysis 1 | Analysis 2 |
|---|---|---|
| Wilks' lambda | 0.719 | 0.765 |
| Eigen value | 0.390 | 0.308 |
| Canonical Correlation Coefficient | 0.530 | 0.485 |
| Canonical function coefficient | | |
| Minimum Relative Humidity | 0.582 | 0.870 |
| Minimum Temperature | 0.284 | 0.259 |
| SD of Wind Speed | -0.491 | - |
| Total East-West Wind Run | 0.658 | 0.742 |
| Total UV Index | 0.751 | 0.864 |

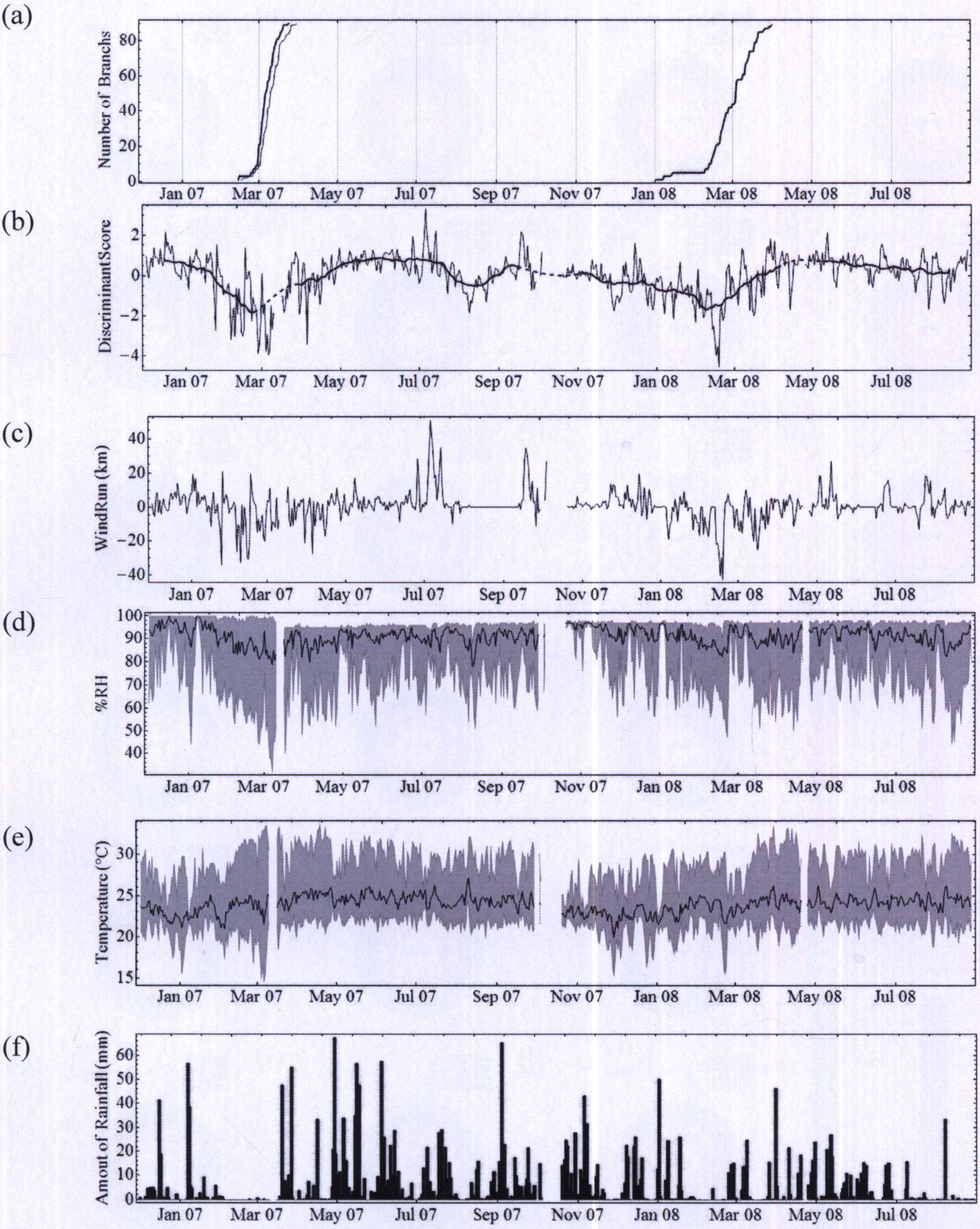

**Figure 13** Time series plot of (a) accumulative budburst (thick line) and accumulative flower bloom (thin line), (b) discriminant scores, (c) East West wind run data, (d) daily mean (solid line) and range (gray area) % relative humidity, (e) daily mean (solid line) and range (gray area) temperature, (f) the amount of daily rainfall.

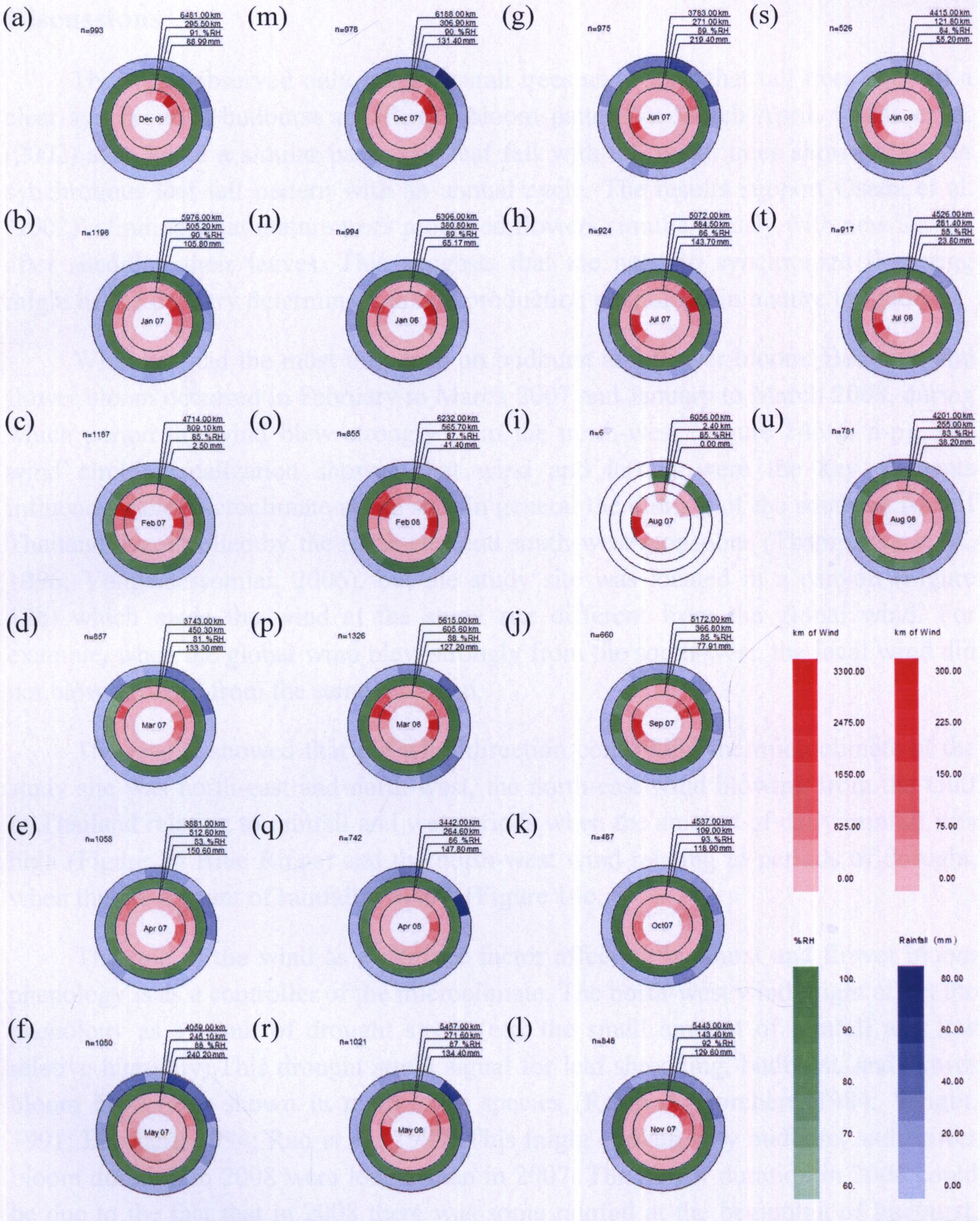

**Figure 14** **Monthly wind circle visualization. Inner red ring shows NOGAPS total wind run, the outer red ring shows total measured wind run, the green ring shows mean %RH, and the blue ring show the total amount of rainfall.**

## Discussions

The study observed only mature parah trees and found that tall trees showed a clear synchronous budburst and flower bloom pattern in March-April. Osada et al. (2002) also found a similar pattern of leaf fall with tall parah trees showing a clear synchronous leaf-fall pattern with an annual cycle. The results support Osada et al. (2002)'s findings that mature trees produced flowers simultaneously with new leaves, after shedding their leaves. This suggests that the need to synchronize flowering might be the primary determinant in leaf production phenology in mature individuals.

Wind run had the most influence on budburst and flower bloom. Budburst and flower bloom occurred in February to March 2007 and January to March 2008, during which period the wind blew strongly from the north-west (Figure 14c-d, n-p). The wind circle visualization showed that wind and terrain were the key elements influencing the microclimate at the site. In general the climate of the southern part of Thailand is controlled by the north-east and south-west monsoons (Thampanya et al., 1996; Vongvisessomjai, 2006), but the study site was located in a canyon (Figure 12b) which made the wind at the study site different from the global wind. For example, when the global wind blew strongly from the south-west, the local wind did not blow strongly from the same direction.

The results showed that the wind direction controlling the microclimate at the study site was north-east and north-west, the north-east wind blowing from the Gulf of Thailand relating to rainfall and wet periods when the amount of daily rainfall was high (Figure 14 Blue Rings) and the north-west wind relating to periods of drought, when the the amount of rainfall was low (Figure 14c, f).

The role of the wind as a climatic factor affecting budburst and flower bloom phenology is as a controller of the microclimate. The north-west wind might affect the phenology as a result of drought stress (e.g. the small amount of rainfall and low relative humidity).This drought stress signal for leaf shredding, budburst, and flower bloom have been shown in many crop species (Reich & Borchert, 1984; Wright, 1991; Borchert, 1994; Rao et al., 1999).This might explain why budburst and flower bloom duration in 2008 were longer than in 2007. The longer duration in 2008 could be due to the fact that in 2008 there was some rainfall at the beginning of budburst, and budburst and flower bloom occurred on only three out of 30 marked branches. This rainfall may have caused 27 marked branches to delay their budburst and flower bloom. This result strongly indicates that climatic factors play a major role in affecting parah phenology in southern and may suggest that parah trees require a drought period as an indicative cue for budburst. Our study found that during budburst and flower bloom in 2007 there was a clear drought period with the total amount of monthly rainfall of 2.75 mm in February. On the other hand, in 2008, the total amount of monthly rainfall was 74.86 mm in February.

## Acknowledgments

We thank Assoc. Prof. Dr. David Harding, Mr. Anun Charoensuk, Mr. Pattanabhorn Rintachak, and Khao Nan National Park rangers for kindly help. This work was supported in part by PTT Pubic Company Limited, the TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT T_549002, BRT T_550005, Complex System research unit, the Institute of Research and Development, Walailak University, and DPST project, IPST (to W. Srisang).

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# Chapter 5

# Conclusions

In chapter 2, we tested the virtual species model with the real eco-geographical variables. Our results suggest that the 'equilibrium' scenario had the highest quantity and quality among the three scenarios. This indicates that ENFA is sensitive to the distribution scenarios but not sensitive to sample sizes. Our results suggest that a) ENFA will be most suitable to model plants or native species that occur in an area for some times and might reach their equilibrium stage, b) ENFA might not be the best model for invasive species and c) since ENFA was not affected by the number of the sample sizes in all three scenarios; therefore, ENFA may be suitable to the model habitat-suitability for other rare species.

In chapter 3, we used ENFA to model species distribution and niche characterization. Marginality factor of both analyses showed the same result in that the higher coefficients are elevation and eastness. As these coefficients are negative species was shown to prefer low altitude areas in west site of hill. Elevation and Eastness have also the higher coefficient of the specialization factor, showing that the distribution of parah tree at Khao Nan is specially restricted by this variable too.

In chapter 4, the results showed that mature parah trees showed a clear synchronous budburst and flower bloom pattern in February-March. There were five factors significantly affecting budburst: total east-west wind run; SD of wind speed; minimum temperature; total UV index; and minimum relative humidity. We concluded the wind plays a major role in budburst and flower bloom phenology. The north-west drought wind might affect the phenology as a result of drought stress (e.g. the small amount of daily rainfall and low relative humidity).

The results from chapter 3 and chapter 4 were concordant that parah tree reproduction was induced by the drought period. parah trees prefer to grow in low altitude. This might be because the weather in higher altitude area is basically moist throughout the year. However, parah trees need the drought period for the synchronous flowering to produce new fruits. In addition, it was found that parah trees are likely to be found more on the west of the hill. This might be because Parh tree are less affected from the east wind from the sea; thus, it may carry more moisture with it

# Appendix

## Field survey of parah tree

# Observation of parah tree at Khao Nan

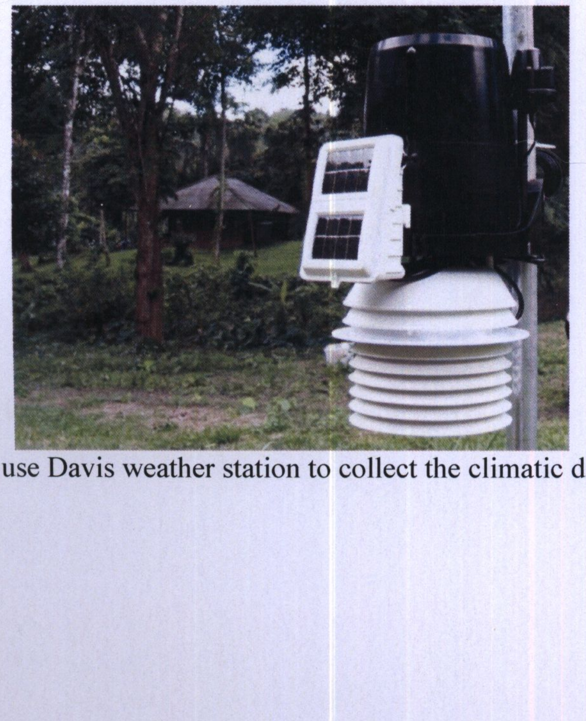
parah forest when parah tree have new Leaf

parah tree
Photographer: Pattanabhorn Rintachak

parah tree at Khao Nan Park ranger station
Photographer: Pattanabhorn Rintachak

parah bud and flower
Photographer: Pattanabhorn Rintachak

parah fruits and seeds
Photographer: Pattanabhorn Rintachak



We use Davis weather station to collect the climatic data.

The first helicopter observation for niche modeling in Thailand

parah Fruits.
Photographer: Pattanabhorn Rintachak

We combined GLOBE Soil protocol to our study.

The study is on going. We marked our parah tree for long term study.

parah trees are conserved for our community and our ecosytem.

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