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Internet-Based Development of Medicinal Plants Geospatial System in Phu Phan Forest Complex: Northeastern Thailand

Rutchanee Chantraket[1,2,*], Pornchai Uttaruk[3], Usa Klinhom[3], David L. Skole[4], Jay H. Samek[4] and Oscar Castaneda[4]

ABSTRACT

This new work developed tools for the management and protection of medicinal plants or herbs in their native habitat in the Phu Phan forest complex, northeastern Thailand. The biological diversity of medical plants was analyzed as well as their distribution and status, and a geoinformatics database was developed including distribution maps to be used for the management of medicinal plants in the Phu Phan forest complex, based on the Local Biodiversity Survey and Data Collection Project conducted by the Ministry of Natural Resources and Environment from July 2006 to January 2009. The 49 permanent sampling plots were established in four provinces. The survey data were used to develop a database for plant management and the ArcGIS 10 Desktop and ArcGIS 10 for Server software packages developed by ESRI were used to develop the geoinformatics database. As a result, the Internet-based Geoinformatics Database of Thai Medicinal Plants has been established as a reference center covering 429 medicinal plant species belonging to 102 families. Of these species, 50 were in the family Leguminosae and *Shorea obtusa* Wall. ex Blume was the most dominant species with the highest importance value index. The Shannon-Wiener species index, species diversity index and evenness index were 3.8377, 46.42 and 0.7390, respectively, with 16 species classified on the International Union for Conservation of Nature Red List of Threatened Species. The geospatial database consisted of 32 layers of basic, environmental and survey data, which can be accessed via the Internet to search for large trees and medicinal plants. The database details of plants include scientific names, common names, local names, morphological characteristics, ethno-medicinal properties, other uses, references, images and distribution maps. The results of this study can be used as basic information and as a model for developing other tools for further planning and management of medicinal plants including their habitat in other regions of Thailand.

Keywords: geoinformatics; medicinal plant; biodiversity; Red List; threatened species

1 Doctor of Philosophy in Biology Program, Faculty of Science, Mahasarakham University, Maha Sarakham 44150, Thailand.

2 Bureau of Technical Services, Department for Development of Thai Traditional and Alternative Medicine, Ministry of Public Health, Nonthaburi 11000, Thailand.

3 Faculty of Science, Mahasarakham University, Maha Sarakham 44150, Thailand.

4 Department of Forestry, Michigan State University, East Lansing, MI 48823, USA.

* Corresponding author, e-mail: chantraket@gmail.com

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INTRODUCTION

Over the last four decades, biodiversity has been declining rapidly and has continued to affect business growth with 34% of Asia-Pacific Chief Executive Officers (CEOs) and 53% of Latin American CEOs expressing concern about the impacts of biodiversity loss on their business growth prospects (WWF International, 2010). Approximately 1 acre (0.40 ha) of tropical rainforest has been reported to be lost per second due to human activities (Orr, 1991). A total of 40,177 species of plants and animals have been reported to be threatened worldwide of which 16,119 species in tropical rainforests were likely to become extinct (International Union for Conservation of Nature, 2006). Tropical rainforests with a rich variety of species form 90% of all species found in the world, on about 7% of the world's total land area and Thailand is among the top 20 countries in the world with the highest biodiversity (Ministry of Natural Resources and Environment, 2008). Over the last four decades, in Asia, Thailand has had the second highest loss of biological resources (Napompeth, 2000); the total forest area has declined from 27.36 million ha in 1961 (53.3%) to 1.29 million ha (25.3%) in 1998 (Rueanpanit, 2005; Suntisuk, 2006), as a result of national economic development, which represents an average drop of 0.38 million ha per year (Department of Forestry, 2001).

As a result of the loss of tropical rainforest ecosystems, plants and animals are likely to be threatened and endangered. Thailand has realized the importance of the rapid loss of biological diversity as its plant registration program reported that 1,131 species of plants were under threat in 2005 (Pooma *et al*., 2005), while in China, 302 plant species were threatened (Zhang and Ma, 2008). Consequently, Thailand has enacted two laws with unique (*sui generis*) principles: the Plant Variety Protection Act (1999) for the protection of significant plant species including three main groups (new species, native species and wild species) and the Protection and Promotion of Thai Traditional Medicine Wisdom Act (1999) for the preparation of plans for medicinal plant protection as well as the preservation of natural ecosystems and biological diversity of native medicinal plants so that they are not affected by human activities.

Over the past half decade, many Thai government agencies responsible for biodiversity have developed database systems to increase the efficiency of information management, conservation and sustainable use of biological resources, in compliance with the Convention on Biological Diversity. For example, a geospatial database system has been developed for managing local biodiversity (Ministry of Natural Resources and Environment, 2008; 2009), as well as the implementation of biological resources and traditional knowledge for the management and use of biodiversity and a networking system of the national biodiversity database and network-centric data links with other agencies (Biodiversity-Based Economy Development Office, 2007). From 2006 to 2008, the Ministry of Natural Resources and Environment of Thailand implemented the Local Biodiversity Survey and Data Collection (LBSDC) Project to collect data on the biodiversity of animals and plants in 19 major forests in 317 subdistricts in all four regions of the country; while the Government of the Philippines also launched the Community-Based Forest Management (CBFM) Project to promote the assessment of biodiversity (Pasa, 2011). However for Thailand, there has been a lack of data analysis and the mapping of at-risk medicinal plants for use in tracking changes in vegetation with geographic information systems for the specific risk management of such plants. Such information is important for the preparation of a management plan to protect endangered or threatened plant species.

Therefore, the current study selected the Phu Phan forest complex as the prototype because its area is minimal compared to the other forest groups in Northeastern Thailand. The Phu Phan forest covers an area of approximately 168,834

km^2 (Rueanpanit, 2005), can be accessed and used by local residents in 89 subdistricts of seven provinces (Ministry of Natural Resources and Environment, 2008; 2009) and is considered to be vulnerable. Thus, a geoinformatics database was developed for the analysis of the biodiversity status of medicinal plants as well as the distribution of medicinal plants, for use as a tool for preparing plant management, monitoring and conservation plans, including the protection of medicinal plants and habitats. It will also help to detect changes that threaten the country's biodiversity. In the long term, the geospatial database is a powerful tool for the analysis and management of spatial data and for planning as well as for tracking changes in the area (Choowaew, 1999).

MATERIALS AND METHODS

The study area

The study data were derived from the LBSDC project, which was undertaken in the Phu Phan forest complex in northeastern Thailand, covering parts of four provinces: Nakhon Phanom, Mukdahan, Kalasin and Sakon Nakhon (18° 27′ N, 14° 7′ S, 105° 37′ E, 100° 54′ W) as shown in Figure 1. The climate of the Phu Phan forest complex contrasts between rainy and dry seasons. On average, the annual rainfall is 1,050–1,470 mm with 75–97 rainy days from May through October and the average temperature is 25–33 °C in the rainy season, 10–25 °C in winter and 30–45 °C in summer (Suntisuk, 2006). The weather is dry in winter, but humid in the rainy season and summer (Rueanpanit, 2005). Topographically, there is a plateau with mountains to the west and south with slopes of 0% to over 35% with an altitudinal range of 50 to 1,300 m above mean sea level (Rueanpanit, 2005; Geoinformatics Center to Develop the Northeast, 2006). Generally, the forests are dry evergreen, mixed deciduous and dry dipterocarp as classified in Table 1 (Chantaranothai, 2007).

System architecture design and development of geospatial databases via the Internet

Design of the system architecture

A geographic information system (GIS) accessed via the Internet was designed on the server center at the Global Observatory for Ecosystem Services, Department of Forestry, Michigan State University, MI, USA to provide data for decision-making on the management and

Table 1 Data on provinces, districts, subdistricts, villages, forest plots, forest types in the area studied.

Province	Number of districts	Number of subdistricts	Number of villages	Number of plots	Forest type	Area (ha)
Kalasin	2	3	8	12	Dry dipterocarp	6,505.12
Nakhon Phanom	1	1	4	4	Dry dipterocarp	17.60
Mukdahan	4	5	21	17	Dry dipterocarp	3,010.40
				3	Dry evergreen	174.88
				1	Mixed deciduous	161.28
				1	Mixed plantation	221.92
Sakon Nakhon	3	3	12	7	Dry dipterocarp	69.44
				3	Dry evergreen	43.36

Source: Modified from the final report of the survey on biodiversity at the local level, Phu Phan forest, 2008.

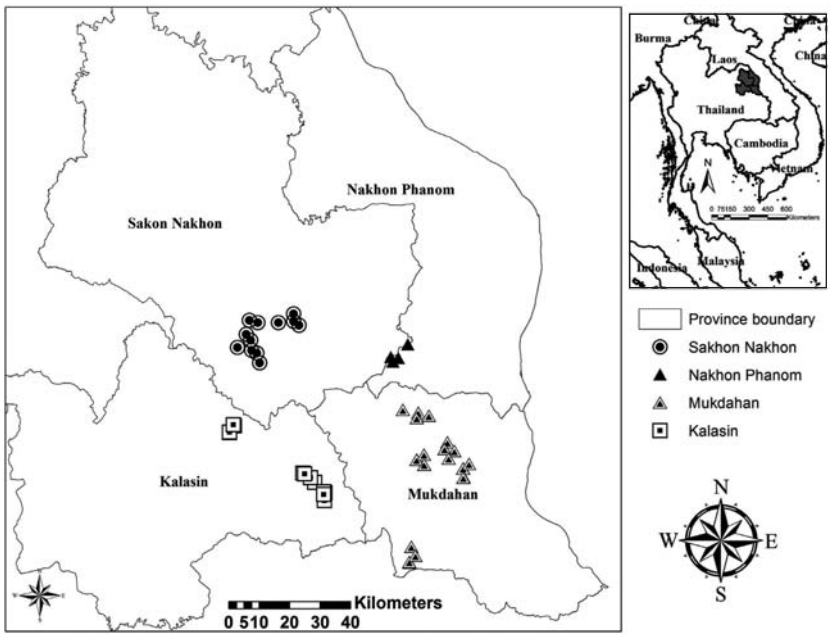

Figure 1 Map of the study area, including the location of the 49 Phu Phan forest plots in the four provinces of northeastern Thailand.

conservation of native medicinal plant species. Using client/server technology, the system architecture contains two main parts of multiple layers, on the client-side and server-side of the process. The server side consists of the Application Server and the Data Server. Based chiefly on the Internet-based GIS, the system functions on the web browser by transferring the client's request via the Internet to the server, which will retrieve non-spatial data and/or geodatabase information and then analyze the data. The results of analyzed data will be sent back as a table or graph to the client as illustrated in Figure 2.

Internet-enabled GIS content mapping: geographic distribution of medicinal plants

1. The GIS database for the development and distribution of medicinal plants was developed using ArcGIS Desktop 10™ (ESRI, 2010a) and ArcGIS® Server 10 (ESRI, 2010b). In the system, Microsoft Excel spreadsheet software (2007; Microsoft; Redmond, WA, USA) is used to calculate village-level data on the distribution of medicinal plants in relation to the standard code, number of plants, plant status and plant profiles.

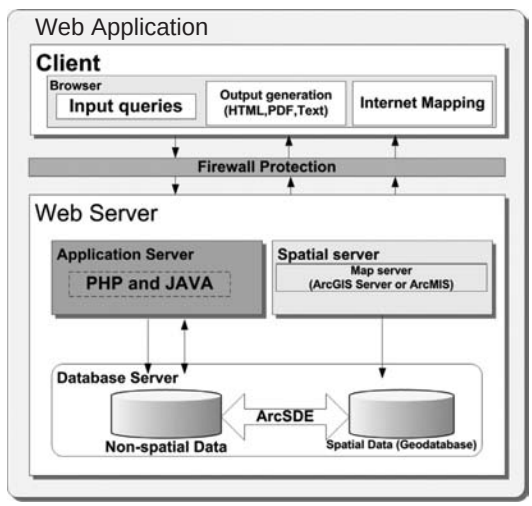

Figure 2 Architecture of the spatial geospatial database system.

The data are linked to the detailed individual plant database created using the Microsoft Word word processing software (2007; Microsoft; Redmond, WA, USA) and then converted to Adobe Acrobat X Standard files (Adobe Systems Incorporated, 2012) through the overlap of information layers from the computer hardware and the computer

software, including Windows Server 2003, ArcGIS Desktop 10 and ArcGIS for Server.

2. The GIS database was developed using 1:50,000 topographic maps produced by the Royal Thai Survey Department with information on topography and administrative boundaries. Furthermore, 1:50,000 environmental maps were also used to provide information on land use, geological layers and forest areas. The important positions and outputs included the positions of demonstration forest plots, large trees, environmental information (land use, geological layers and forest areas), and survey data related to the distribution of herbs and at-risk plants as well as the information on the plots surveyed and large trees.

3. Tables and records were created with details on the distribution of 2,713 plants (trees) from 49 permanent forest plots.

4. The Phu Phan geospatial information consists of four overlapping data layers:

(1) The basic data set contains the elevation line layers, point elevation layers, transport layers, surface water layers (water and rivers) and thematic layers (villages, subdistricts, districts and provinces).

(2) The remote sensing data covers the pseudo-topography (hillshade) map with features on raster images and a Delorme world base map possessing an image file in PNG8 format.

(3) The environment data set consists of land use types, geological layers, forest layers, thematic areas of rain and rainfall statistics.

(4) The survey data and distribution of medicinal plants contain the coordinate information on the 49 forest plots in the four provinces and the coordinate information on the large trees out of the 2,713 plants.

Assessment of status of medicinal plants

The Phu Phan forest complex was surveyed under the LBSDC project from July 2006 to January 2009 and involved the following steps.

1. Preparation of the list of plant species. A species list was developed by using the line transect method. The results could not be used to calculate any meaningful ecosystem parameters. The collected data, however, included study area information (villages, subdistricts, districts and provinces), names of forests, forest sizes, forest types, climatic conditions, characteristics of the areas, geographic coordinates of the plots and the altitude above mean sea level. The plant data included scientific names, common names, local names, family names, general morphological characteristics, ethno-medicinal properties and other uses (from interviews with local sages) and the UTM coordinates of large trees (with a girth greater than or equal to 30 cm).

2. Sampling plots were established to determine the minimum area justification because the minimal area shows the structure of plant communities; the 20 m x 50 m plots were used in this research.

3. Analysis of biological diversity and the importance of plants using the species Shannon-Wiener index (*H*') and the importance value index (IVI) (Krebs, 1999).

4. Analysis of the conservation status of medicinal plants. The analysis of medicinal plant conservation status was conducted based on the information obtained from the classification of species regarding the genus, family and plant habitat; the determination of endemic or non-endemic plant species was referenced to Thai plant names (Smitinand, 2001).

The identification of plant species for inclusion on the Red List was based on the documents "Threatened Plants in Thailand" (Pooma *et al.*, 2005), "Rare Plants in Thailand" (Pooma, 2008), "Thailand Red Data: Plants" (Santisuk, 2006), and "The IUCN Red List of Threatened Species" (International Union for Conservation of Nature, 2009). The classification of plant status was carried out using the species diversity (*D*) values of trees—trees with a low *D* value were regarded as at-risk species (Rs),

which were at risk of extinction from the locality and those with a high *D* value were considered as common species (C), commonly found in the area.

RESULTS

Functional testing of the web-based geographic information system

The functional testing of the web-based GIS or database for decision-making on the conservation of medicinal plants and their habitats has shown that the user can query the data from the GIS analysis to present plant distribution maps as well as reports on plant conservation status and habitats. The user can search from the menu of query attributes that classifies the status of a plant into: common species, least concern/ low risk, rare species and threatened species. Selecting the "Threatened species" option shows all plants in the selected group or the group of plant status in the Thai language; more detailed information (in a PDF file) on each plant can be downloaded under the "Plant information" option. The system can also display the spatial information requested from the spatial database with accuracy and timeliness for making better management decisions in complex situations. In particular, it can provide a clearer picture through Internet access for executives and the general public (Figure 3).

Flora assessment

In total, 429 plant species were identified, belonging to 102 families; most abundant were Leguminosae (64 species), followed by Rubiaceae (26 species), Poaceae (19 species), Apocynaceae (14 species) and Phyllanthaceae (14 species). In total, 348 species of medicinal plants were found (from interviews with local sages); among them 16 species were recorded as threatened in the Red List such as *Bauhinia strychnifolia* Craib, *Cycas siamensis* Miq. and *Scleropyrum pentandrum* (Dennst.) Mabb. (Table 2).

The plant classification according to habitat produced 210 tree or shrub species, with 60 species of minor shrubs and woody climbers and 53 herbaceous species. The traditional status classification indicated there were 415 native species and 10 alien species. The forest area was classified into four forest ecosystems (Table 1).

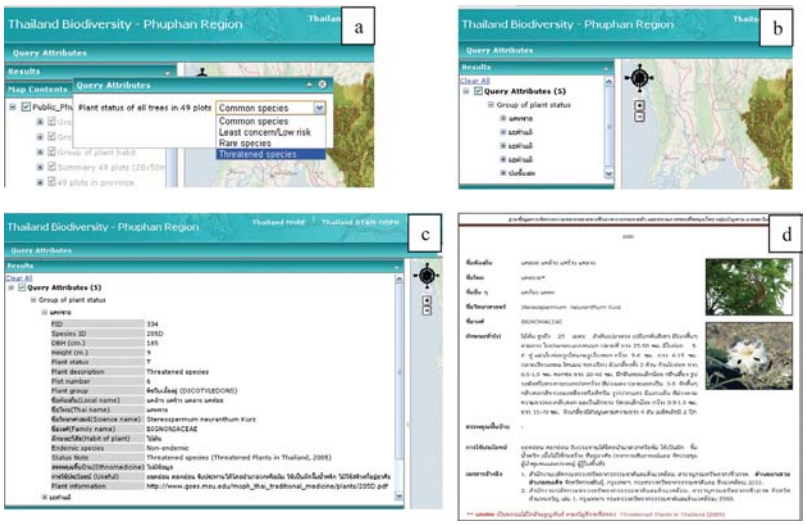

Figure 3 Screen outputs resulting from a search for medicinal plant conservation information via the Internet (a) Selection of plant status; (b) Results from query by species, (c) Report of species information; (d) Results and more detailed information in Thai language (in a PDF file) on each species can be downloaded.

Table 2 Status and distribution of 16 medicinal plant species on the Red List (International Union for Conservation of Nature and Natural Resources, 2009) from 49 forest plots in the four provinces of Nakhon Phanom (NP), Mukdahan (MH), Kalasin (KS) and Sakon Nakhon (SK).

List no.	Thai name	Scientific name	Family name	Habit	Endemic species	Plant Status	Province			
							KS	MH	NP	SK
1	ขยัน (Khayan)	*Bauhinia strychnifolia* Craib	Leguminosae	Climber	E	T		/		
2	ส้มเสี้ยวเถา (Somsiao Thao)	*Bauhinia lakhonensis* Gagnep.	Leguminosae	Climber	-	R		/		
3	ก่อดาน (Ko Dan)	*Castanopsis purpurea* Barnett	Fagaceae	Tree	E			/		
4	ปรง (Prong)	*Cycas siamensis* Miq.	Cycadaceae	Shrub	-	T	/			/
5	ลำบิดดง (Lam Bit Dong)	*Diospyros filipendula* Pierre ex Lecomte	Ebenaceae	Tree	-	R	/	/	/	/
6	คำมอกหลวง (Kham Mok Luang)	*Gardenia sootepensis* Hutch.	Rubiaceae	Shrub Tree	-	R	/	/		/
7	ปอขี้แฮด (Po Khi Haet)	*Goniothalamus laoticus* (Finet & Gagnep.) Bân	Annonaceae	Tree	-	T		/	/	/
8	แดงสะแง (Daeng Sa Ngae)	*Schoutenia ovata* Korth.	Tiliaceae	Tree	-	R	/			/
9	มะไฟแรด (Mafai Raet)	*Scleropyrum pentandrum* (Dennst.) Mabb.	Santalaceae	Tree	-	R		/		/
10	มะค่าแต้/แต้ลิง (Makhatae/ Tae Ling)	*Sindora siamensis* Teijsm. & Miq. var. *maritima* (Pierre) K.Larsen & S.S. Larsen	Leguminosae	Tree	-	T	/	/	/	/
11	แคทราย (Khaet Kai)	*Stereospermum neuranthum* Kurz	Bignoniaceae	Tree	-	T			/	/
12	เนระพูสีไทย (Naraphusri Thai)	*Tacca chantrieri* André	Dioscoreaceae	Herb	-	T		/	/	/
13	เปือย (Pueai)	*Terminalia pedicellata* Nanakorn	Lythraceae	Tree	-	R		/		
14	ตาแหลว (Ta Lae)	*Xylopia vielana* Pierre	Annonaceae	Tree	-	R	/	/		/
15	ลำไยเครือ (Lamyai Khruea)	*Dimocarpus longan* Lour. subsp. *longan* var. *obtusus*-(Pierre) Leenth.	Sapindaceae	Tree	-	NT			/	
16	มะค่าแต้/ แต้หนาม (Makhatae/ Tae Nam)	*Sindora siamensis* Teijsm. & Miq. var. *siamensis*	Leguminosae	Tree	-	LD		/		
					Total		6	11	5	10

Quantitative analysis of the ecological values of tree species using IVI analysis showed that the top five highest IVI values were for *Shorea obtusa* Wall. ex Blume (17.2653), *Dipterocarpus obtusifolius* Teijsm. ex Miq. (13.3712), *S. siamensis* var. *siamensis* Miq. (13.2130), *Xylia xylocarpa* (Roxb.) Taub. var. *kerrii* (Craib & Hutch, I. C. Nielsen) (12.9833) and *Pterocarpus macrocarpus* Kurz (6.3416). The plant species diversity analysis shows an *H'* value of 3.8377, a *D* value of 46.42 and an evenness index (*J*) value of 0.7390 for the 180 large tree species.

Status of threatened plant species

Based on the 429 species (consisting of 2,713 plants in 96 families) collected from the 49 forest plots, analysis of species status was undertaken on 180 tree species, of which 16 were on the Red List such as *Bauhinia strychnifolia* Craib, *Cycas siamensis* Miq., *Scleropyrum pentandrum* (Dennst.) Mabb., based on four references (Pooma *et al*, 2005; Pooma, 2008; Santisuk, 2006; International Union for Conservation of Nature, 2009) as shown in Table 2. The 180 large tree species were classified by their species diversity (*D*)—those with a low *D* value were regarded as at-risk species (Rs) being at risk of extinction from the locality and those with a high *D* value were considered as common species (C) in the area.

The distribution of medicinal plants was noted at the plot, village, subdistrict, district and provincial levels with more detailed information provided in Thai language on each species of medicinal plant.

DISCUSSION

The developed system application allows a search for the status of the plants in the Phu Phan forest complex and to map data such as shown in Figures 4–6 on the website (jointly managed by the Ministry of Natural Resources and Environment and the Ministry of Public Health, 2012), which is used as a database developer licensing program. However, in developing the database or system, importance was given to the application of open source software to reduce royalties; thus, Quantum GIS and Map Windows (Laosuwan *et al.*, 2008) were used to show the relationships of the two databases on the Internet.

Of the 16 plant species (12 families) on

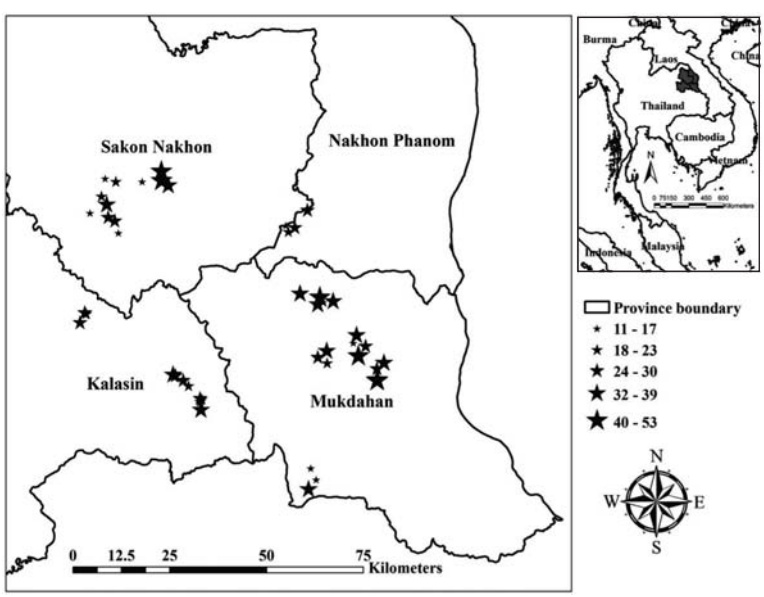

Figure 4 Number of large trees and the forest locations in a part of the target area.

the Red List, the five most abundant species were in the Leguminosae, followed by the Annonaceae (2 species). Most species were classed as having a tree and shrubby tree habit (12 species), followed by woody climbers (2 species) and shrubs and herbaceous plants (1 species). It is noteworthy that most of the plants were large trees, whereas shrubs, woody climbers and herbaceous herbs were found in small numbers. Some have medicinal properties, some are used as food and for making agricultural tools and construction purposes.

A study on the use of plants in the forest based on the ethnobotany and exploitation of plants in the Khok Rai Forest Community in

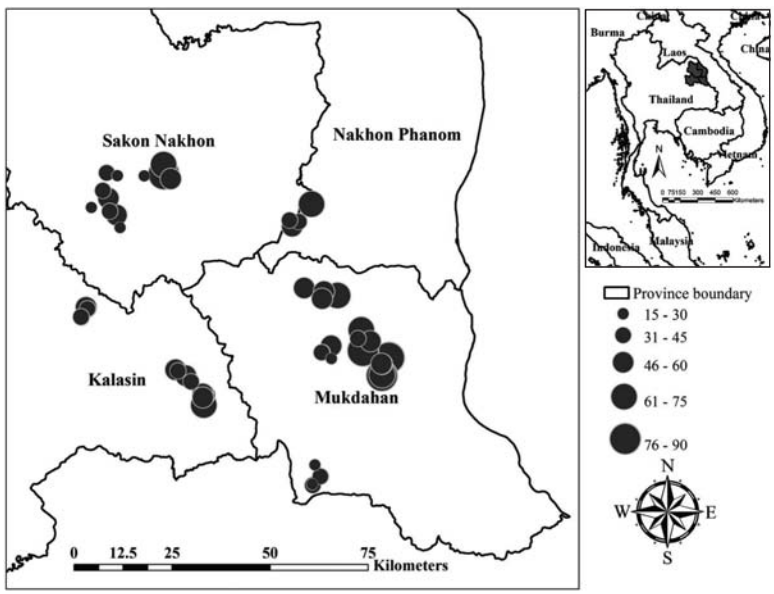

Figure 5 Total number of plant species and the names of forests in a part of the target area.

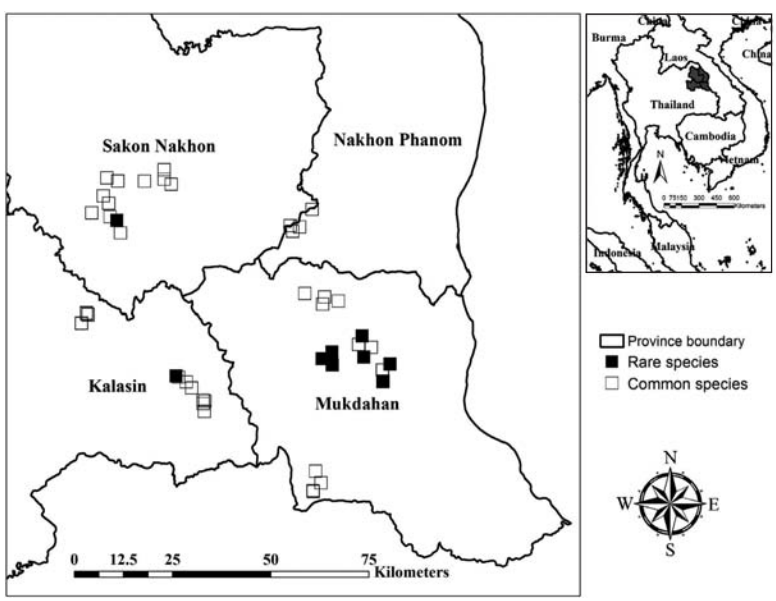

Figure 6 Conservation status and distribution of medicinal plants in s sample of the target area.

Chiang Yuen district, Maha Sarakham province, indicated that were five plant groups: medicinal plants, housing-related plants, edible plants, ritual/symbol plants and clothing/dyeing-related plants with 97, 84, 79, 6 and 4 species, respectively (Chupan, 2005).

In another community forest study, the useable or edible products which were collected and used throughout the year included mushrooms, wild fruits, vegetables, medicinal herbs and tubers (numbering 42, 27, 23, 14 and 5 species, respectively) as well as grass for animals. In 2007, the average value of forest products used by each household was estimated at 12,014 baht (USD 372.15) per year; Bukhaew, 2009).

Most people (57%) in the Phu Phan National Park, Sakon Nakhon province collected mushrooms and some collected firewood (Patanasak, 2004). There have been efforts made by the Inpaeng network of community development groups in the Northeast to undertake carbon trading from agroforestry projects, aiming to promote the use of plant products from their farms rather than from natural forests in the national park (Samek *et al.*, 2011). The network has modified traditional agricultural practices and adopted the Sufficiency Economy Philosophy initiated by His Majesty the King Bhumibol Adulyadej by not using chemicals, but using the crop diversity approach, that is, growing rice, fruit trees and medicinal plants for household consumption on their own farmland (Samek *et al.*, 2011).

Such a forest utilization approach still prevails through community participation for the conservation and protection of forest plants for sustainable uses. For the Dong Tongton forest area in Kalasin province, a public-private knowledge sharing forum was held on community forest management, especially into the restoration and conservation of forests (Pinthong *et al.*, 2004). Forester volunteer groups have been established for forest protection, reforestation, forest culture promotion or ancestor-shrine establishment and local wisdom compilation (Pinthong *et al.*, 2004).

Local community volunteers played a more active role in forest management than the Subdistrict Administrative Organization of the Dong Namon community forest in Kalasin and Roi Et provinces (Chongchuvit, 2003). However, the conservation of forest resources is a difficult task; it takes a lot of time, money, and human resources to accomplish, with an important requirement to have faith in and be grateful for nature (Suddee, 2003).

The problems related to forest conservation exist not only in Thailand; for example, as mentioned earlier, the government in the Philippines has launched the CBFM Project to resolve similar problems, (Pasa, 2011) and found that the biodiversity of forest ecosystems is a source of genetic resources taken by humans from the wild for use as food and medicines and was worth over USD 40 million per year, with a total of 1,400 species of tropical plants having chemicals with cancer fighting potential. However, many may become extinct before humans can really use them. The Philippines is a country with more than 7,100 islands; its government has launched a number of projects on public education about agriculture and conservation of the biodiversity and ecosystems on a continuous basis (Pasa, 2011).

The species diversity (*D*) was determined for 180 large tree species whose average *D* value was 46.42. Over all the plant species, 133 with low *D* values (ranked 48 to 180) were regarded as risk species (Rs) in the 49 forest plots under study, whereas the other 47 with high *D* values (ranked 1 to 47) were regarded as common species (C) generally found in the forests.

Distribution patterns of threatened plants

The conservation status groupings were based on a susceptible plant being defined as (1) having a low diversity (species diversity, *D*) or being vulnerable to extinction in the area, (2) being on the IUCN Red List of Threatened Species

(International Union for Conservation of Nature, 2009) and (3) being listed in the four references (Pooma *et al.*, 2005; Pooma, 2008; Santisuk, 2006; International Union for Conservation of Nature, 2009). Susceptible species can be classified as:

1. Threatened (T)
2. Endemic (E)
3. Rare (R)
4. Lower risk, which are further divided into three subgroups:

(1) Conservation dependent species (CD)

(2) Near threatened species (NT)

(3) Least concern species (LD)

5. Species classified by species diversity (D)

Among the 16 plant species on the Red List (Pooma *et al.*, 2005; Pooma, 2008; Santisuk, 2006; International Union for Conservation of Nature, 2009), each may belong to more than one status group (Table 2), but two were endemic species—*Castanopsis purpurea* Barnett and *Bauhinia strychnifolia* Craib.

Six medicinal plants were classified as threatened species—*Goniothalamus laoticus* (Finet & Gagnep.) Bân, *Tacca chantrieri* André, *Stereospermum neuranthum* Kurz, *Bauhinia strychnifolia* Craib, *Cycas siamensis* Miq. and *Sindora siamensis* Teijsm. & Miq. var. *maritima* (Pierre) K. Larsen & S.S. Larsen—which are at high risk of extinction from nature.

Seven medicinal plant species were classified as rare—*Terminalia pedicellata* Nanakorn, *Schoutenia ovata* Korth., *Gardenia sootepensis* Hutch., *Xylopia vielana* Pierre, *Cycas siamensis* Miq., *Scleropyrum pentandrum* (Dennst.) Mabb., *Sindora siamensis* Teijsm. & Miq. var. *maritima* and *Dimocarpus longan* Lour. subsp. *longan* var. *obtusus* (Pierre) Leenth. Such plants represent rarely found species and their habitats are region-specific or locality-specific; some might be found sparsely scattered in many areas and some might have been found in the past, but their populations are very small at present.

The medicinal plants that were grouped differently were *Sindora siamensis* Teijsm. & Miq. var. *maritime* and *Dimocarpus longan* Lour. subsp. *longan* var. *obtusus* (Pierre) Leenth. In Thailand, both are classified as rare species (Pooma, 2008), but according to the IUCN Red List (International Union for Conservation of Nature, 2009), they are classified as "lower risk species", that is, least concern species (LD) and near threatened species (NT), respectively, which means that they are at low risk of extinction and can be rehabilitated.

Of the 180 large medicinal plants from the 49 forest plots under study that were classified by their species diversity (*D*), 133 have low *D* values (ranked 48 to 180) and are actually species at risk of extinction. Such plants are rarely seen or have a small population in the study area. Some are endemic species in specific localities. Some are at high risk of extinction from their natural habitats; some are rarely found as they have limited habitats only in a particular region or place in the country, or might be sparsely scattered in several localities. However, such plants mostly have medicinal properties and can be used in health care by local residents and so they are also at risk of extinction. Those with high *D* values (ranked 1 to 47) are abundant and regarded as common species (C) in the forests under study.

The information on plant species status is important for formulating a management plan for the protection of medicinal plants and their origins as prescribed in sections 44 to 65 of the Protection and Promotion of Thai Traditional Medicine Wisdom Act (1999), which requires that a list of controlled herbs be published with details on the type, nature and name, especially for those of economic importance or endangered species. For the protection of such herbs, a "Management Plan for the Protection of Herbs" may be designed as a short-term, medium-term or long-term plan as appropriate and should include programs and operational guidelines for relevant government authorities to coordinate the survey, study and research in the areas of herbal origins.

Furthermore, the herbal conservation zones must be designated so that collaborated efforts among relevant agencies will be effectively operational. In addition, any privately-owned land from which herbs can be sourced can be registered and government support can be requested under the Act.

A comparative study conducted by Zhang and Ma (2008) on the assessment of conservation status, especially of threatened wild plants, which had been declared for protection purposes, covering 302 species in 92 families and 194 genera in China and based on the International Union for Conservation of Nature classification criteria, found that three species were already extinct or extinct in the wild (EW), 79 species were critically endangered (CR), 99 species were endangered (EN) and 112 species were likely to be endangered or vulnerable (VU).

CONCLUSION

The geoinformatics database of the Phu Phan forest complex in northeastern Thailand has been developed in the form of a database system, based on data date stamped 2008. The database structure was designed to include different maps with data links and layouts using GIS development programs. The analysis of data on tree species, medicinal plants status and the import of such information to the database results in the information maps showing the status and distribution of medicinal plants (Figures 4–6). The 2008 survey showed that there are 16 species (out of 429) in the susceptible group. In Thailand, there are 1,131 rare plant species, while as noted earlier, in China, 302 species (92 families and 194 genera) have been designated as threatened species under protection. The distribution patterns of threatened plants were analyzed using a GIS system to identify areas with such species. The threatened species were unevenly distributed and some were concentrated in eight forest areas. The maps showed various threatened species being scattered in forest reserves, conserved forests and protected areas. This study gives in-depth information to be used for prioritizing plant species with threatened biodiversity and for designing management plans for protecting medicinal plants in the Phu Phan forest. The approach in this study can be used as a model for similar studies in other forests of Thailand.

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