Application of Geo-informatics to Trans-boundary Biodiversity Conservation across Thailand, Lao PDR, and Cambodia

Yongyut Trisurat

Faculty of Forestry, Kasetsart University, Thailand

ABSTRACT

The objective of this paper was to elaborate the application of Geo-informatics for trans-boundary biodiversity conservation across Thailand, Lao PDR, and Cambodia under the Pha Taem Protected Forests Complex (PPFC) Project Phase I (2001-2004). This involved monitoring land use/land cover change, mapping distributions of selected wildlife species, and defining management zones. The results predict that forest cover in the PPFC landscape will continue to decline in the future, while agricultural area, especially in the buffer zone, will significantly increase. In addition, protected areas in the south of the complex and areas across the national borders contain relatively high to high suitability for landscape species while protected areas in the northern part provide relatively low suitability due to intensive human pressures. However, further clearing of forest could jeopardize the viability of rare large mammal species. Furthermore, ecological management zones were developed to provide a framework for trans-boundary biodiversity conservation in the adjoining protected forests and reducing the conflict of resource uses by local residents in the buffer zone. The outputs of Geo-informatics applications were providing valuable inputs to formulate long-term management plan of the PPFC and the formulation of the Project Phase II.

KEYWORDS

Pha Taem Protected Forests Complex; Trans-boundary biodiversity conservation; Ecological management zones; Geo-informatics

INTRODUCTION

The Southeastern Indochina Dry Evergreen Forests ecoregion occurs in a broad band across northern and central Thailand into Laos, Cambodia, and Vietnam, covering approximately 124,300 km^2. The ecoregion is globally outstanding for the large vertebrate fauna it harbors within large intact landscapes. Among the impressive large vertebrates are the Asian elephant and tiger. The list includes the second known population of the critically endangered Javan rhinoceros, Eld's *deer, banteng, gaur, clouded leopard, among others. About two-third of the original forest of this ecoregion has been cleared or seriously degraded (Wikramanayake* et al.*, 2000). A few large forest blocks also remain in Thailand and Laos.*

Recent years have seen an increasing interest in the creation of trans-boundary protected areas for more effective management of politically fragmented ecosystems. With the financial assistance from the International Tropical Timber Organization (ITTO), the Royal Forest Department (RFD) of Thailand has initiated a program of managing trans-boundary biodiversity conservation areas (TBCA) and selected the Pha Taem Protected Forests Complex (PPFC), one of the four protected forests complexes as a pilot project because there is an increasing pressure on biodiversity from trade in plants and animals across the border with Cambodia and Laos (ITTO/RFD, 2000). The objectives of project phase I (2001-2004) were to strengthen the management of the PPFC and to initiate cooperation in trans-boundary biodiversity conservation among the three countries. One of key significant activities leading toward the management planning of biodiversity was to develop geospatial information of the PPFC using geo-informatics (Trisurat, 2003a).

Geo-informatics is defined as an interdisciplinary field requiring synergistic modeling and analysis for dealing with geospatial data and phenomenon. Geo-informatics encompasses geospatial data collection, geospatial information analysis and modeling, as well as geospatial data processing (Ratanasermpong, 2000). These technologies include Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning System (GPS). Geo-informatics essentially involved capture, integrating, analyzing, managing, and depicting geo-spatial information. Example geo-informatics applications are inventory, modeling, natural resources and environmental management, biodiversity conservation. A comprehensive review of GIS applications in biodiversity conservation was compiled by Olivieri and Backus (1992). Recent applications of geo-informatics are as follows: Phillips et al., (2006) employed GIS and the maximum entropy methods to predict species distributions with presence-only data. Shivanand et al., (2004) used GIS methods to integrate the knowledge of local and thirty-three technical experts from USA, Canada, and Mexico with existing spatial environmental data to establish priority areas for biodiversity conservation of the North America region. The method provided a novel cooperative mechanism to aid spatial knowledge management and building consensus between local people and experts on biodiversity conservation. Similarly, Trisurat (2007) used GIS to assess the representation of ecosystems in the protected area system of Thailand. The results reveal that the existing protected areas in Thailand nearly meet the 25% targets, but some ecosystems are underrepresented. The objective of this paper emphasizes the application of Geo-informatics for trans-boundary biodiversity conservation across Thailand, Lao PDR, and Cambodia. This involved monitoring land use/land cover change, mapping distributions of selected wildlife species, and defining management zones.

LOCATION OF THE PPFC LANDSCAPE

The PPFC is located in Ubon Ratchathani Province in northeast Thailand and covers an area of 1,737 km^2. It comprises five protected areas, namely Pha Taem, Kaeng Tana, and Phu Jong-Na Yoi National Parks, Yot Dom Wildlife Sanctuary, and Bun Thrik-Yot Mon proposed Wildlife Sanctuary (Figure 1). The area slopes gently towards the southeast and is drained by the Mekong River, which forms the border between Thailand and Laos. The PPFC's buffer zone contains eighty-two villages populated by eighty-nine thousand people (Tanakajana, 2003). The major occupations of the residents are agriculture, keeping livestock, and fisheries. On the Lao side, the 1,200 km^2 Phouxeingthong National Biodiversity Conservation Area (NCBA) is located adjacent to the northern part of the PPFC, while the 1,900 km^2 Protected Forest for Conservation of Genetic Resources of Plants and Wildlife abuts the border on the Cambodian side (Galt *et al*., 2000). The tripartite border area has been dubbed, in Thailand at least, the Emerald Triangle because of its extensive tracts of monsoon forests.

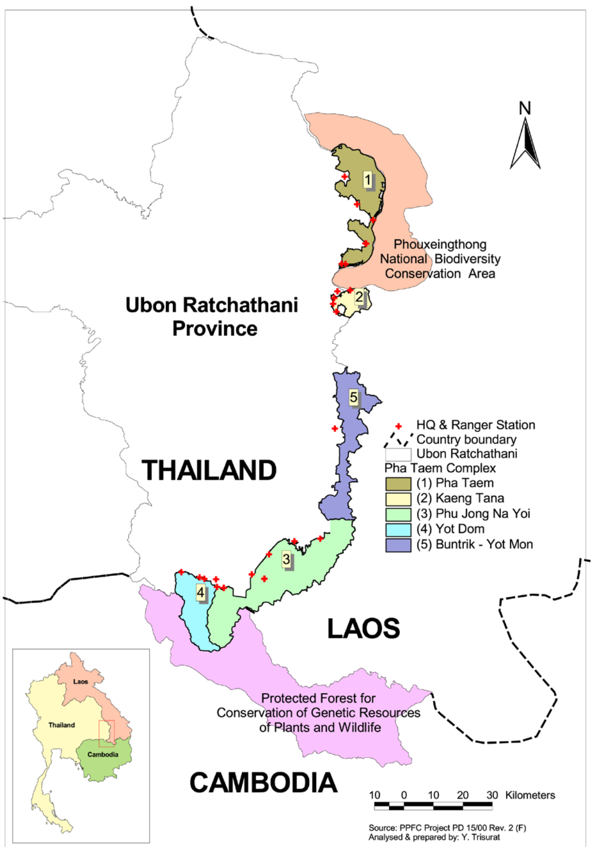

Figure 1. Location of the Pha Taem Protected Forest Complex and adjoining protected areas.

METHODS

1. Prediction of Land Use/Land Cover Changes

Basically, there are four main steps of image processing and prediction of land use/land cover changes. These steps are described as follows:

A) *Prediction of land use/land cover changes*: Cloud-free multi-temporal Landsat digital imageries dated 10 January 1990 and 20 February 2002 were acquired from the Geo-informatics and Space Technology Development Agency. Then a subscene of image covering the PPFC was extracted and mosaiced using ERDAS Imagine software.

B) *Geometric correction*: The raw images were rectified to the Universal Transverse Mercator (UTM) coordinate system of Zone 48 using forty to fifty ground control points per subscene selected from the reference points of up-to-date topographic maps at scale 1:50,000.

C) *Classification*: Visual interpretation was adopted for land use/land cover mapping. Key image features of the sampling vegetation type plots across the PPFC were developed to assist visual interpretation (Marod, 2003).

D) *Prediction of land use change*: After deriving land use/land cover maps in years 1990 and 2002, the *Markov Chain Model* was employed to simulate future land use changes every twelve years until 2050. Note that the Markov Chain Model is a mathematic simulation model to examine potential long-term trends in land use/land cover changes (Gergel and Turner, 2002).

2. Mapping Potential of Wildlife Habitats

A habitat is defined as any part of the biosphere where a particular species can live, either temporarily or permanently. Basically, there are two approaches for developing wildlife suitability maps: *deductive approach* and *inductive approach*, and the selection of these techniques are dependent on objectives and data availability (Stoms *et al*., 1992). The deductive approach extrapolates known habitat requirements to the spatial distributions of habitat factors, including food, cover, water, and space (Patton, 1992). If the habitat requirements are not well known, the habitat map can be derived from a sample of observations of the species geo-referenced to one or more resource factors, therefore called inductive approach. For instance, Austin (2006) and Phillips et al., (2006) used species presence-only data to predict geographical distributions of plant and animal species. Austin (2006) reviewed various statistical models predicting species distributions using environmental variables and species occurrence. In this project, the deductive approach was selected because limited sample points were obtained due to land mines (Trisurat, 2003b).

Eight focal wildlife species were selected to develop potential habitats. These species are Asian elephant (Elephas maximus), *common leopard* (Panthera pardus)*, sambar (*Cervus unicolor*), Southern serow (*Naemorhedus sumatraensis*), banteng* (*Bos javanicus*)*, Siamese crocodile (*Crocodylia siamensis*), pig-tailed macaque (*Macaca nemestrina*), and Siamese fireback pheasant (*Lophura diardi*) (Bhumpakphan, 2003; Trisurat, 2003b). The general approaches to define habitat suitability of selected species are described follows:*

A) Spatial data collection: The spatial data were divided into two main categories: wildlife observations and habitat factors. The geo-referenced wildlife observations were recorded by rangers using GPS. In addition, bio-physical and anthropogenic factors for determining habitat suitability were developed. The bio-physical factors include land use/land cover, accessibility to water, elevation, and slope, while anthropogenic factors consists of distance to road, distance to ranger station and distance to village.

B) *Developing wildlife habitat models*: All wildlife habitat factors were categorized according to their attributes. Then, each attribute of habitat factor was ranked to determine its suitability for each species. The ranking scores were assigned as: 3 (suitable), 2 (moderate) and 1 (not suitable). For instance, dry evergreen forest is suitable for Asian elephant, therefore it is ranked as score 3, while it is moderately preferable for banteng (score 2).

C) Simulating wildlife distribution models: All habitat factors were superimposed into one layer using raster-based GIS ArcView. Grid size was designed at 30 m x 30 m. The output map contained accumulated scores, and they were masked by settlements, agricultural areas and water bodies because these regions did not inhabit wildlife. The preliminary map was generalized to remove noise pixel for better visualization and more practicality on the ground. Finally, the accumulated scores were categorized into five classes to represent habitat suitability index: (1) low, (2) relatively low, (3) moderate, (4) relatively high, and (5) high.

D) Predicting high concentration of wildlife: The raw accumulated suitability scores of eight wildlife species varied extensively because they were derived from a different additive mechanism. Thus, the raw values were standardized from 0 to 1, and superimposed to evaluate high concentrations of focal wildlife species or *hot spots*. The output map was also classified into five classes to represent species richness in the PPFC landscape.

3. Defining Ecological Management Zones

The ecological management zone of the PPFC landscape was developed as a broad collaborative framework for trans-boundary biodiversity conservation. The zoning concept was modified from the zoning scheme of the UNESCO Biosphere Reserves (Phillips, 1998; Miller and Hamilton, 1999). This approach proposes four zones in human-altered landscape: core zone, buffer zone, corridor, and matrix, in order to maintain biological diversity across the entire landscape while meeting people's needs.

The zoning scheme was developed based on four ecological quality factors: 1) critical habitat, 2) environmental service, 3) naturalness, and 4) remoteness (Table 1). Critical habitat is represented by the concentrations of eight wildlife species, while environmental service is represented by the erosion sensitivity index derived by combining elevation and slope factors. Present land use/land cover stands for naturalness. Remoteness is determined by distance from human settlements and roads.

Table 1. Zoning scheme for the Pha Taem Protected Forest Complex landscape.

Character/ criteria	Core zone	Buffer zone	Corridor	Matrix
Biophysical condition	A critical ecosystem(s) that supports viable population of focal species and environmental services, normally remote from disturbances and human settlements	A natural area situated around the core area to manage unfavorable impacts that flow between the core area and its surrounding landscape	A linear assemblage of mainly continuous vegetation connecting fragmented critical ecosystems to encourage and facilitate migration and dispersal	An extensive cover and connectivity in the landscape where human settlements and intensive development are conducted
Spatial criteria Critical habitat	Critical	Moderate	Critical-moderate	Low
Environmental service	Sensitive	Moderate	Sensitive-moderate	Low
Naturalness	Undisturbed vegetation	Undisturbed vegetation	Remnant vegetation, slightly disturbed	Settlement, reservoir, agriculture
Remoteness	>3 km from settlement >2 km from main road >1 km from large agricultural activities	Disturbed areas inside protected areas	Preferably remote from settlement	-----
Physical setting	>1 km^2	Not overlapping with core zone and matrix	May overlap with core area and buffer zone	Extensive and connected

After overlaying the four criteria, any pixels that matched the zoning scheme were queried and named. Any region smaller than 100 ha was generalized and the draft map was distributed to superintendents and concerned parties for review and comment; consequently, it was revised according to comments and field validation.

RESULTS

1. Land Use/Land Cover

Land use/land cover was classified into ten categories as shown in Table 2. Dry evergreen forest occupied 22.2% in 1990, and about 3,000 ha been converted to other land uses and most of them occurred in the buffer zones of the PPFC. In addition, about 19,200 ha of mixed deciduous forest were changed to other land uses during 1990-2002. Deciduous dipterocarp forest covered 21.1% in 1990 but the existing area occupied only 17.3%, which indicates that approximately 3.8% has been changed. On the other hand, agricultural areas, mainly paddy fields are found over a rather large area. It constitutes nearly 24% in 1990 and substantially increased to 31.9% in 2002. It is noticed that there was no para rubber in 1990 but in 2002 this perennial tree covered about 1,500 ha or 0.1% of the PPFC landscape (Table 2). The coverage of bare soil and water body are almost stable.

Table 2. Forest types inside and outside the PPFC Project and their coverage (ha).

Type of land use	Area in ha		Change (ha)	Change in percentage	
	1990	2002	+/-	12 yrs.	Yearly
Dry Evergreen Forest	237,550 (22.2%)	234,558 (21.9%)	-2,999	-1.3	-0.1
Mixed Deciduous Forest	208,079 (19.5%)	188,867 (17.7%)	-19,212	-9.2	-0.8
Deciduous Dipterocarp Forest	225,721 (21.1%)	185,373 (17.3%)	-40,348	-17.8	-1.5
Scrub	99,642 (9.3%)	69,367 (6.5%)	-30,275	-30.4	-2.5
Eucalyptus	2,019 (0.2%)	3,323 (0.3%)	1,304	64.6	5.4
Para Rubber	0 (0%)	1,502 (0.1%)	1,502	150.2	12.5
Agriculture	253,586 (23.7%)	340, 826 (31.9%)	87,240	34.4	2.9
Village	5,675 (0.5%)	9,766 (0.9%)	4,092	72.1	6.0
Bare soil	1,638 (0.2%)	1,540 (0.1%)	-98	-6.0	-0.5
Water body	36,060 (3.4%)	34,848 (3.3%)	-1,212	-3.4	-0.3
Total	1,069,970	1,069,970	-----	-----	-----

The results of *Markov Chain Model* indicated that the proportion of deciduous dipterocarp forest, mixed deciduous forest and scrub forest will be significantly decreased from year 1990 to year 2050. For instance, deciduous dipterocarp forest will cover 14.3, 11.8, 9.7 and 7.9% in years 2014, 2026, 2038 and 2050 respectively (Figure 2). This change occurs due to the fact that these forest types exist along the buffer zones of PPFC and are close to villages. Therefore they are the main target for agricultural encroachment. The proportion of agriculture will continuously increase in the future, and there is no stable stage. Agricultural area will enlarge from 32.1% in 2002 to 53.3% in 2050, respectively, if the circumstances remain the same in the future with no strict enforcement in the PPFC. Eucalyptus and para rubber plantations have greatly expanded in the last twelve years; however, these two categories constitute only a low percentage of the PPFC landscape. The enlargement of agriculture into protected areas and the remaining forest can be lessened if strict law enforcement is implemented by park rangers. In addition, community-based forest management program in the buffer zone to raise local awareness in conservation is also essential.

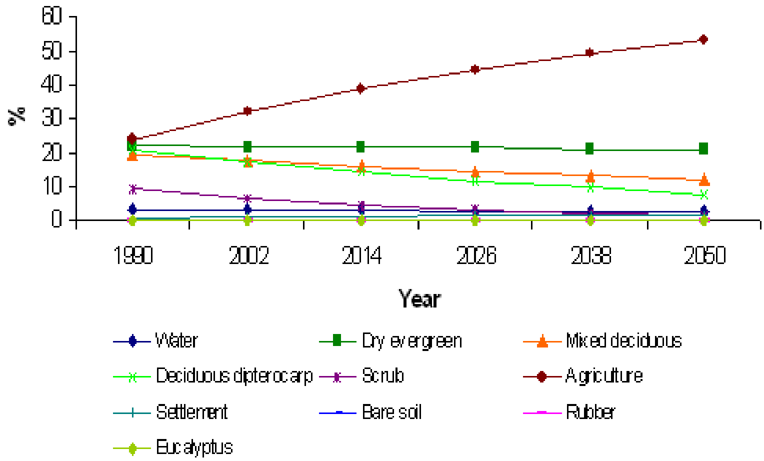

Figure 2. Land use and prediction (1990-2050).

2) Potential of Wildlife Habitats and Wildlife Hotspots

Potential habitat suitability maps of eight wildlife species were developed with the knowledge of wildlife experts and local knowledge. Basically, the predicted maps of focal wildlife species shows that relatively highly to highly suitable habitats extend along the national border areas adjoining protected areas in Laos and Cambodia because there are low human pressures. Most areas situated in the buffer zone of PPFC complex are predicted as having low to relatively low suitability for the selected wildlife. These areas have been totally converted to farmlands or human settlements and a dense road network has been constructed.

By overlying suitable habitats of the eight focal wildlife species, it shows that high concentrations of all species or "*hot spots*" are found along the tri-national borders and clustered in three places. The highest and largest area is located along the western border of Phu Jong-Na Yoi adjoining Laos. The second region is found in Phouxiengthong NBCA and the third area extends along the northern border of Bun Thrik-Yot Mon (Figure. 3). In considering the trans-boundary biodiversity conservation among three countries, the first concentration area is recognized as the most important critical habitat because protected areas in Thailand alone cannot support the population viability of these species which are seasonally migrate across the national boundaries species. In addition, park rangers and limited data obtained from field survey confirmed the output of spatial analysis.

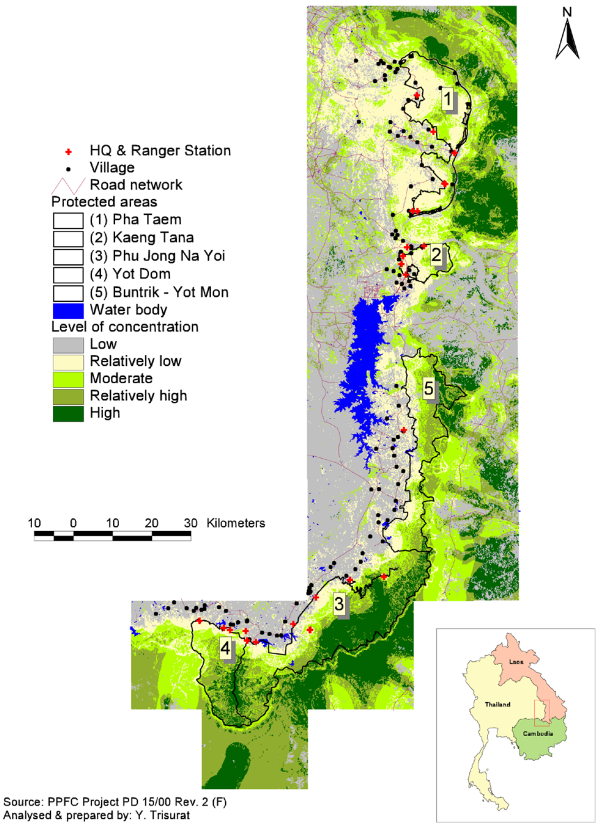

Figure 3. Concentration of focal wildlife in the PPFC landscape.

3) Ecological Management Zones

The ecological management zones of the PPFC are shown in Figure 4. Core zones are found in Phouxiengthong NBCA and along the southern border joining Thailand, Laos, and Cambodia, covering approximately 27.5%. The buffer zones cover the remaining forest area in the PPFC and degraded forest, as

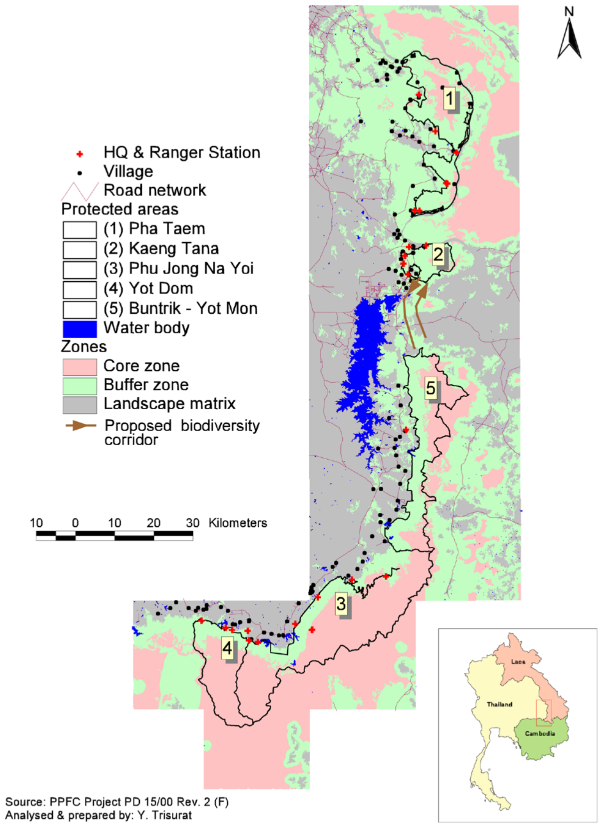

Figure 4. Ecological management zones of PPFC landscape.

well as a few agricultural areas inside the PPFC. The total area of buffer zone is 36.6%. Most areas of Pha Taem and Kaeng Tana National Parks are classified as buffer zones of the PPFC complex because these two protected areas contain low suitability habitats for focal wildlife species and most areas are accessed by the local people and used for cattle grazing. In addition, the forested areas in Laos situated to the east of Bun Thrik-Yot Mon Proposed Wildlife Sanctuary where legal logging is practiced, are also defined as buffer zones.

The boundary of the Kaeng Tana does not adjoin the Pha Taem. Therefore, it is proposed that the biodiversity corridor should be established and investigated in this gap to link the fragmented protected areas. This corridor covers vegetation remnants along approximately 17 km length. In addition, both Thai and Laotian wildlife scientists with local assistants should conduct wildlife survey and rehabilitate the degraded habitat. The remaining areas in the PPFC landscape dominated by extensive agriculture and human settlement are classified as landscape matrix.

DISCUSSION AND CONCLUSIONS

The results of this project reveal that geo-informatics is a powerful tool for providing geospatial information for monitoring land use/land cover change, mapping distributions of selected wildlife species, and defining ecological management zones in the context of trans-boundary biodiversity conservation. The results of *Markov Chain Model* predict that forest covers in the PPFC landscape will decrease, especially in the buffer zone, while agricultural area will increase significantly within the next four decades. While this prediction is totally based on previous land use change phenomenon and excluded socio-economic factors, it also provides warning signals to park officials where to put more efforts for protection. The prediction models can be improved by integrating important determinant factors of land demand for agriculture such as population size, crop productivity, crop diversification index (Panayotou and Parasuk, 1990), as well as ecological constraint (e.g. slope, land suitability).

In addition, the *deductive model* and GIS were employed to extrapolate the distributions of wildlife using physical and anthropogenic factors. The predicted maps show that protected areas in the south of PPFC complex and areas along the tri-national borders extending to protected forests in Lao PDR and Cambodia contain relatively high to high suitability for landscape species, while protected areas in the northern part provide relatively low suitability due to intensive human pressures and cattle grazing. The PPFC also modified the zoning scheme of the UNESCO Biosphere Reserves to develop ecological management zones for providing a framework for trans-boundary biodiversity conservation in the adjoining protected forests and reducing the conflict of resource uses by local residents in the buffer zone. Most areas of core zones are found in Phouxiengthong NBCA and along the southern border joining Thailand, Laos, and Cambodia.

If more data on species presence are collected in the future, it is recommended that the existing models should be replaced by inductive approach such as logistic multiple regression, generalized linear model, and maximum entropy, because these statistic techniques yield more accurate results and provide opportunity to test accuracy of models (Austin, 2006; Elith, 2002; Phillips et al., 2006). In addition, the proposed biodiversity corridor to link Kaeng Tana and Bun Thrik-Yot Mon should be further investigated during the project phase II which was recently approved by ITTO. The example of assessing wildlife habitat connectivity in the Interstate 90 Snoqualmie Pass in Washington, USA by Singleton and others (http://www.dot.state.fl.us/emo/sched/text.pdf) using GIS as least-cost path modeling is applicable to the PPFC landscape.

Even though the geo-informatics is a very powerful tool for biodiversity conservation planning and assessment of wildlife habitat connectivity, the key factors of success are the effective management of protected areas and collaboration with neighboring countries. In addition, it is essential to reinforce bioregional planning across politically fragmented protected areas through the involvement of decision-makers and local residents in the buffer zones (Sandwith *et al*., 2001). Park officials should promote community-based conservation activities and alternative occupations to the local people which are biodiversity-friendly land and water in order to reduce dependence on forest resources such as ecotourism, in addition to raising awareness of the adverse effects of unsustainable land use practices.

REFERENCES

Austin, M. 2006.Species distribution models and ecological theory: a critical assessment and some new possible new approaches. Ecological Modelling. doi10:1016/j.ecolmodel.2006.07.05.

Bhumpakphan,N. 2003. Management of the Management of the Pha Taem protected forest complex to promote cooperation for trans-boundary biodiversity conservation between Thailand, Cambodia and Laos (Phase I): Wildlife ecology final report. Faculty of Forestry, Kasetsart University, Bangkok.

Elith, J. 2002. Quantitative methods for modeling species habitat: comparative performance and an application to Australian plants. In Ferson, S., Burgman, M (Eds.), Quantitative Methods for Conservation Biology. Springer-Verlag, New York, pp. 39-58.

Galt, A., Sigaty, T., and Vinton, M. (Eds.). 2000. The World Commission on Protected Areas, 2nd Southeast Asia Regional Forum, Pakse, Lao PDR: Volume I: Executive summary. Vientiane: IUCN.

Gergel, S.E. and Turner, M.G . (Eds.) 2002. Learning Landscape Ecology: A Practical Guide to Concepts and Techniques. Springer-Verlag. New York.

ITTO/RFD. 2000. Project Document PD 15/00 Rev.2 (F): Management of the Pha Taem protected forest complex to promote cooperation for trans-boundary biodiversity conservation between Thailand, Cambodia and Laos (Phase I). International Tropical Timber Organization and Royal Forest Department, Bangkok.

Marod, D. 2003. Management of the Management of the Pha Taem protected forest complex to promote cooperation for trans-boundary biodiversity conservation between Thailand, Cambodia and Laos (Phase I): Forest ecology final report. Faculty of Forestry, Kasetsart University, Bangkok.

Miller, K. and Hamilton, L. 1999. Bioregional approach to protected areas. *Parks*. 9: 1-6.

Olivieri, S.T. and Backus, E.H. 1992. Geographic information systems (GIS) applications in biodiversity conservation. Biological International 25: 10-16.

Patton, D.R. 1992. Wildlife-Habitat Relationships in Forested Ecosystems. Timber Press Inc., Oregon, USA.

Panayotou T. and Parasuk, C. 1990. Land and forest: projecting demand and managing encroachment. 1990 TDRI Year-end Conference on Industrializing Thailand and Its Impacts on the Environment. Thailand Development Research Institute Foundation (TDRI), Bangkok.

Phillips, A. 1998. Biosphere reserves and protected areas: What is the difference? In IUCN, Proceedings: Biosphere Reserve-myth or Reality Workshop?, (pp. 7-10). IUCN World Conservation Congress. Gland and Cambridge:

Phillips, S.J., Anderson, R.P., and R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling 190: 231-259.

Ratanasermpong, S. 2000. Monitoring mangrove forest in relation with shrimp farm. Proceedings of the Ninth Regional Seminar on Earth Observation for Tropical Ecosystem Management, Khao Yai, Thailand, 20-24 November 2000 (pp.127-133). The National Space Development Agency of Japan.

Sandwith, T., Shine, C., Hamilton, L, and Sheppard, D. 2001. *Trans-boundary Protected Areas for Peace and Cooperation*. Gland and Cambridge: IUCN-The World Conservation Union.

Shivanand, B., Deagicevic, S., and Meredith, T. 2004. A Collaborative GIS Method for Integrating Local and Technical Knowledge in Establishing Biodiversity Conservation Priorities. *Biodiversity and Conservation,* 13: 1195-1208.

Singleton, P., H., and Lehmkuhl, J.F. Assessing Wildlife Habitat Connectivity in the Interstate 90 Snoqualmie Pass Corridor, Washington. U.S. Forest Service, Wenatchee, Washington. Available at: http://www.dot.state.fl.us/emo/sched/text.pdf (02/01/2007).

Stoms, D.M., Davis, F.W., & Cogon, C.B. 1992. Sensitivity of wildlife habitat models of uncertainties in GIS data. Photogrametric Engineering & Remote Sensing 58 (11), 1587-1591.

Tanakajana, N. 2003. Management of the Management of the Pha Taem protected forest complex to promote cooperation for trans-boundary biodiversity conservation between Thailand, Cambodia and Laos (Phase I): Socio-economic final report. Faculty of Forestry, Kasetsart University, Bangkok.

Trisurat, Y. 2003a. Lessons Learned for Trans-boundary Biodiversity Conservation: A Case Study of Pha Taem Protected Forest Complex. *Journal of Wildlife in Thailand*, Vol. 11: 194-208.

Trisurat, Y. 2003b. Defusing the Trans-boundary Minefield. *Tropical Forest Update*, *International Tropical Timber Organization (ITTO)*, Vol. 13 pp. 10-13.

Trisurat, Y.2007. Applying gap analysis and a comparison index to evaluate protected areas in Thailand. Environmental Management 39: 235-245.

Wikramanayake, E., Boonratana, R., Rundel, P. and Aggimarangsee, N. 2000. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press, Washington, D.C.