LANDSCAPE-SCALE CONSERVATION PLANNING AND WILDLIFE MONITORING IN SOUTHEAST ASIA

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PREFACE

This collection of papers focuses on monitoring and conservation planning in two large landscapes: Thailand's Western Forest Complex and the country of Cambodia. Both landscapes present planners with complex challenges including how to meet the current and future needs of human populations, how to conserve biodiversity, and how to maintain ecosystem stability over very long periods of time. These challenges bring into focus both human values and the range of technologies and tools that have been developed to assist decision-makers in the face of uncertainty and complex, multi-variable systems.

Thailand's Western Forest Complex (Prayurasiddhi et al.) is an approximately 17,000 Km^2 area shared by the world's second largest population of tigers and a growing human population. It is Southeast Asia's largest protected wilderness and in many ways, the geographic crossroads of historic and modern tiger distribution. Modernization has dramatically altered Thailand's landscape—especially over the last 60 years. Like most neighbors in the region, the country has struggled with the challenge of setting conservation policy and making natural resource management decisions based on what is often a limited amount of baseline data and constantly changing political and economic conditions. As in many parts of the world, the 20th century saw the extinction of species that in some cases were doomed before declines in populations were even documented.

A current priority for managers in this area is developing and deploying survey and monitoring techniques that are both affordable and capable of delivering data relevant to the management of the regions tigers and the habitat they depend on. In Chapter 1, I develop predictive models of tiger and tiger prey distribution as a means of providing needed focus for limited survey resources. In Chapter 2, I evaluate both practical and statistical aspects of potential survey and monitoring strategies for tigers at the landscape level.

Chapters 3-5 relate to a national-level systematic conservation planning process that was initiated in 2004. I evaluate the selection of planning tools and techniques in light of Cambodia's unique conservation and socio-economic context and review the planning process as a means of developing an adaptive framework for ongoing conservation planning and implementation.

Although the chapters are interrelated, I have prepared each as a stand-alone manuscript for submission to appropriate peer-reviewed scientific journals.

ACKNOWLEDGMENTS

This work would not have been possible without the significant contributions and support of numerous people.

My committee members all contributed expertise, guidance, and extraordinary amounts of patience during what turned out to be a long process of collecting, analyzing and writing up my data. In particular, Dave Smith provided guidance, friendship, and continuous support in both the field and the laboratory and introduced me to most of the other people who have made this work a success. Peter Jordan and Paul Bolstad provided much experienced review and their encouragement led to great improvements in model development and validation. Steve Polasky's inputs and advice in the use of spatial planning approaches were invaluable in completing the Cambodia analysis in particular. Francie Cuthbert was a consistent source of support and encouragement in both the US and in Asia throughout the project. Sean Ahearn from Hunter College provided valuable inputs at several stages, joined me in the field to assist in data collection protocols, and provided thoughtful comments on the final dissertation. Todd Arnold patiently shared his statistical, modeling and general wildlife ecology expertise with me; Chapter 2 would simply not have been possible without his valuable suggestions and guidance.

Dr. Schwann Tunhikorn provided official support and encouragement at several critical junctures in the project. Mark Graham provided enthusiasm, a pragmatic working style, and indispensable guidance during the early part of the investigation. His memory was a constant source of inspiration to the project team even after his tragic death in 1999.

Mr. Chachawan Pitdamkham, Chair of the Royal Forest Department's Western Forest Complex Management Committee (WEFCOM) was supportive in many ways, from providing transportation in a pinch to introducing the project to many of the protected area leadership and staff with whom we worked. Saksit Simcharoen introduced me to the tiger population in the Western Forest Complex and provided expert knowledge, encouragement, and official support throughout the project. Achara Petdee was generous with both her time and with background data on the study area. Pornchai Pattumratanathan was a great friend and was generous with both his time and his expertise with tigers, four-wheel drive trucks, and numerous other relevant issues.

Theerapat Prayurasiddhi has been a both a friend and professional colleague throughout this work providing ecological insights into the ecology of the Western Forest Complex and providing unparalleled perspective on conservation issues in Thailand. Passanan Cutter contributed a truly unique and invaluable set of skills, an unflinchingly positive attitude in her role as research assistant and interview coordinator. Other WEFCOM staff including Anuk Patanawiboon, Yongyut Trisurat, Sompoad Maneerat and others provided invaluable logistical support and important background information.

Local residents living in and around the study area were, without exception, gracious hosts during our field surveys and selflessly contributed everything from a comfortable place to spend the night to unparalleled knowledge and appreciation of a wilderness that most find mystifying if not intimidating. Most of the fieldwork would have been impossible without the enthusiastic assistance of numerous rangers from the Department of National Park, Wildlife, and Plant Conservation who were quick to pick up new skills and eager to apply them in the field.

The staff of the Department of National Park, Wildlife, and Plant Conservation's Forest Boundary Survey Division contributed their time and expertise in many ways to help create and process much of the GIS data used during the course of the project. In particular, I would like to thank Mr. Somporn Tanhan for his kind support and assistance in gathering much of the geographic information necessary for the analysis.

This project was made possible through funds from a number of sources. The Save the Tiger Fund provided initial funds and John Seidensticker, Mahendra Shresta, and others and the National Fish and Wildlife Foundation have been remarkably supportive and patient throughout the term of the project.

The U.S. Fish and Wildlife Services Tiger and Rhino Fund provided important funding and Fred Bagley was gracious to personally travel to Thailand to visit with me and other members of the project team.

Much of the Cambodia analysis builds on work that I carried out while serving working with the Cambodia Ministry of Envirionment and the Biodiversity and Protected Area Management Project. In particular, Klaus Schmitt and David Ashwell provided important discussion and inputs to this part of the analysis and I am very grateful for their inputs.

Meas Sophal from the Ministry of Environment also provided a tremendous amount of support and encouragement.

I would not have been able to survive many cold months in Minnesota were it not for the friendship, inspiration, and intellectual support I received from other students and staff in the Conservation Biology Graduate Program at UMN. In particular, I would like to thank Anup Joshi, Mahendra Shresta, Rob Steinmetz, Adam Barlow, Bhim Gurung, Lynne Baker, and Paul Kapfer.

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Many other contributors, too numerous to list here, made the project possible and we would like to thank them all for their dedication and interest in establishing an important foundation for future surveys and monitoring efforts in the area.

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PART I

Landscape Scale Habitat Associations and Monitoring of Tigers in Thailand's Western Forest Complex

CHAPTER 1. LANDSCAPE SCALE TIGER AND TIGER HABITAT PATTERNS: EVALUATING MODELS FOR WESTERN THAILAND

Models can be a useful tool for understanding the relationship between animals and the resources they rely on for survival, reproduction, and persistence in an area. In turn, these insights can inform conservation and management efforts. In this study, predictive models representing relative tiger prey abundance and relative tiger abundance were developed at resolutions that can inform on-the-ground management and conservation action in western Thailand.

The relationship between tiger occurrence and several landscape-scale variables was explored through the construction and exploration of both standard multiple regression and logistic regression models. Models of tiger habitat quality were developed using data collected at two spatial resolutions: one using survey units the approximate size of male tiger homeranges in the area (Ecological Survey Unit Model or "ESU model") and one based on smaller (~3 km2) survey units ("logistic model"). Both of these models involved the use of data derived from a third model relating a measured index of tiger prey quality to a suite of landscape-scale variables ("prey model").

The preferred prey model included distance to nearest village and ruggedness. The best-supported tiger models included relative prey quality (ESU model) and relative prey quality together with mean elevation (logistic model).

Results suggest that management to encourage tiger conservation should focus on 1) monitoring and managing patterns of human activity within western Thailand's extensive conservation landscape; 2) protecting and/or recovering populations of large prey species; and 3) if feasible, managing forests to preserve and enhance dry, open forest types within the Western Forest Complex.

Introduction

Models are often used to explore the relationship between animals and the resources they rely on for survival, reproduction, and persistence (Conroy & Moore 2002; Morrison et al. 1998; Shenk & Franklin 2001). One of the diverse goals of modeling exercises is that of external validity, the extrapolation (or prediction) to areas beyond those where parameters were measured directly.

In this study, I used linear and logistic regression techniques to model relationships between tiger prey species and their environment and between tigers and their environment across a large conservation landscape in western Thailand. The purpose of the analysis was to provide a sound scientific basis for decision-making related to information for research, training, monitoring, management, and protection activities aimed at increasing the likelihood of persistence of a robust tiger population in western Thailand and neighboring Burma. In addition to these immediate functional goals, the analysis is also meant to contribute to our understanding of tiger and tiger prey ecology in Western Thailand.

Data used in the analysis were collected in the field during a four-year period from 1997-2000. Primary data consisted of indices of prey relative abundance derived from pellet/dung plot counts and of indices of tiger relative abundance derived from rates of tiger sign encountered during focused surveys of likely tiger travel routes. Field surveys attempted to directly document patterns of prey and tiger distribution and relative abundance representative of an area of approximately 10,000 km^2. These data were then used to develop predictive models that were applied to a larger landscape of approximately 25,000 km^2. Models of tiger relative abundance developed at two spatial scales provided insight into the environmental variables that affect tiger distribution and shed light on the scales at which these phenomena matter to tigers. Implications for monitoring and management were considered throughout the data collection, modeling, and evaluation processes.

Study Area

The Western Forest Complex (WFC) is a large area of mostly intact forest encompassing 17 separately managed protected areas (Figure 1-1). Together with extensive areas of contiguous forest on the Myanmar side of the border and the Kaeng Krachan complex to the south, the area represents the third largest ‘Tiger Conservation Landscape’ identified by Sanderson et al. (2006) in their range-wide tiger conservation priority-setting exercise. Details of the study area relevant to this analysis are summarized below.

Located in the southeastern end of the Dawna Mountain Range and Northern portion of the Tenasserim Mountain Range, the area is mostly rugged, mountainous terrain interspersed with wide valleys and plateaus. Elevations range from 100 meters to 2200 meters. Most watersheds in the area are part of the large Mae Klong River system that flows south into the Gulf of Thailand; a few drain west into the Salween river system, which empties into the Andaman Sea.

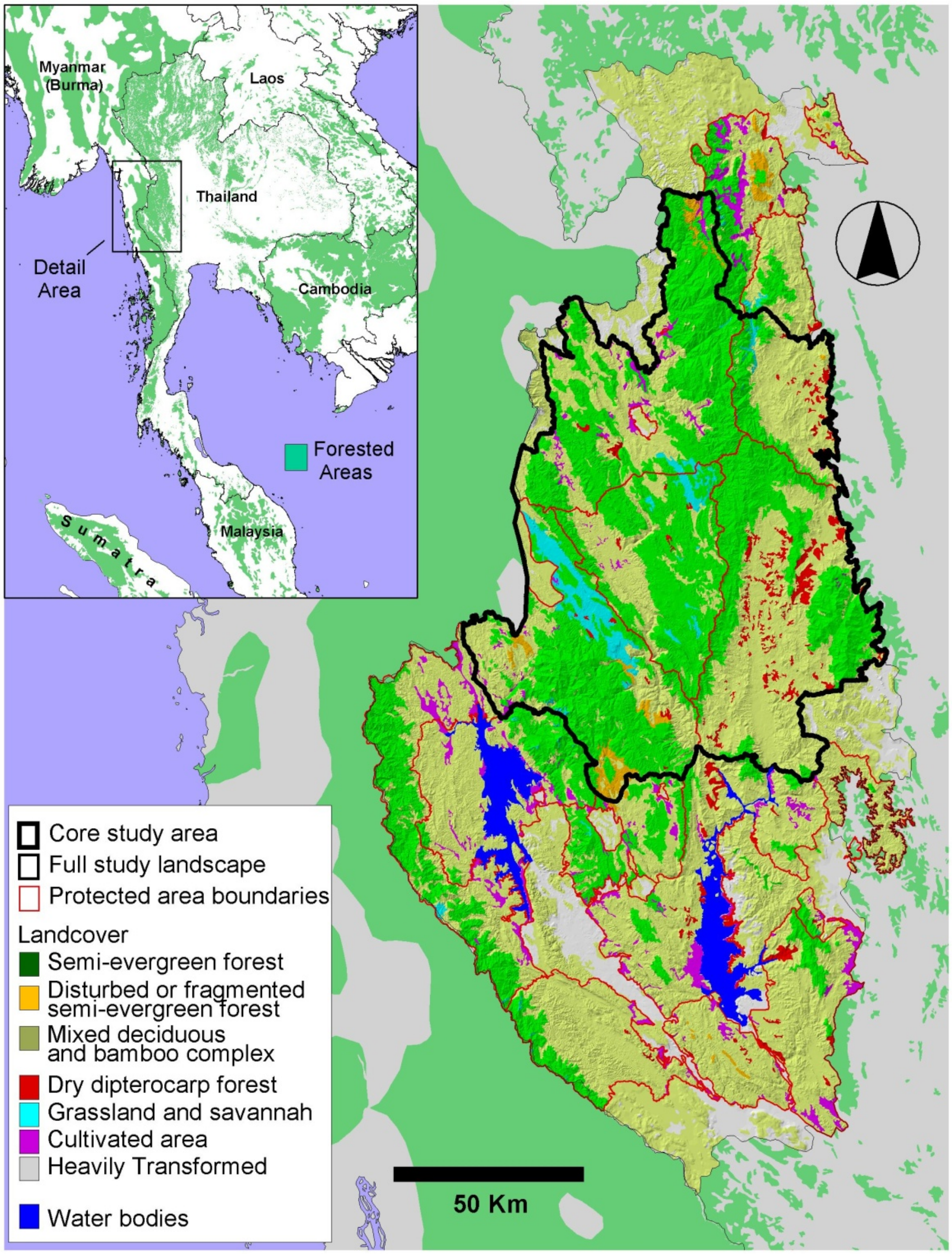

Figure 1-1. Reference map of the study area

Weather patterns in the region are driven by a seasonal monsoon system originating in the Indian Ocean during the wet season (May through October) and by dryer weather from the Pacific Rim during the rest of the year (November through April). Several high mountain ranges intercept monsoon rains during the wet season resulting in a marked difference in precipitation patterns from the southwest to the northeast.

The vegetation pattern within the study area is a mosaic of evergreen and deciduous forests. Bangkurdpol (1979) separates evergreen forests in the area into *semi-evergreen* (or *seasonal* evergreen) and hill evergreen types and deciduous forests into tropical mixed deciduous and dry deciduous (or dry dipterocarp) types. Stands differ markedly in terms of both species composition and structure; few areas exhibit clear edges and most stands are intermediate among the described primary vegetation types. Interspersed with forested areas are smaller patches of natural grassland, savannah woodland, and cultivated fields. Patches of secondary vegetation occur in all forest types where anthropogenic events or the foraging activities of elephants have altered primary structure and composition. Secondary patches are also highly variable; some are dominated by high grasses and shrubs while others have developed larger trees or bamboo. Bamboo (primarily *Bambusa* and *Dendrocalamus* spp.) is common in most of these vegetation types—occurring in both small patches and large stands. Bamboo distribution patterns are frequently associated with disturbance (e.g. annual fire patterns, forest clearing, livestock grazing and elephant foraging).

Human beings have long been a part of this landscape. Ethnic Karen and Hmong populations have lived in villages within the boundaries of the protected areas for at least 200 years. Although some villages have been relocated over the last 40 years as part of protected area establishment and management efforts, approximately 4000 people (mostly Karen) still live at about 35 village sites—most near the Thai/Myanmar border. Most villages practice a rotating crop system with dry-farmed rice as their staple food. However, an increasing number of villages are moving to paddy rice cultivation with sometimes elaborate, semi-permanent irrigation systems. Additionally, over 70 permanently staffed forest protection stations in and around the area house over 300 people. Outside of the protected area boundaries, human population densities increase substantially. Although officially restricted, activities such as the collection of forest products, hunting, fishing and logging--originating from villages and stations both inside and outside of protected areas—take place to some degree throughout most of the region.

Methods

Data on the occurrence of tigers and the relative abundance of tiger prey were collected between 1997 and 2000 over ~10,000 km^2 of Thailand's Western Forest Complex in west-central Thailand (referred to here as the “core study area”). Tiger occurrence was recorded based on the presence of unambiguous sign.

Based on published accounts of tiger-habitat relationships, a number of landscape-scale variables presumed to be related to tiger and tiger prey distribution were mapped as continuous surfaces for a large area of western Thailand extending beyond the core study area. This larger area, referred to here as the “study landscape”, covers approximately 25,000 km^2.

Data were derived from both field surveys conducted during the course of this analysis and from various existing sources (described in detail below). Using data collected from the core study area, standard regression techniques were used to develop three predictive models 1) a continuous model of relative tiger prey quality (“prey model”), 2) a continous surface model of likelihood of tiger sign encounter (“logistic model”), and 3) a model of tiger sign encounter rates within large, discrete units based on watershed and other natural features.

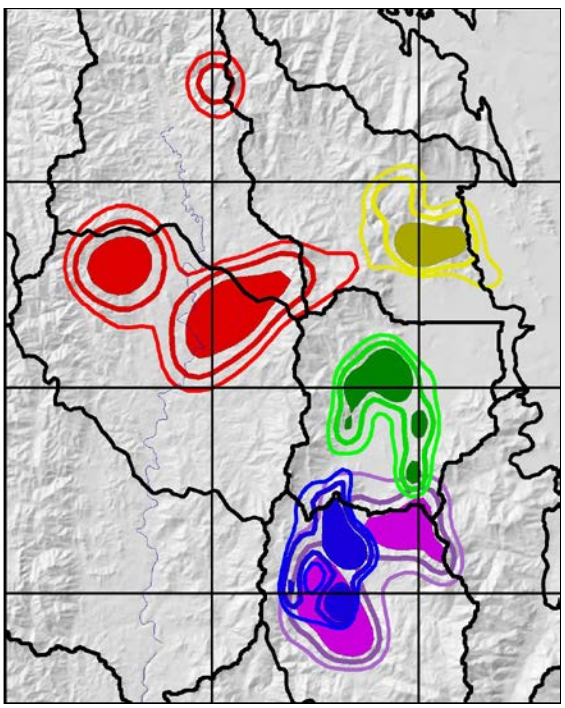

Figure 1-2. Home ranges of five tigers in Huai Kha Khaeng Wildlife Sanctuary showing grid-based survey units (narrow black lines) and ecologically-derived survey units (ESUs (thick black lines)). Movement patterns of individual tigers mostly align with ESU boundaries making ESUs preferable to grids for many survey and modelling purposes.

Of the two tiger habitat models, the logistic model roughly reflects third order habitat selection (e.g. selection of habitat patches within home ranges (Johnson 1980)) whereas the model based on natural topographical features roughly reflects second order tiger habitat selection (e.g. selection of home ranges within the landscape (Johnson 1980)).

Defining Survey Units

Survey units provide an explicit basis for organizing surveys and for summarizing and analyzing wildlife occurrence data. Uniform grid squares are often used for expressing occurrence patterns and when little is known about how the movements of a target animal relate to other features on the landscape, this configuration may be reasonable. However, in many modeling situations, details of survey unit configuration can be adapted to minimize violations of model assumptions and improve inference.

I developed a system of contiguous, irregular spatial units that were delineated on the basis of watershed boundaries, large rivers, and, where further subdivision was necessary for units to fall within a target size range, on administrative boundaries or partial ridgelines. I refer to these as ecological survey units (ESU) to emphasize that they are based on natural features rather than arbitrary grid squares.

High resolution studies of tiger movement in the study area demonstrate that while tigers frequently move throughout large areas of low slope habitat, they rarely use midslope areas and ridgetops and even more rarely regularly cross over high ridges in their movements (Saksit Simcharoen, pers. comm.). The result of this is that home range areas tend to be bounded by, rather than intersect, ridges. Additionally, whereas tigers are strong swimmers capable of crossing wide streams and other bodies of water, like other authors (e.g. Barlow (2008)) I concluded that sufficiently deep, wide and fast-flowing streams likely represent similar boundaries to tiger movement. These features would probably present a risk to an adult animal trying to cross and would certainly be dangerous to an adult moving with cubs.

These ‘semi-permeable’ barriers to tiger movement thus tend to define home range boundaries more often than not. Any survey configuration integrating these boundaries will thus have a higher likelihood of satisfying closure assumptions and will therefore yield better estimates within an occupancy analysis framework.

I first used a digital elevation model and topographic algorithms available in standard GIS software (ESRI 2002) to identify watershed units larger than 100 km^2. Where these calculated watersheds were larger than 300 km^2, I further divided them along such features as partial ridgelines, wide, permanent streams (which present a barrier to both wildlife and human movement), and/or protected area boundaries to achieve spatial units of approximately 150 km^2. This target size was selected to roughly reflect the size of male tiger home ranges in this area (estimated at 168 km^2 based on a long-term study of radio-collared individuals (Saksit Simcharoen, pers. comm.)). Proceeding in this way, I delineated contiguous ‘ecologically-derived’ survey units (‘ESUs’) covering the entire Western Forest Complex (Figure 1-2).

These ecologically-derived survey units (ESUs) have several useful properties:

- They can be readily identified in the field through reference to distinct topographic and other natural features;
- They roughly reflect the movement patterns of resource use and of many large mammal species (e.g. heavier use in lower, flatter areas with more permanent water, lighter use in higher, more rugged areas with more ephemeral water);
- They parallel human impact patterns (e.g. higher impacts and more travel routes in lower areas); and

Documenting Response Variable – Tiger Prey Relative Quality

I counted the number of dung piles (e.g. deer pellet clusters, wild bovid dung boluses, and other tiger prey fecal occurrences) along 500 m transects consisting of twenty-five 10 m^2 circular plots spaced 20 m apart. I carefully searched each plot for dung piles as well as for tracks and other sign. I then summed individual plot data for all plots in each transect. Although much of the sign encountered could be unambiguously assigned to an individual species, tracks and pellets from one of two barking deer species known to occur in the area (common muntjak (*Muntiacus muntjak)* and Fea's barking deer (*Muntiacus feai*)) were grouped as were the dung and tracks of two wild cattle species (banteng (*Bos javanicus)* and gaur (*Bos gaurus)*). Figure 1-3 shows transect locations and numbers of pellet piles/dung boluses for 4 prey species. To summarize prey abundance as a single variable relevant to tigers I converted dung piles to sambar units. A sambar unit is based on the relative weight of each species compared to the weight of a sambar (Shrestha 2004).

$$\sum_{i=1}^{n} \textbf{(number of dung/pellet groups) * (average weight of prey species/average weight of sambar deer)}$$

Where $n_1 \ldots n_i$ are the species for which pellets/dung were recorded. For the purposes of this analysis, I assumed both defecation and deterioration rates were equal for all species over all survey units. Average weights of species considered in the analysis and associated "sambar units" are shown in Table 1. Mass estimates for *Cervus unicolor, Muntiacus muntjak, Sus scrofa*, and *Hystrix brachyura* are taken from Sunquist et al. (1999) and represent the estimated sex and age class ratios of animals actually killed by tigers in Nagarahole National Park, India. The estimate for *Bos* spp*.* reflects the estimate for *Bos frontalis* in the same study. Estimates for *Tragulus javanicus* and *Capricornus sumatraensis* are reported lower weight range estimates following Lekagul and McNeely (1977).

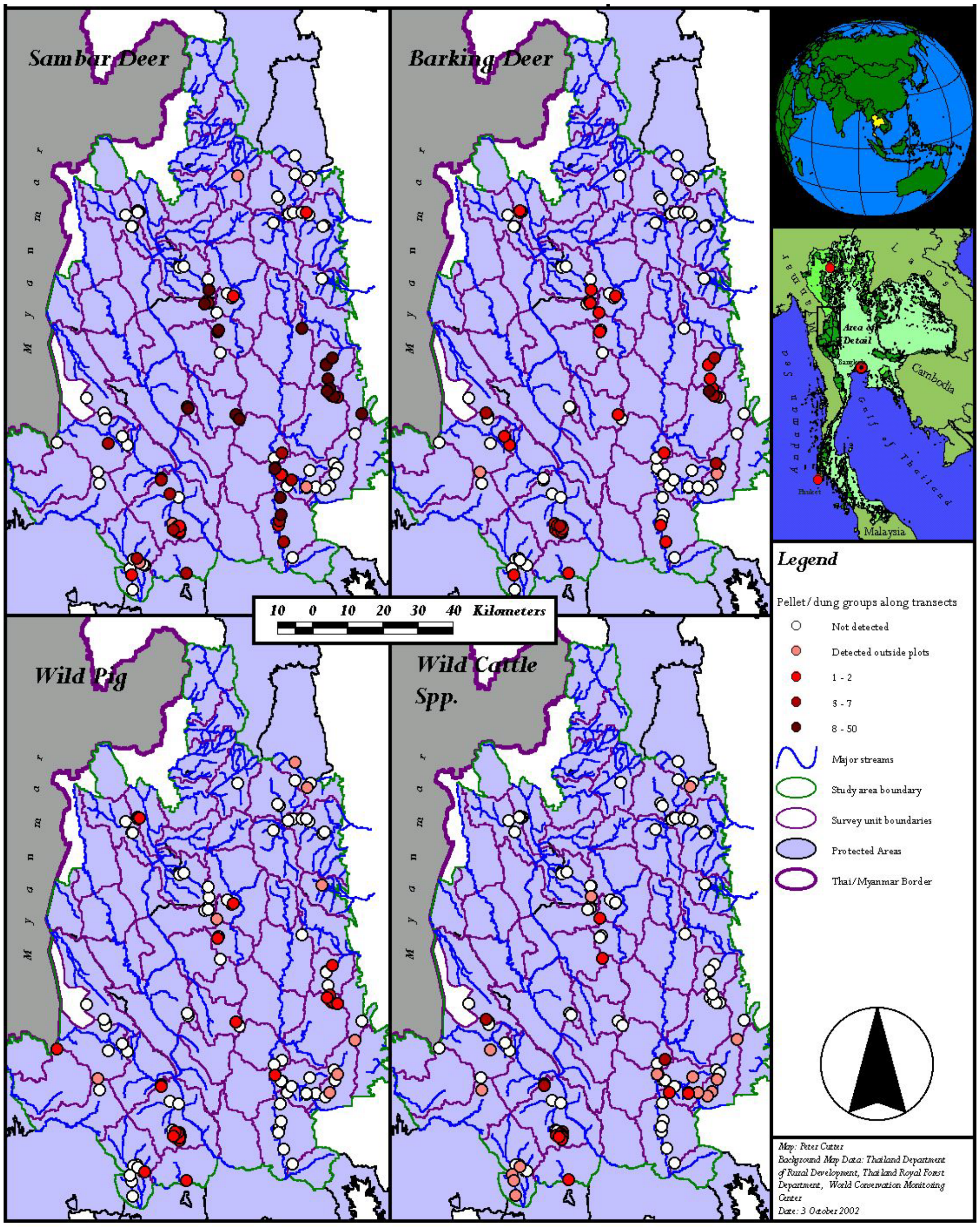

Figure 1-3. Summary maps of tiger prey relative abundance (by species).

Table 1-1. "Sambar units" calculated from relative weights of prey species encountered in transects. Biomass estimates for Cervus unicolor, Muntiacus muntjak, Sus scrofa, and Hystrix brachyura are taken from Sunquist et al. (1999) and represent the estimated sex and age class ratios of animals actually killed by tigers in Nagarahole National Park, India.

Species	Estimated Average Mass of Killed Animals (kg)	Source of Estimate	Sambar Units
Cervus unicolor **(sambar deer)**	212	Sunquist et al. 1999	1.00
Muntiacus muntjak **(barking deer)**	20	Sunquist et al. 1999	0.09
Bos spp. **(banteng and gaur)**	287	Sunquist et al. 1999[1]	1.35
Sus scrofa **(wild pig)**	38	Sunquist et al. 1999	0.18
Hystrix brachyura **(Malayan porcupine)**	8	Sunquist et al. 1999	0.04
Tragulus napu **(greater mouse deer)**	4	Lekagul & McNeely 1977 – Lowest weight in adult range	0.02
Capricornus sumatraensis **(serow)**	103	Lekagul & McNeely 1977 – Lowest weight in adult range	0.49

Documenting Response Variable – Tiger Occurrence and Encounter Rates

Extensive surveys were carried out within the study landscape to document the occurrence of tiger sign and subsequently calculate encounter rates expressed as the number of signs encountered per km of survey route conducted within each ESU. One assumption underlying the collection of these data and their use in the models introduced here is that a positive correlation exists between the rate of sign encountered in an area and the density of animals in that area. Although this assumption has not been independently validated within the study landscape, significant and useful correlation of sign abundance and density has been established for numerous other carnivores under similar situations (Miquelle et al. 2002; Sharp et al. 2001; Staender 1998; Tuyttens et al. 2001; Webbon et al. 2004) and this relationship is a key element in a number of active landscape-scale conservation projects (Miquelle et al. 2002; Wilson & Delahay 2001). One weakness of the use of these raw encounter rates is that this statistic does not account for detection probabilities--which are certainly less than 1.

Compilation and Preparation of Predictor Variables

Landscape variables considered in this analysis included those judged to be significant to tiger prey distribution and/or tiger distribution based on published literature, personal experience, and the availability of continuous data at this landscape scale. To provide consistency for calculations and interpretation, predictor variables for models were translated into 50m x 50m gridcell continuous spatial datasets (Figures 6-13).

Many of the datasets used were derived from baseline data provided by the Department of National Parks, Wildlife and Plant Conservation (DNP), the Western Forest Complex Ecosystem Management Project (WEFCOM) (Smith et al. 1989; Western Forest Complex Ecosystem Management Project 2004), Department of Rural Development, Kasetsart University, Chulalongkorn University, and the World Conservation Monitoring Center. Data on human activity levels and relative prey abundance were derived from data collected in the field.

Elevation and ruggedness were derived from a digital elevation model (DEM) of the area which in turn had been constructed based on a triangulated area network based on nodes of contours of 1:50000 scale topographical maps). Ruggedness was calculated using a "neighborhood analysis" or kernel approach whereby the standard deviation of all cells contained within a constant-sized circular area around each cell in the coverage was assigned to that cell.

Landcover-related variables were derived from a high-resolution landcover map of the area (van de Bult 2003) combined with ancillary GIS information from the CommDev GIS project (Thailand Department of Rural Community Development & Chulalongkorn University 1999). Although this dataset was the best available general landcover map available for this area at the time, there remain concerns about the utility of the ecological types with regard to ecological modeling applications (van de Bult pers. comm.). Specifically, the major forest types are so generalized that they may not reflect some of the patterns that are likely related to ungulate distribution and movements such as frequency and extent of canopy openings, density of key grazing and browsing species, density of understory vegetation, etc.

Two additional variables, human activity index and relative prey density, were compiled through more elaborate procedures as described below.

<u>Human activity index</u>. Areas of relatively high human activity were mapped by combining mapped patterns of human activity with the results of systematic interviews of DNP personnel and local residents near the end of the fieldwork period (November 1999-December 2000) (Figure 1-11). Interviews were conducted with either individuals or focus groups using 1:50,000 scale topographic maps for reference. Interview sessions began

with a spatial orientation period in which subjects and interviewers clarified the names and geographic relationships of locally important landmarks such as streams, peaks, and unique vegetation patterns. This step facilitated the development of a shared spatial context within which information gathered could then be placed.

In the course of the interview process, the following areas were identified and mapped:

- hunting and collecting routes that are used on at least a monthly basis (mapped as areas representing a 1 km buffer around mapped routes) and
- areas of intensive bamboo or other forest product harvesting, hunting activity, or selective logging (e.g. areas where humans are estimated to be present in the area for more than 30 days per year).

These areas were then combined with paved roads with open public access (mapped as areas representing a 1 km buffer around roads), and human settlement areas (mapped as areas representing a 2 km buffer around towns, villages, and other known clusters of human settlement)

to generate a map classifying all areas as having relatively high human activity or low human activity.

Relative prey abundance***.*** A continuous surface reflecting relative prey quality was constructed using standard multivariate regression techniques to fit a model associating ecological variables with an index of relative prey abundance. This model was then used to extrapolate the modeled relationship over the entire study landscape (see details below). The model was based on pellet/dung counts (response variable) and a number of predictor variables occurring at 112 buffered transect locations throughout the core of the study area (see Figure 1-4).

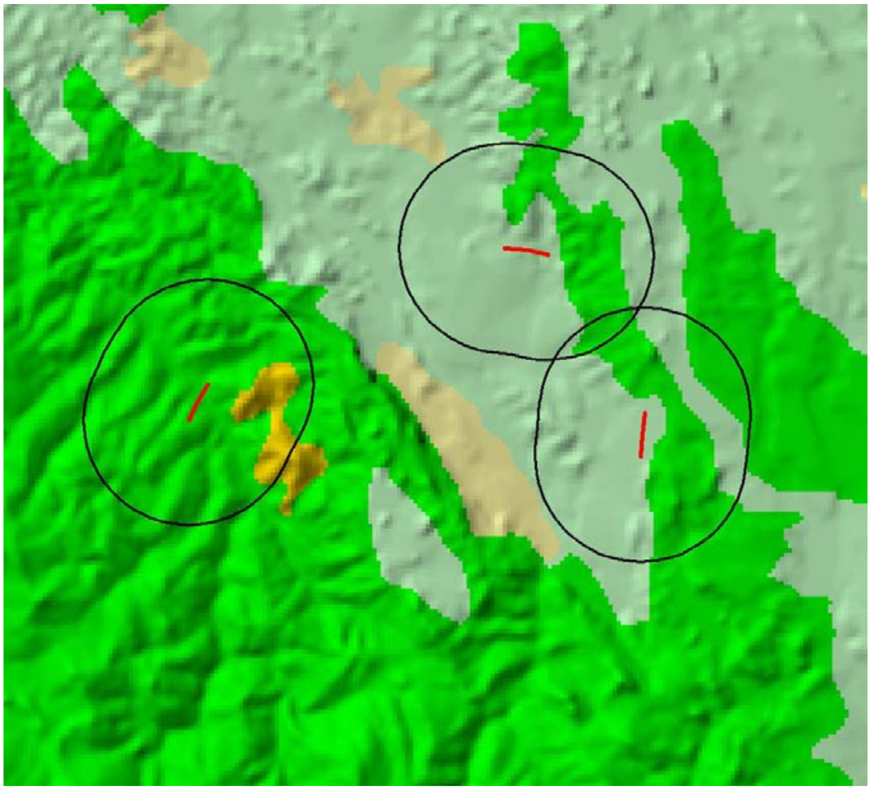

Figure 1-4. Configuration of buffer regions (radius = 1.3 km) around prey survey plot lines. Predictor variable values represent summary values for these areas.

Modeling and Evaluation Procedures—General Description

The development of predictive models was carried out using an information-theoretic (IT) approach (Burnham & Anderson 2002) as suggested by MacNally (2000). Rather than finding a given model “significant” or not, the IT approach focuses on the comparative predictive value of models from a plausible set of possibilities.

For each model-fitting process, the distribution pattern of the measured response variables informed the selection of an appropriate model form (e.g. standard least squares, generalized linear model, etc.) and extreme outliers were removed. A conservative number of plausible models was then developed reflecting the documented ecology and behavior of the species considered. Where there was strong correlation between predictor variables (e.g. $|r| > 0.5$), the variable most practically accessible to efficient field measurement was retained to maximize the practicality of models with regard to fieldwork.

Data from sample locations were used to define a relationship between predictor and response variables using a least squares model fitting approach. Potential models were then evaluated on the basis of Akaike’s (1973) Information Criterion adjusted for small sample bias (e.g. AIC_c (Hurvich & Tsai 1989)) and, in some cases, for small sample size and overdispersion (e.g. $QAIC_c$ (Anderson et al. 1994)). For a set of competing models $\{M_k$: k = 1, 2, . .. $K\}$, AIC_c and $QAIC_c$ are calculated as:

$$AIC_c = (-2 \log L(\theta_k) + 2k) + 2k(k + 1)/(n - k - 1)$$

and

$$QAIC_c = (-2 \log L(\theta_k)/\hat{c} + 2k) + 2k(k + 1)/(n - k - 1)$$

respectively, where $L(\theta_k)$ is the ratio between the maximum of the likelihood function under a given model and the corresponding unconstrained maximum. The variable k is the number of parameters in a given model, n is the number of samples from which the model was built, and ĉ is a variance inflation factor reflecting the level of overdispersion in the data (Liang & McCullagh 1993). Because AIC_c values converge to AIC with large sample sizes, it is good practice to use AIC_c calculations in most cases (Burnham & Anderson 2004). Models with relatively low AIC_c values (or $QAIC_c$ values) within a set of competing models are those deemed most plausible given the data.

Initial model evaluation was based on a comparison of ΔAIC_c values. For a given model:

$$\Delta AIC_c = AIC_{c(i)} - AIC_{c(min)}$$

where $AIC_{c(i)}$ is the model of interest and $AIC_{c(min)}$ is the model with the lowest AIC_c value for a given set. A model with a ΔAIC_c value of at least 2 below any other model in a set of competing models can be said to have significantly more predictive strength than other models in the set, whereas models with ΔAIC_c values of greater than 10 are not supported by the data (Burnham & Anderson 2004).

Another useful set of values arising from the information-theoretic model evaluation framework is the Akaike weights for a model set. Assuming a balanced model set where each variable appears a similar number of times, when Akaike weights are summed for all models containing a particular predictor variable, the resulting values indicate the relative importance of each predictor in terms of predicting response variables (Johnson & Omland 2004). In some cases, this inference method was used to compare a set of single variable models to gain insight into the univariate predictive values.

Best-supported models were tested for spatial autocorrelation of response residuals by comparing calculated Moran's I statistics with test distributions. I used ArcView GIS software (ESRI 2002) to manage geographic data, extrapolate results, and produce predictive maps; JMP statistical software (SAS Institute Inc. 2005)to fit and compare models; and GeoDa spatial statistics software (Anselin 2004) to perform tests of spatial autocorrelation.

Model Development and Evaluation—Prey Quality Index

The prey quality model was developed using predictor and response variables associated with 114 pellet/dung transect locations (see Table 1-2). Values for predictor variables were derived by averaging cell values from continuous surfaces occurring within an area defined by a 1.3 km buffer around each transect (Figure 1-4). The 1.3 km buffer distance was selected to result in overall buffer areas of ~6 km^2 – reflecting the upper size estimates of female sambarhomeranges and the lower size estimates of sambar stag homeranges (Richardson 1972; Sankar 1994; Shea 1986).

Table 1-2. Description of variables used in the construction of relative prey quality index models. Range, mean, and standard deviation values pertain to areas of 1.3 km radius constructed around linear prey pellet/dung plot lines.

Variable	Value for Sample Areas (areas defined by 1.3 km buffer around each plot line)	Units	Range of Values	Mean	SD	CV
Measured sambar unit values (sample response values used to fit model)	Sambar units per sample (see text)	Sambar units / plot line	0-48.5	4.195	7.679	183
Elevation	Elevation at center of pellet plot line	meters	180.0 - 1341.2	603.8	275.8	46
Ruggedness	Standard Deviation of elevation values within sample areas	SD	16.39 - 177.14	58.98	30.89	52
Human activity index	Percent of high human activity area within sample areas	proportions	0 - 1	0.272	0.310	114
Distance to village	Straight line distance from sample area centroid to nearest permanent water source	Meters	602 - 26728	12890	5283	41
Distance to water	Straight line distance from sample area centroid to nearest permanent water source	Meters	0 - 2511	721	624	87
% dry dipterocarp forest	Percent dry dipterocarp forest within sample areas	%	0 - 0.522	0.057	0.119	209
% mixed deciduous forest	Percent mixed deciduous forest within sample areas	%	0 - 1	0.514	0.378	74
% semi-evergreen forest	Percent semi-evergreen forest within sample areas	%	0 - 1	0.254	0.325	128

The model evaluation set included a single hypothesized "best" model which included ruggedness, human activity index, and % mixed deciduous forest variables. Additional models in the assessment set were designed to compare univariate models and to compare the relative predictive value of the difficult-to-assess ***human activity index*** with a more simplistic measure of human disturbance, ***distance to nearest village***.

Model Development and Evaluation – Tiger Encounter Rates within ESUs

The tiger encounter rate model was developed using predictor and response values associated with 45 ecological survey units in which sign surveys were carried out at a minimum effort rate of 0.08 linear km for per km^2 within the unit. Values for predictor variables were derived by summarizing values for continuous data (e.g. 50 x 50 m grid cells) occurring within each ecological survey unit (Table 1-3).

Table 1-3. Description of variables used in the construction and extrapolation of encounter rate models. Range, mean, standard deviation, and coefficient of variance values pertain to all ecological survey units (ESUs) (n=158) used to extrapolate model results except in the case of tiger sign encounter rate values where reported values pertain only to 45 ESUs used to fit models.

Theme	Units	Value for Sample Areas (ESUs)	Range of Values	Mean	SD	CV
Measured tiger sign encounter rate values	Sambar units / plot line	Values for 45 units surveyed intensively	0.0 - 1.5076	0.187258	0.286405	153
Summed Prey Quality Index	Relative values	Modeled relative prey quality values	-139275 – 326744	19730	71001	360
Mean Prey Quality Index	Relative values	Modeled relative prey quality values	-2.2728 - 4.0566	0.29493	1.17537	399
Mean Elevation	meters	Mean value of all pixels occurring within sample areas	181.87 - 1234.56	605.14	233.78	39
Mean Ruggedness	SD	Standard Deviation of elevation values within sample areas	58.9 - 386.6	190.64	65.86	35
Mean distance to village	m	Mean value of all pixels occurring within sample areas	1876.17 - 28267.96	9199.3	6262.70	68
Mean Human Activity Index	%	Percent of high human activity area within sample areas	0.0 - 0.966	0.255	0.223	87
% dry dipterocarp forest	%	Percent dry dipterocarp forest within sample areas	0.0 - 0.008700	0.000651	0.001460	224
% mixed deciduous forest	%	Percent mixed deciduous forest within sample areas	0.0 - 0.039200	0.012068	0.012058	100
% semi-evergreen forest	%	Percent semi-evergreen forest within sample areas	0.0 - 0.98100	0.30178	0.30144	100

The model evaluation set included a single hypothesized "best" model which included summed prey quality, ruggedness, human activity index, and % dry dipterocarp forest. Additional models in the assessment set were designed to compare univariate models, to compare two plausible representations of human impacts (e.g. a derived 'human activity index' with 'distance to nearest village'), and to compare summed prey quality with mean prey quality within ESUs.

Model Development and Evaluation – Likelihood of Sign Encounter

A logistic regression approach was used to construct a model to predict the likelihood of encountering tiger sign at any point within the study landscape given a nominal amount of focused survey effort. The form of models considered was:

$$p(Y) = (1 + e^{-Xb})^{-1}$$

where '$-\chi b$' represents a linear model of X terms of the form:

$$Y = a + b_1X_1 + b_2X_2 + ... + b_pX_p$$

Predictor values used to fit models were derived by summarizing environmental conditions within circular units defined by a one kilometer radius around tiger detection points and complimentary units defined by a set of survey points where tigers were not detected (Figure 1-5).

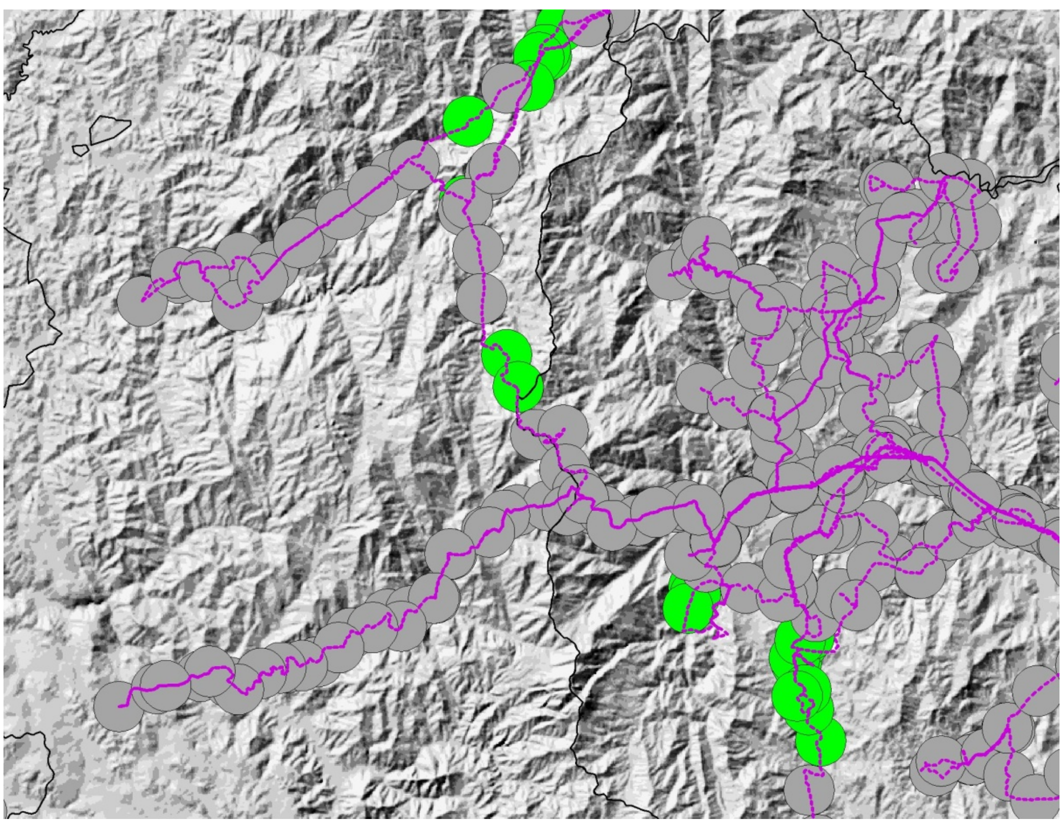

Figure 1-5. Sample areas used to explore logistic regression tiger occurrence models. Dashed purple lines are likely tiger travel survey routes. Detection areas (green circles) are 1 km

radius areas constructed around points where tiger sign was encountered. Non-detection points where tigers were not detected on a given survey. Non-detection points (grey circles) are 1 km radius areas constructed around points spaced evenly (at 1 km intervals) along all stretches of a given survey where tiger sign was not detected.

Table 1-4 summarizes the values used in the logistic regression modeling process.

Table 1-4. Summary of variable values within detection and non-detection areas along surveyed routes.

			Variable means and standard deviations within sample areas	
Variable	**Derivation**	**Units**	**Tiger sign not detected (n=764)**	**Tiger sign detected (n=269)**
Prey Quality Index	Modeled sambar units summed by sample area	Sambar units per plot line	2.267 (5.078)	5.121 (4.989)
Elevation	Mean value of all pixels occurring within sample areas	meters	522.0 (290.1)	674.7 (289.4)
Ruggedness	Standard Deviation of elevation values within sample areas	SD	48.90 (30.65)	39.75 (21.79)
Distance to nearest village	Distance from sample area centroid to nearest population center	meters	10223 (6987)	17757 (5810)
Human Activity Index	Percent of high human activity area within sample areas	%	0.504 (0.418)	0.165 (0.299)
% dry dipterocarp forest	Percent dry dipterocarp forest within sample areas	%	0.5038 (0.3881)	0.377 (0.400)
% mixed deciduous forest	Percent mixed deciduous forest within sample areas	%	0.6601 (0.3750)	0.439 (0.404)
% semi-evergreen forest	Percent semi-evergreen forest within sample areas	%	0.1965 (0.3404)	0.345 (0.380)

Model development consisted of the following steps (carried out sequentially): 1) characterization of response variable form (e.g. normal, Poisson, etc.), 2) removal of highly correlated variables and highly influential outliers, 3) initial specification of a suite of plausible models, 4)calculation of appropriate information-theoretic evaluation statistic, 5) final selection of a preferred model based on information-theoretic statistic and visual evaluation of spatially extrapolated model results, and autocorrelation assessment of model residuals.

Evaluating Model Performance Beyond the Area of Data Collection

Model construction was based on the core area of a larger landscape with similar patterns of land cover, human settlement, and other variables used in the models. While a formal evaluation of model performance over this larger landscape was beyond the scope of this investigation, I used model relationships to extrapolate values to areas beyond the core model. I then used a combination of subjective assessment (Johnson 2001) of mapped patterns and comparison with a limited set of tiger occurrence data to evaluate model performance over this larger area.

Results

Delineation of ESUs

The survey unit delineation process resulted in 157 units ranging in size from 88 km^2 to 251 km^2 with a mean size of 152.24 km^2 (Figure 1-1).

Field Surveys

Surveys were conducted between the months of January and April over four consecutive years from 1997-2000. Total distance covered on walking surveys was just over 1800 km. Excluding several events where distance covered within a survey unit represented very low survey effort, a total of 51 units were surveyed during at least one year and most of these were surveyed during two or more years.

Average survey distance walked within units on a given survey occasion was 17.3 km and ranged from 1 to 171 km.

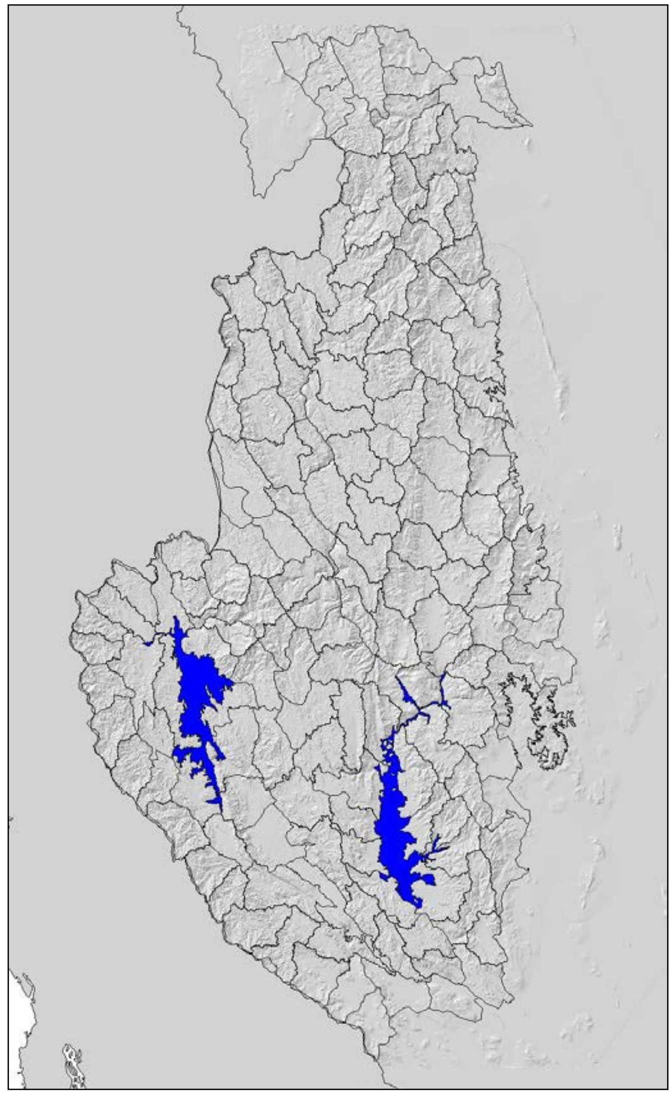

Figure 1-6. Summary map of ecologically-bounded survey units used to organize survey activities and analyze data.

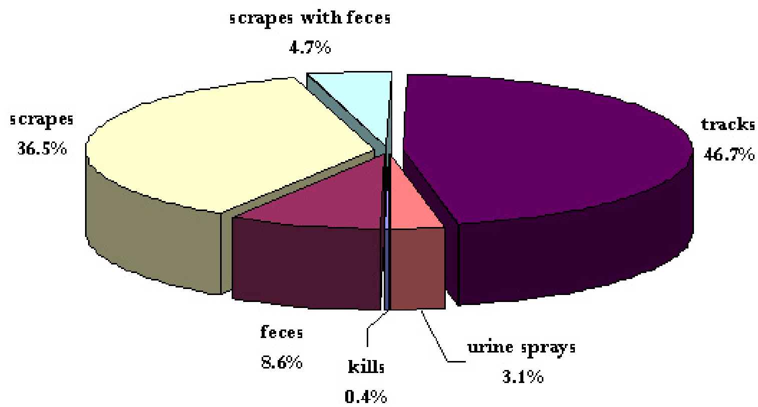

Figure 1-7. Relative proportions of sign categories encountered in a field survey of Indochinese tigers. Numbers are proportions of a total of 271 signs encountered over a total distance of approximately 1860 kilometers of roads, trails, ridges, and streambanks, and dry streambeds.

Average encounter rate (calculated for each survey unit for each survey occasion) averaged 0.227 signs/km and varied from 0-2.3 signs/km.

Tiger sign encountered along survey routes and in the course of other project activities included tracks, scrapes, feces, urine sprays, and the remains of prey items. Of 271 signs encountered, the largest proportion were tracks (Figure 1-7). During sign surveys from 1997-2000 I found tiger sign in each of the 5 protected areas and each of 6 major vegetation types surveyed. (Figure 1.8).

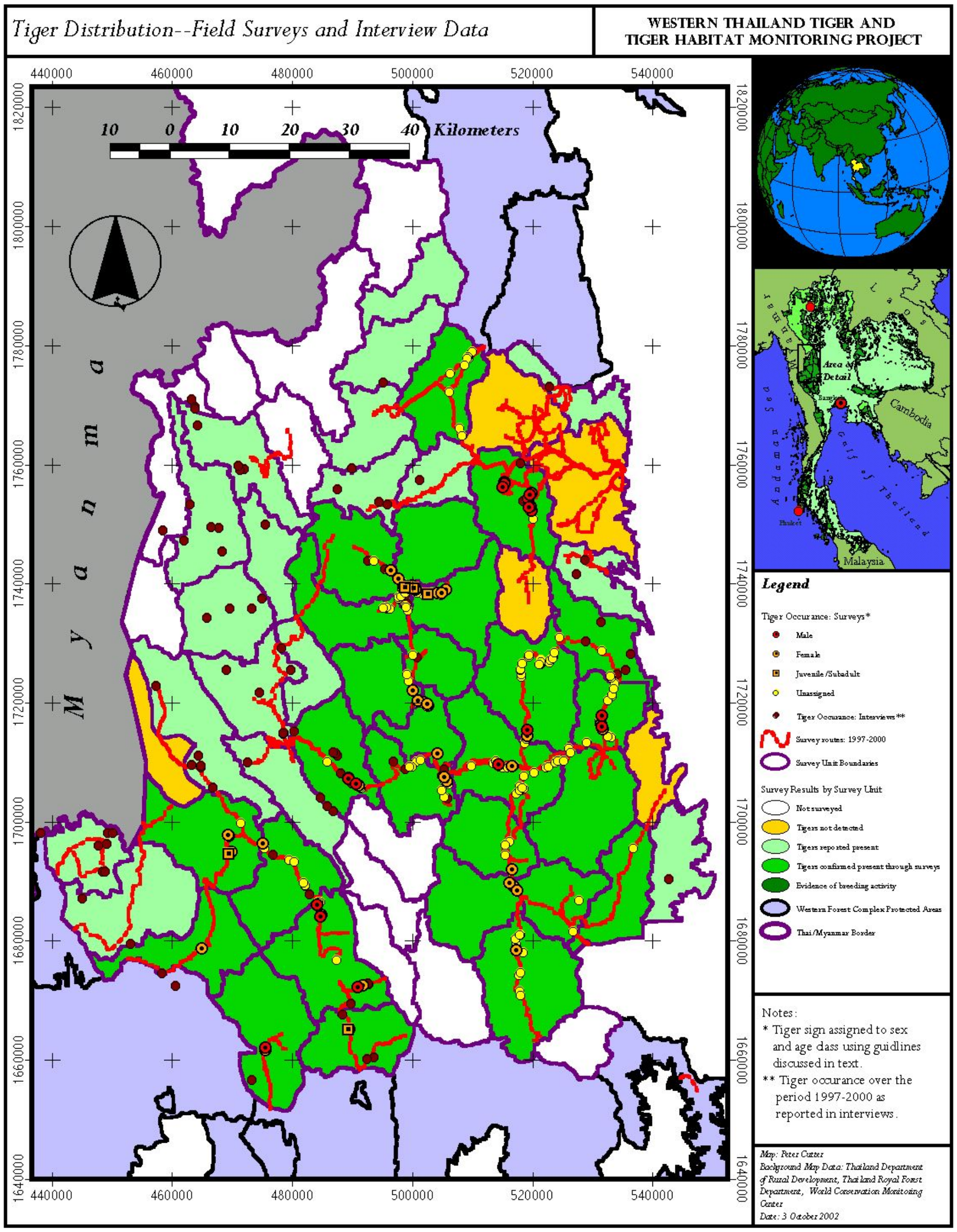

Figure 1-8. Map of tiger sign survey routes and detection locations 1997-2000. The red lines show the routes surveyed and the point data are locations of tiger sign.

Continuous Landscape Variables

Figures 4-12 show the landscape-scale spatial patterns of data themes developed to fit, evaluate, and extrapolate model data.

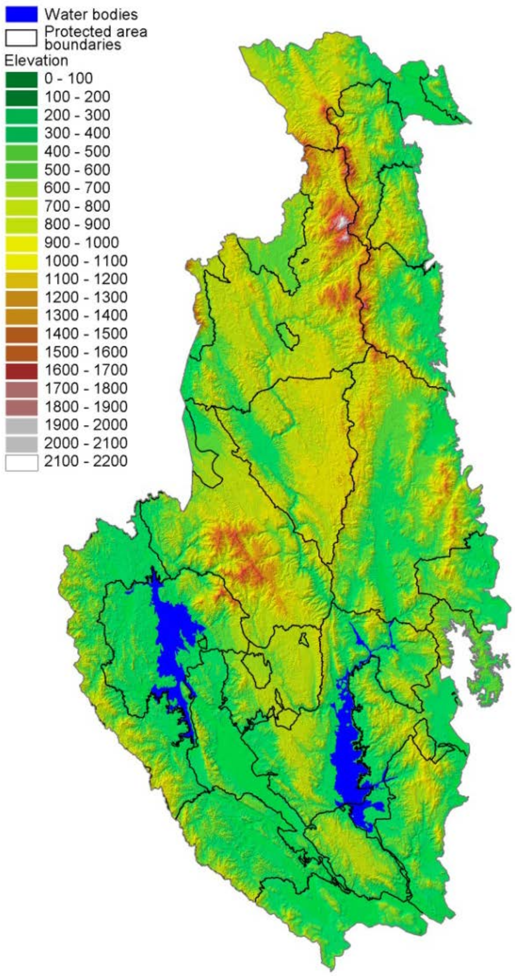

Figure 1-8. Digital elevation model (also used to derive ruggedness index).

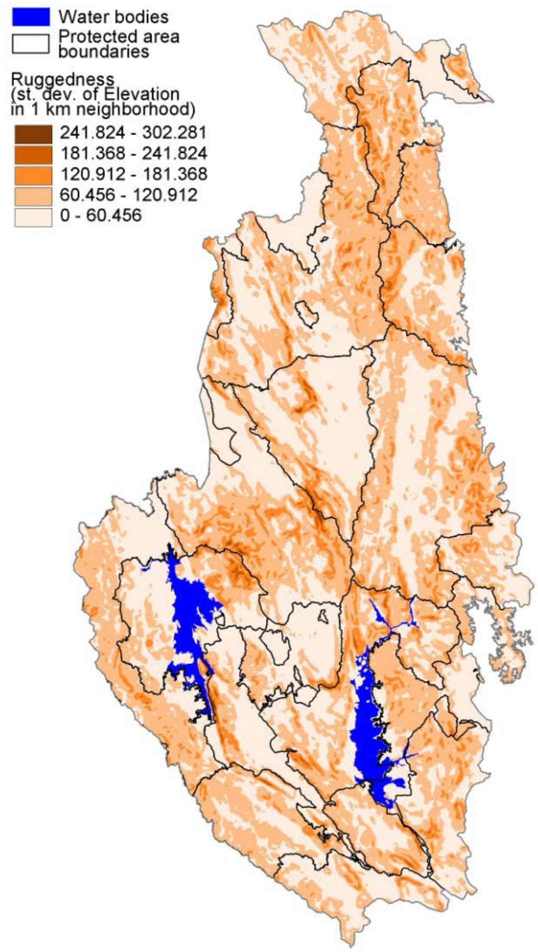

Figure 1-9. Index of ruggedness. Ruggedness is expressed as the standard deviation of elevation within a one km radius "circular neighborhood" around each cell in the model landscape.

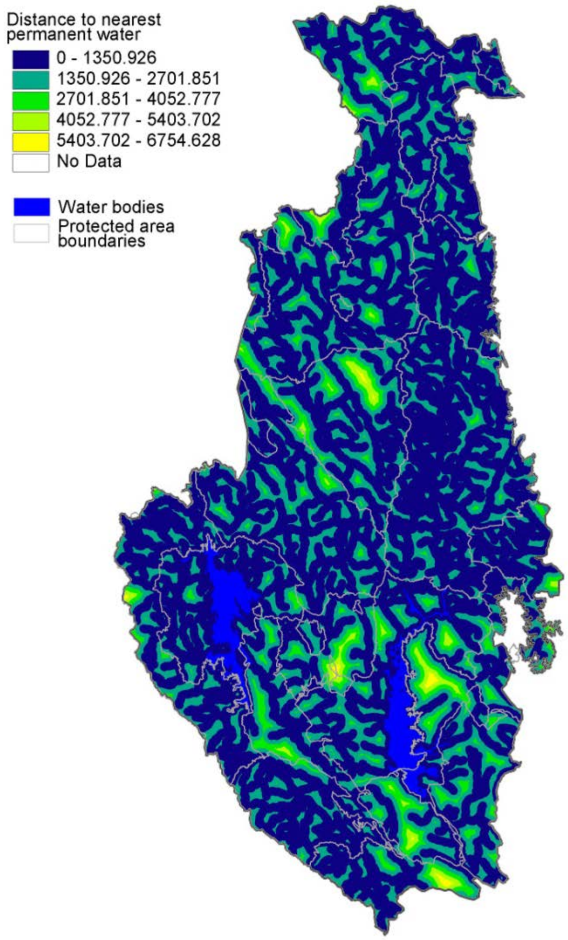

Figure 1-10. Distance to nearest permanent source of water (meters).

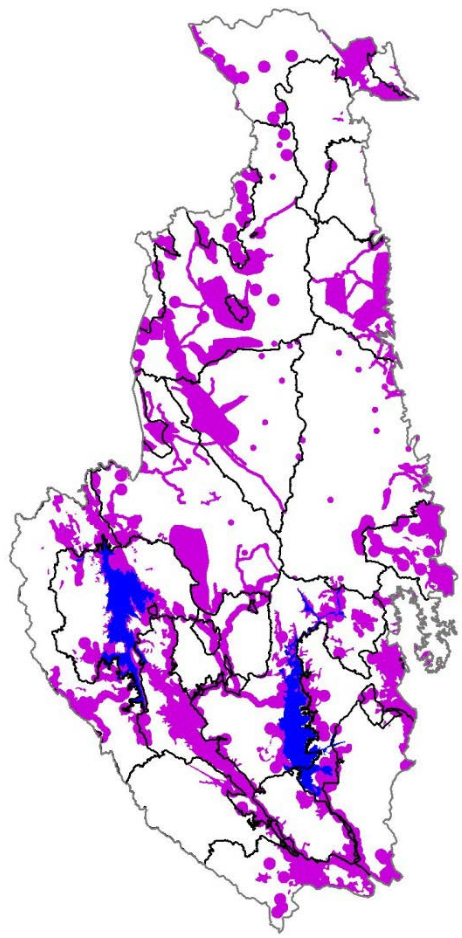

Figure 1-11. Areas of high relative human activity. Map derived from interviews at over 100 villages and forest stations throughout the study landscape (see text for detailed description of methods).

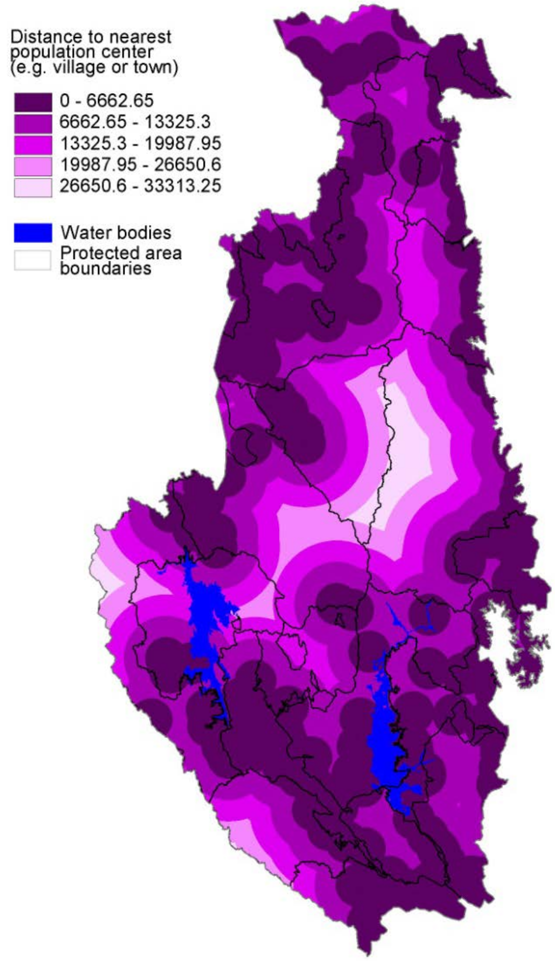

Figure 1-12. Distance to nearest population center (meters).

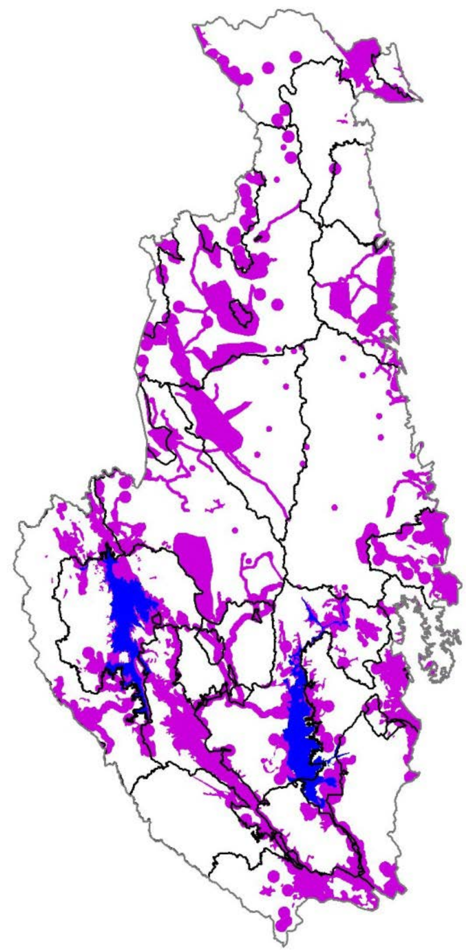

Figure 1-13. Zones of high human activity.

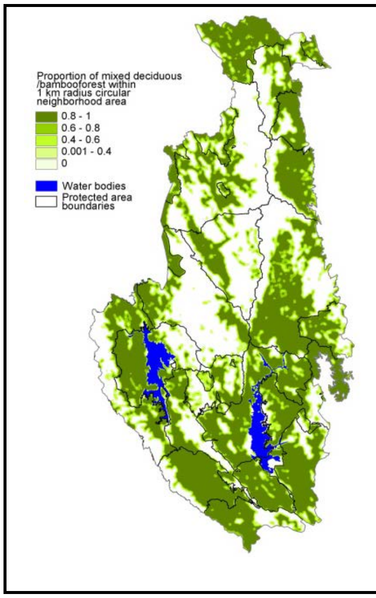

Figure 1-14. Proportion of mixed deciduous forest within 1 km radius circular neighborhood area.

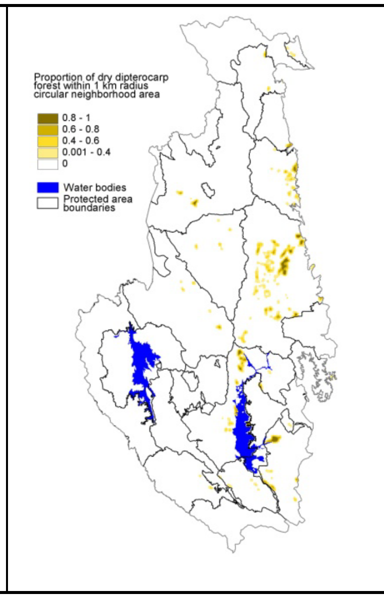

Figure 1-15.Proportion of dry dipterocarp forest within 1 km radius circular neighborhood area.

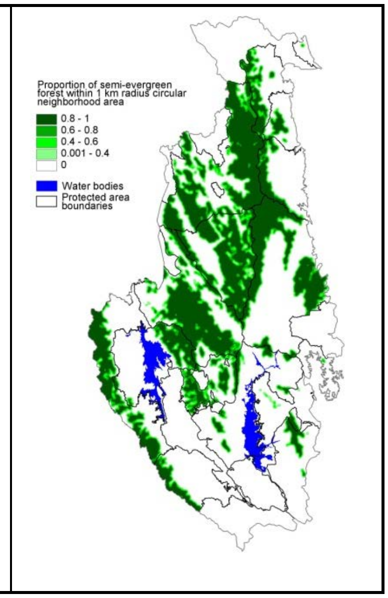

Figure 1-16. Proportion of semi-evergreen forest within 1 km radius circular neighborhood area.

Tiger Prey Model

The form of the response data set was Poisson so I used a general linear model platform for poisson distributions. Screening of variables for bivariate correlation revealed a strong correlation between percent mixed deciduous and percent semi-evergreen forest values. The semi-evergreen variable was retained due to its narrower ecological definition and therefore greater practical and interpretive value. One extreme outlier (sambar units = 48) was removed from the model fitting process. All models showed evidence of overdispersion (c-hat = 8.2-10.8) and so the $QAIC_c$ statistic was used for comparison.

The respective univariate predictive values of *distance to nearest village* and the more difficult to compile *human activity index* were similar. Given that the human activity index variable will always be expensive and time-consuming to compile as it requires extensive interview and field mapping work, the more efficient *distance to nearest village* variable was retained for subsequent model assessment and interpretation.

Models evaluated and corresponding $QAIC_c$ values are summarized in Table 1-5.

Table 1-5. Comparison of prey models by predictive value. Lower QAICc values represent better supported models given the data.

		Sample Size	# of param-eters	variance inflation factor	negative log Likelihood	Adjusted AIC	Distance from lowest AIC	log transformed Δ	AIC wieght
No.	**Model**	**n**	**k**	$\hat{c}$	$-\ell(\theta)$	**QAIC$_c$**	Δ_i	$_e\Delta_i$	w_i
1	hdisturb	113	1	10.797	51.71	11.61	0	1	.26
2	dist2vill	113	1	10.07	52.237	12.41	0.8	0.6715	0.24
3	%sef	113	1	10.39	54.51	12.53	0.9	0.6327	0.22
4	ruggedness	113	1	10.073	53.7	12.70	1.1	0.5816	0.20
5	elevation	113	1	9.39	58.13	14.42	2.8	0.2457	0.09
6	%dd	113	1	9.04	56.14	14.46	2.8	0.2415	0.09
7	rggd+dist2vill	113	2	9.786	51.536	14.64	3.0	0.2201	0.08
8	rggd+dist2vill+ %sef	113	3	9.847	51.021	16.58	5.0	0.0834	0.03
9	el+rggd	113	2	8.938	58.355	17.17	5.6	0.0623	0.02
10	rggd+dist2vill+ %dd	113	3	8.70	49.80	17.67	6.1	0.0485	0.02
11	el+dist2vill	113	2	8.265	58.834	18.35	6.7	0.0345	0.01
12	el+rggd+dist2vil l	113	3	8.362	56.572	19.75	8.1	0.0171	0.01

Based on QAIC$_c$ values, the best-supported models were the univariate models reflecting human disturbance (e.g. the human disturbance index and distance to village as predictors). Given the greater efficiency of the distance to village variable as discussed above and similar model performance, the univariate model using this variable was retained for use in subsequent models. Univariate models including human disturbance, percent semi-evergreen forest, and ruggedness all performed well. However, given concerns about the ecological breadth of definitions used for forest types, I used the model combining human disturbance with ruggedness to extrapolate predicted prey densities over the study area.

An autocorrelation assessment of model residuals indicated that autocorrelation is present in the fitted model (Moran's I = 0.225, p = 0.001, n = 113) so estimates of standard errors should be viewed with caution. A map of this model extrapolated to the entire study landscape is shown in Figure 1-17.

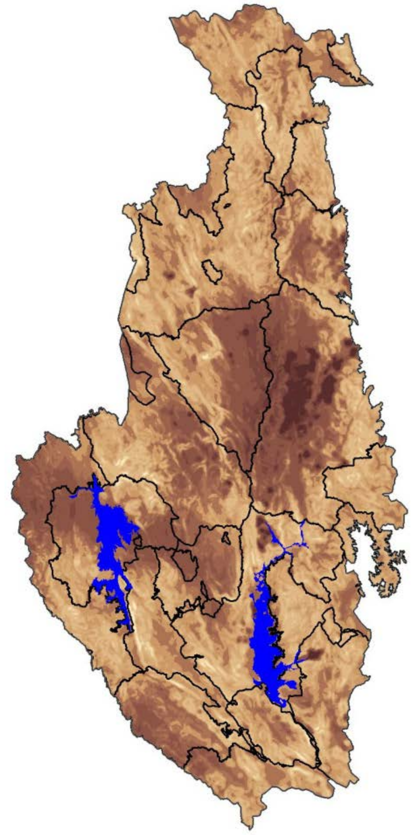

Figure 1-17. Tiger prey relative quality (results of extrapolation of predictive model).

Tiger ESU Model

The most likely form of the response data set was poisson so modeling proceeded using a general linear model platform for poisson distributions. Initial screening of variables indicated unacceptable correlations between summary and mean prey quality index values and between percent mixed deciduous forest and percent ddsemi-evergreen forest. Mean prey quality index was retained as it is more efficient to assess in the field (e.g. does not require assessment of prey quality in all areas of an ESU). Percent semi-evergreen forest values were retained based on the fact that the semi-evergreen forest type has a narrower ecological definition and is therefore likely to have higher interpretive value in resulting models. An examination of the plot of studentized residuals against predicted values did not indicate any extreme outliers so all data points were retained in the modeling process.

There was no indication of overdispersion in the model set so the AIC_c statistic was used for model comparison. The top model was a single varaible model of just prey abundance (Table 1-6).

Table 1-6. Comparison of tiger encounter rate models at the ESU scale by AIC_c values. Lower AIC_c values represent higher predictive value given the data used to fit models.

		Sample Size	# of param-eters	negative log Likelihood	Adjusted AIC	Distance from lowest AIC	log trans-formed Δ	AIC wieght
No.	**Model**	**n**	**k**	**$-\ell(\theta)$**	**AIC_c**	**Δ_i**	**$_e\Delta_i$**	**w_i**
1	prey_mean	45	1	18.8717	39.836	0.000	1.00000	0.16618
2	dist2vill	45	1	18.9416	39.976	0.140	0.93249	0.15496
3	prey_sum	45	1	19.0951	40.283	0.447	0.79979	0.13291
4	human_pct	45	1	19.4406	40.974	1.138	0.56615	0.09408
5	prey_mean+el	45	2	18.4655	41.217	1.380	0.50150	0.08334
6	prey_mean+rggd	45	2	18.8017	41.889	2.053	0.35831	0.05955
7	prey_mean+dist2vill	45	2	18.8246	41.935	2.098	0.35020	0.05820
8	lusef	45	1	20.0698	42.233	2.396	0.30177	0.05015
9	el	45	1	20.2765	42.646	2.810	0.24542	0.04078
10	rggd	45	1	20.4668	43.027	3.190	0.20289	0.03372
11	prey_mean+el+dist2vill	45	3	18.4619	43.509	3.673	0.15939	0.02649
12	ludd	45	1	20.7476	43.588	3.752	0.15322	0.02546
13	prey_mean+dist2vill+ludd	45	3	18.527	43.639	3.803	0.14935	0.02482
14	prey_mean+rggd+ludd	45	3	18.5284	43.642	3.806	0.14914	0.02478
15	rggd+dist2vill+prey_mean	45	3	18.6405	43.866	4.030	0.13332	0.02216
16	el+rggd+prey_mean+dist2vill+ludd	45	5	18.3807	48.300	8.463	0.01453	0.00241

Table 1-7. Variables in best performing tiger sign encounter rate model showing coefficients, standard errors, and significance values and significance values derived from the chi-square test of individual variable influence.

Variable	Coefficient	SE	*P*
Intercept	-2.109453	0.265130	
Mean prey quality index	0.8369534	0.235111	0.0004

An assessment of autocorrelation in the preferred model indicated an acceptable level of autocorrelation (Moran's I = 0.038, p = 0.291, n = 45) indicating that estimates of coefficient standard error are robust.

Tiger Logistic Model

Response variable values were binary (e.g. tiger sign detected or not) so standard logistic regression techniques were used to fit and evaluate models. Initial screening of variables for correlation indicated that ruggedness and distance to nearest village variables were both closely related to prey mean so the more process-oriented prey quality index value was retained for further analysis. Percent dry dipterocarp, mixed deciduous, and semi-evergreen forest values were closely correlated with each other. The percent dry dipterocarp variable was retained because these patterns are relatively easy to quantify over large areas and dry dipterocarp forest occurs throughout an area where relatively high tiger densities have been well documented (Simcharoen et al. 2007).

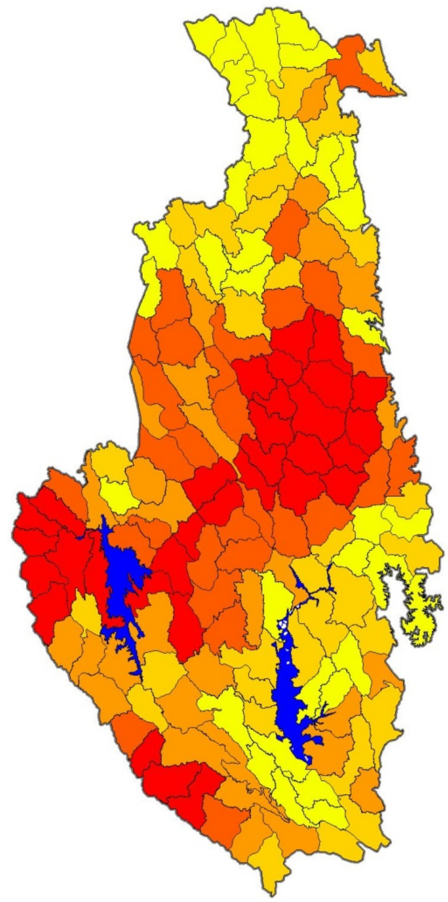

Figure 1-18. Map of predicted relative tiger sign encounter rates within ESUs based on preferred model (mean prey quality index values only).

Models showed no sign of overdispersion so the AIC_c statistic was used for IT assessment of model performance.

A summary of models with associated AIC values is shown in Table 1-8.

Table 1-8. AICc comparison of tiger logistic models.

		Sample Size	# of parameters	negative log Likelihood	Adjusted AIC	Distance from lowest AIC	log transformed Δ	AIC wieght
No.	**Model**	**n**	**k**	**$-\ell(\theta)$**	**AIC_c**	**Δ_i**	**$_e\Delta_i$**	**w_i**
1	prey_mean+elevation	1033	2	471.961	947.934	0.000	1.00000	0.72985
2	prey_mean+elevation+dd	1033	3	471.949	949.921	1.988	0.37015	0.27015

		Sample Size	# of parameters	negative log Likelihood	Adjusted AIC	Distance from lowest AIC	log transformed Δ	AIC wieght
3	prey_mean+dd	1033	2	491.742	987.496	39.562	0.00000	0.00000
4	elevation+dd	1033	2	566.863	1137.738	189.804	0.00000	0.00000
5	prey_mean	1033	1	514.670	1031.344	83.410	0.00000	0.00000
6	elevation	1033	1	567.118	1136.240	188.306	0.00000	0.00000
7	dd	1033	1	582.106	1166.216	218.282	0.00000	0.00000

The top model out preformed all other models. Model 2 is rejected because the added parameter, “dd”, does not improve the maximum log likelihood value (Burnham and Anderson 2002). The formula used for extrapolating the preferred model was thus as follows:

$$p(Y) = (1 + e^{-([\text{prey quality index} * -1.2475977) + ([\text{Mod\_elevation}] * -0.0023758 + 3.39021583)})^{-1}$$

Table 1-9 summarizes the preferred model. A map of predicted values is shown in Figure 1-19.

Table 1-9. Variables in tiger sign detection probability multiple logistic regression model showing coefficients, standard errors, and significance values derived from the chi-square test of individual variable influence.

Variable	Coefficient	Standard error	*p*
Intercept	3.39021583	0.2220879	
Prey quality index	-1.2475977	0.1016766	<.0001
Elevation	-0.0023758	0.0002647	<.0001

An autocorrelation assessment of model residuals indicated autocorrelation is present in the fitted model (Moran’s I = 0.6133, p = 0.001, n = 113) so estimates of coefficient standard error should be viewed with caution.

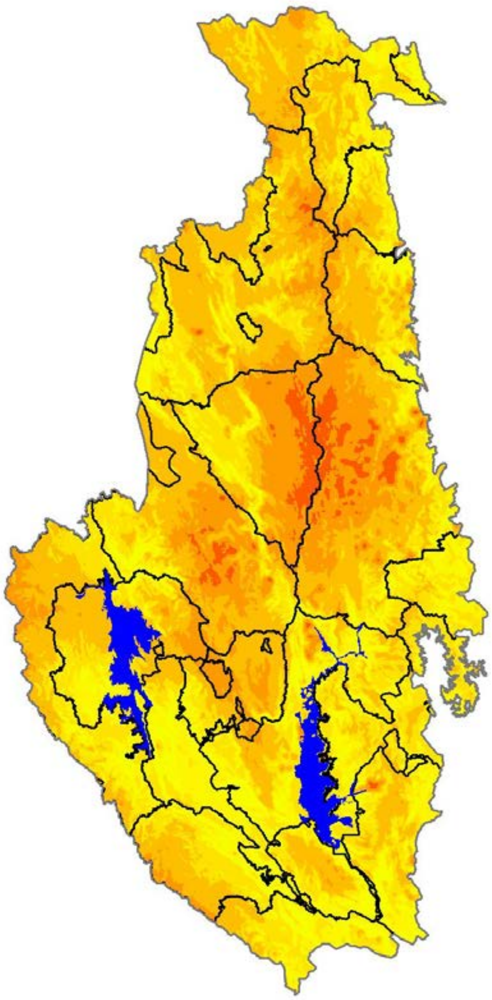

Figure 1-19. Predicted relative likelihood of tiger sign detection throughout the study landscape. Darker reds are areas of higher relative likelihood of sign encounter.

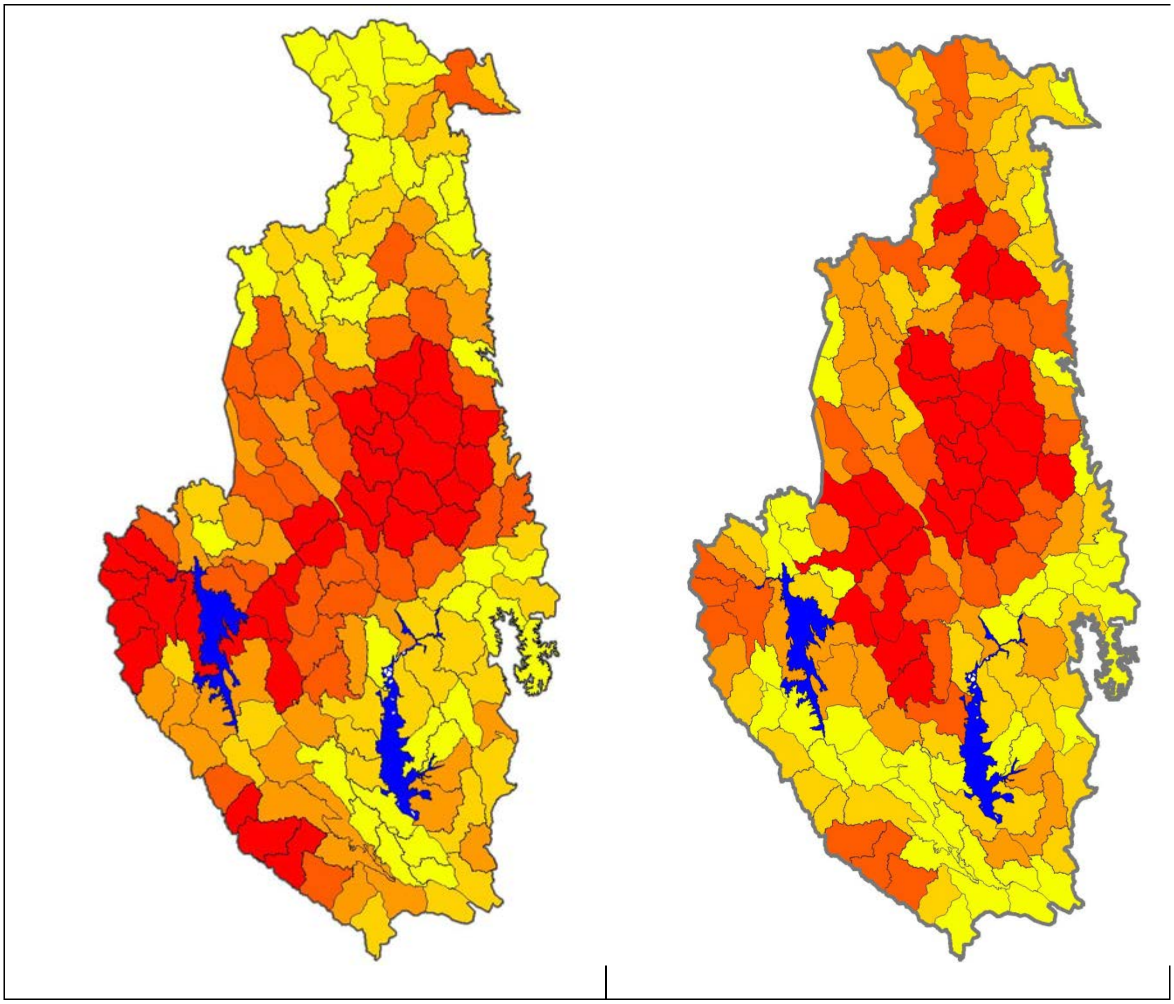

Figure 1-20. Comparison of relative likelihood of tiger encounter from the encounter rate model (left) and the logistic regression model (right).

Discussion

The modeling process outlined above provides insight into factors related to tiger and prey distribution at the landscape scale. Although models have been constructed for western Thailand, it is likely that some patterns are relevant to other parts of the tiger's global range.

As noted above, one weakness in the data collection procedures used here is that methods did not explicitly measure or account for detection probabilities that are likely less than one, and failure to accommodate undetected occurrences can bias results and conclusions (MacKenzie et al. 2006). Future analysis should explore the advantages of using survey and analysis methods that account for detection probabilities and whether these methods (which likely will require greater survey effort) provide for significant gains in model performance.

Prey Model

The relative prey quality model involves what may be considered a "combined" response variable in that it is derived from values for multiple species. Although the majority of sign driving the index comes from banteng and sambar, which are in some ways ecologically similar, it is likely that the ecology of other species that contribute to these values may be responsible for the excessive overdispersion in the response variable for these models. Building a relative prey quality surface from individual species data may be a more ecologically robust means of specifying this response. However, such a process would involve a dramatically higher level of survey effort and the specification of several individual models. The marginal advantages of such an approach may not be justifiable if the ultimate purpose is simply predictive performance.

Visual assessment of the modeled prey surface indicates only a few areas where model predictions are likely inaccurate compared with ad-hoc observations made during the course of this project. In particular, the model seems to overestimate prey relative quality in some areas where prey species have surely declined due to habitat degradation and poaching (for example lowland areas surrounding Khao Laem reservoir and those near the eastern boundary of Mae Wong National Park). Model results in all such low-lying and heavily degraded areas should be viewed with some degree of skepticism.

Tiger ESU Model

The encounter rate model allows for the use of a continuous variable, tiger sign encounter rate, as a response in standard least squares regression analysis. Encounters with tiger sign are relatively easy to record in the field and this type of survey can be carried out by a team with a moderate level of training. However, I am ignoring varaition in detectability of tiger sign, which may vary in response to differernt ecological varaibles.An important aspect of sign surveys is establishing consistent search and data compilation protocols. For example, surveys for tiger sign in the Western Forest Complex currently include some measure of effort to detect tiger sprays whereas this was not an active part of survey efforts prior to about 2002 (Saksit Simcharoen, pers. comm.).

It is tempting to interpret tiger sign encounter rates as reflecting tiger relative abundance and there is likely a linear relationship between the two. However, this relationship has not been quantified so patterns generated in this predictive modeling work should be viewed as relative patterns only. Subsequent work on prey assemblage structure or density thresholds sufficient for tiger residency and breeding may further inform the interpretation of such patterns.

The ESU models which performed best based on comparison of AICc values were ultimately rejected as they predicted tiger occurrence in areas where we know there are no tigers; however, these models might still be useful in predicting areas where tigers could potentially recolonize.

Logistic Model

The purpose of the logistic model was to gain insight into third order tiger habitat selection by measuring the association between tiger sign occurrence and a variety of environmental variables. The most basic of these confounding factors is the relationship between sign detection and tiger occurrence. Whereas the presence of signs provides robust evidence that a tiger used an area, the absence of sign could mean the area is unused by a tiger or that the area is used by tigers but, for any number of reasons, sign was not detected during surveys. While the logistic model environment used for these data should still be able to uncover habitat associations, the strength of these signals is surely dampened by some unknown degree due to this problem. I attempted to overcome low detection probability by increasing the length of survey segments.

Another potential pitfall in interpreting these data is the necessary but clearly non-random selection of “likely tiger travel routes” as the basis for surveys. Such a protocol clearly imposes an a priori bias onto resulting data. The condition of the substrate of these routes is also likely influences the chance of sign detection and the potential for such bias was not measured in this study.

Even if detection did reflect tiger occurrence with high accuracy, the presence of sign could simply represent the movement of a tiger between sites with desired resources. It is also quite possible. In this case, it is possible that the routes selected for surveys may coincide more strongly with routes used by tigers for this type of movement whereas areas with important resources such as high prey may have been under sampled. Additionally, given the habit of tigers to systematically patrol and mark the periphery of their territory (Smith et al. 1989), signs could represent movement to achieve this goal rather than indicating resource selection.

Interview Surveys

In this study, interviews provided information that would not have been available by other means. This included specific information on tiger presence, livestock predation, and hunting patterns. Interviews, if carried out systematically, can and should inform landscape-scale assessments of wildlife (Rabinowitz 1993b). Karanth (2000) suggests that questionnaire surveys “gain importance if large regions can not be surveyed using field teams” and details appropriate methods and materials for such surveys. Much recent work focused on assessing the status of tigers in Southeast Asia has emphasized the value of interviews in collecting information and effectively carrying out other fieldwork (Smith et al. 1998, Hean 2000, Lynam et al. 2001).

Interviews can provide information on sightings, cattle killings etc. that provide evidence for tiger presence in an area. These reports can then be substantiated by the informant directing the investigator to physical evidence (sign, kill, remains of poached animal) (Gurung 2002). Interviews can also provide information on trends in tiger status that are not expressed in point-in-time estimates of absolute or relative numbers. The importance of this type of trend data is highlighted in the range-wide tiger conservation plan proposed by Dinerstein et. al. (1997).

Assessing various threats to existing wildlife populations is a vital part of setting priorities for tiger conservation action. Interviews can help in this process by providing information on: hunting routes, hunting areas and the intensity levels of hunting activities, details about local hunting practices (e.g., taboos on killing of certain animals), information on the local economics of wildlife products (e.g. identification of restaurants that serve bushmeat, locations of markets for wildlife products, identification of middlemen), areas and intensity levels of current protection and law enforcement activities, human activities that may affect the quality of tiger habitat (e.g. grazing, tree-felling, burning), the nature and level of armed conflict in an area (often associated with prey depletion), and patterns of human settlement.

Interviews can provide information useful for coordinating the logistics of conservation efforts. Useful information often includes local customs, the identification of local field experts, security risks, transportation options and travel routes, and other logistical details. Conservation efforts require the participation of a wide range of stakeholders and interviews can facilitate the engagement and communication necessary to achieve this.

Interviews acknowledge the value of local knowledge and interests by seeking such information in a deliberate and organized fashion. Furthermore, they can often be conducted concurrently with field surveys in an area with little additional overall cost.

Future Modeling Efforts

Given the weakness of not accounting for detection probablility, future modeling efforts should explore models that provide explicit estimates of detection probability. While such models typically require repeated surveys, they are a powerful framework that can inform many aspects of survey design as well as improving inferences about the habitat relationships of target species.

A second problem for future modeling was the problem of overdispersion of the pellet count data. While increasing the size of sampling units would address this issue, personel and finacial costs necessary to reach sufficient sample sizes are are often prohibitive. Greater insight into the movements of ungulates (especially sambar deer) at the level of second and third order habitat selection would likely facilitate more effective pellet sampling strategies.

CHAPTER 2. LANDSCAPE-SCALE MONITORING OF TIGERS IN THE TENASSERIM: EVALUATING THE UTILITY OF SIGN SURVEYS AND OCCUPANCY MODELS

The tiger population occurring in the area of the Dawna and Tenasserim mountain ranges is one of the largest in the world and therefore understanding the status of tigers here is critical to understanding their global status. Insight into patterns of tiger occurrence and abundance and how these patterns change over time is also useful to managers who would like to decide where to apply management actions, or to understand the effects of past decisions. In virtually all situations, tigers—even when present in an area--cannot be detected all of the time. While camera trap techniques are widely used for estimating abundance patterns on a relatively small scale, they have proven too resource-intesive to be used effectively for monitoring over very large landscapes.

I explored a number of approaches for estimating tiger occurrence and abundance over a large landscape (~20,000 km^2) in Western Thailand. All approaches are based on the detection of distinctive signs (e.g. tracks, kills, scrapes, scats, urine sprays) that tigers leave when they move through an area. Detecting and recording these data requires minimal training and can be carried out in conjunction with routine patrol activities that already take place over larger areas.

Specifically, I evaluated four approaches to modeling occurrence and abundance: 1) a minimum abundance technique combining track characteristics and spatial criteria, 2) a basic occupancy model based on detection / non-detection within sample units that approximated the home-range size of male tigers, 3) a similar occupancy model that differentiated between sites that are merely occupied versus sites that support reproduction, and 4) a model that related sign detection frequencies to estimates of actual abundance. Finally, I used to the basic occupancy model framework (#2) to construct a simulation model to explore how the number of repeat surveys conducted at each unit, the number of units surveyed, and the level of survey effort (i.e. kilometers walked) applied in each unit might impact the power to detect declines in occupancy between two time periods (these results are also applicable to approaches 3 and 4).

Results indicate that an equivalent power to detect a trend of a desired magnitude may in many cases be achieved through a variety of permutations of the number of sites surveyed, the effort expended to locate tigers at a site, and the number of repeat surveys conducted throughout a period deemed to be "closed" with respect to tigers. This should be encouraging to managers and argues for the use of preliminary modeling as a potentially cost-saving exercise in the monitoring survey design phase. As increasing data will tend to improve exiting models, modeling should also be seen as a routine part of adaptive management.

Introduction

The precipitous decline in numbers of wild tigers has been well documented (Duckworth & Hedges 1998; Knowell & Jackson 1996; Sanderson et al. 2006; Seidensticker et al. 1999; Wikramanayake et al. 1998). The causes of this decline, also well documented, fall into two main categories: direct threats (i.e. poaching and poisoning of tigers) and loss of habitat that supports tigers (i.e., habitat destruction, degradation, and fragmentation, as well as declines in tiger prey). Millions of dollars are spent each year on tiger conservation, yet there is little evidence that wild tigers are any more secure than they were 10 years ago. In fact, recent field surveys suggest that the primary causes of decline are still present and, in some cases, may pose more of a threat than they did in the recent past (Carbone et al. 2001; Daltry & Momberg 2000; Rabinowitz 1998). Recent calls for more 'results-oriented' use of conservation funds (Christensen 2002) highlight the need to develop cost-effective monitoring methods for the world's remaining tigers.

Like most complex global efforts, tiger conservation takes place on multiple scales. In an attempt to describe the ecological linkages in tiger distribution across their entire range, Wikramanayake et al. (1998) have outlined a system of "tiger conservation units" (TCUs) that encompass "entire landscape[s] of natural habitats over which tigers may disperse and become established." Their approach has been widely adopted as a basis for funding and policy decisions, but stops short of analyzing patterns of tiger distribution within the proposed landscape-scale units (Sanderson et al. 2006). Seidensticker et al. (1999) underscored the need for "breaking down the larger problem into smaller focused ones with technically practical and politically feasible solutions." Providing practical direction for monitoring was the main motivation for this analysis.

Monitoring the status of tigers has consistently been identified as a management priority in most regions where tigers still occur (Barlow 2004; Barlow et al. 2008; Cutter & Smith 2002; Gurung 2002; Hayward et al. 2002; Karanth 1999b; Karanth & Nichols 2002b; Miquelle et al. 2002; Yu et al. 2000). Tiger monitoring efforts seek to detect changes in tiger abundance within important tiger landscapes. While absolute abundance is usually the preferred variable for monitoring purposes, there is growing interest in the utility of occupancy (Bailey et al. 2007; MacKenzie 2005; MacKenzie & Nichols 2004; Nichols et al. 2007), especially in the case of rare and elusive species where estimating abundance may not even be practically possible (MacKenzie & Nichols 2004). Estimating occupancy has been shown to require less effort than estimating abundance (Tyre et al. 2001), and occupancy is particularly well-suited to studies of distribution, range, and metapopulation dynamics (MacKenzie et al. 2006; Scott et al. 2002). Occupancy has also been shown to be associated with productivity and habitat quality (Sergio & Newton 2003). Moreover, if sampling unit size is carefully chosen, measures of occupancy can be highly correlated with absolute abundance (Baker 2009).

A profusion of recent studies has highlighted problems that can arise when imperfect detection of a target animal is not explicitly accounted for in abundance estimates, monitoring techniques, and habitat relationship models based on occupancy (MacKenzie & Kendall 2002; MacKenzie et al. 2005; Tyre et al. 2003). Whether the target state variable is abundance or occupancy, inferences about change in these is only accurate when detection probabilities are equal or nearly equal between survey occasions; a condition that many argue is rarely encountered in the field (MacKenzie et al. 2006). When a target animal occupies a site but is not detected (and thus not recorded), resulting occupancy estimates are biased—potentially leading to erroneous conclusions—and the degree of bias is not expressed. This bias is especially problematic if the probability of detecting an organism varies with time, by habitat type, or with any other covariate that is likely to be important in affecting occupancy (i.e., if tigers behave more secretively and are less detectable in landscapes where humans are more active). However, occupancy models use data from multiple surveys to simultaneous estimate detection and occupancy probabilities for a given set of data (Bailey et al. 2007; MacKenzie et al. 2004a; Nichols et al. 2007; Royle 2004), thereby allowing for unbiased estimation of parameters of interest.

Sign surveys have been used to delineate the distribution and population trends in tigers (Barlow et al. 2008; Hayward et al. 2002), other large felids (Beier & Cunningham 1996), and a variety of other carnivores (Cagnacci et al. 2004; Carroll et al. 1999; Gaines 2001; Reid et al. 1987) and have been defended as the most efficient means of doing so—especially when target populations occur at low densities over large spatial scales (Barea-Azcón et al. 2007; Bonesi & Macdonald 2004). Sign surveys are considered particularly appropriate when the secretive nature or low densities of target species limit the effectiveness of other detection techniques (Thompson 2004; Wilson et al. 1996).

In this analysis I used sign data collected over four years in western Thailand to contrast several approaches to modeling tiger abundance and distributioin at the landscape scale. Since effective monitoring methods represent a pressing need in tiger conservation efforts, and are a natural extension of these approaches, I further explored how changes in basic survey design affect the power of monitoring programs arising from these types of surveys.

Important considerations for any vertebrate monitoring exercise are those related to sampling frame and survey unit configuration (MacKenzie et al. 2006), the counting method used, the underlying distribution of the target animal, and costs (Thompson et al. 1998). Throughout the analysis, I therefore explored how changes in assumptions related to these issues might impact resulting inferences. My primary objective was to inform survey design and logistical planning aspects of future monitoring efforts at the landscape scale.

Study Area

In broad terms, my study area was Thailand's Western Forest Complex, an extensive, mostly forested landscape of roughly ~24,000 km^2 with the vast majority of that area falling under the protection of 17 protected areas. At the southeastern end of the Tenasserim and Dawna mountain ranges, the area is mostly rugged, mountainous terrain interspersed with wide valleys and plateaus. Elevations range from 100 meters to 2200 meters. Most watersheds in the area are part of the large Mae Klong River system that flows south into the Gulf of Thailand; a few drain west into the Salween river system which in turn empties into the Andaman Sea.

Together with a large area of contiguous forest on the Myanmar side of the border and an additional large protected area complex (the Kaeng Krachan complex) to the south, the area represents the 3rd largest Tiger Conservation Unit (TCU) identified by Sanderson et al. (2006) in their range-wide tiger conservation priority-setting exercise. Armed conflict and travel restrictions have precluded systematic fieldwork in many potentially important areas on the Myanmar side of the border in recent years.

Sample data were collected from the core of this extensive landscape represented by five contiguous protected areas that cover approximately 10,000 km^2.

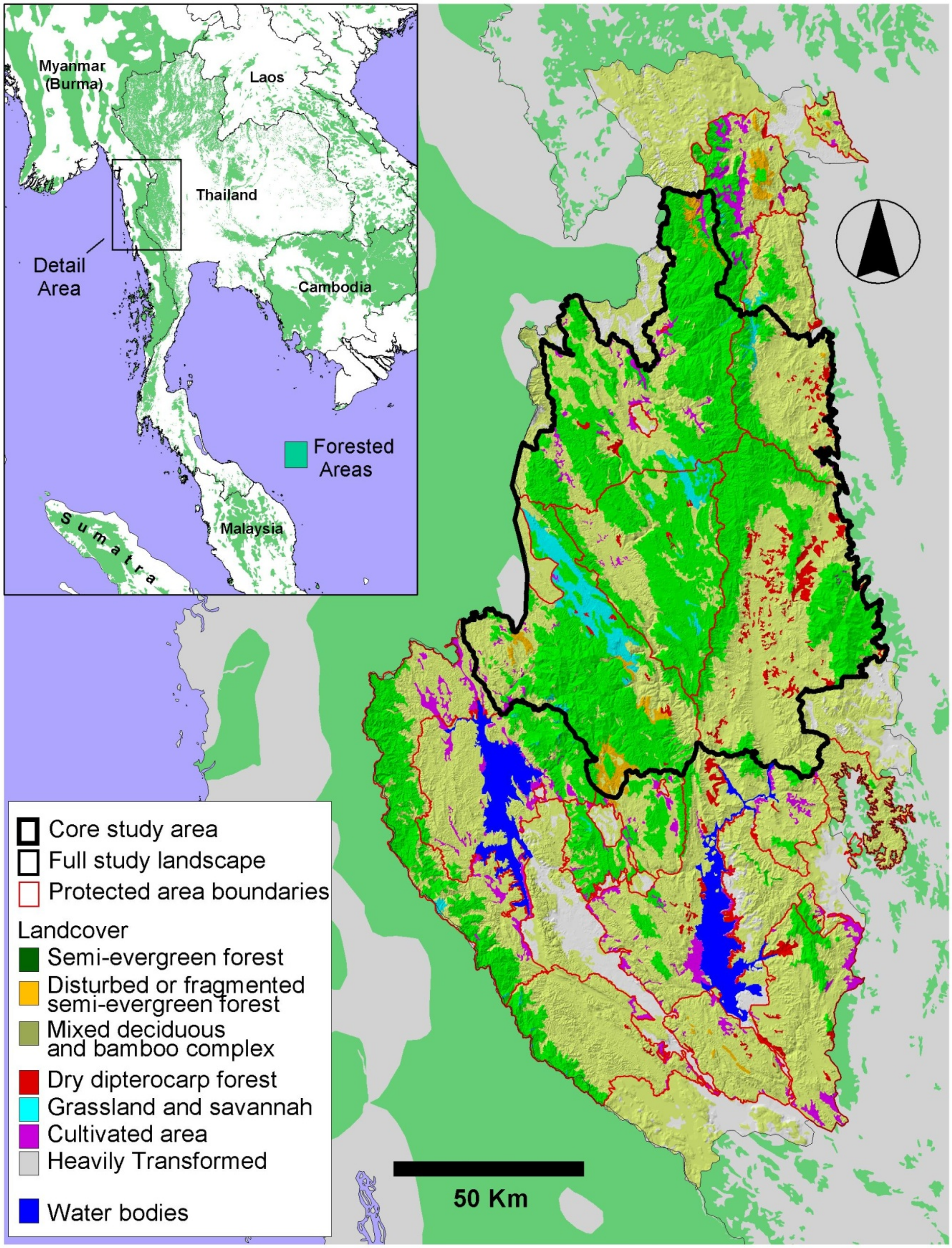

Figure 2-1. Reference map of the study area.

Weather patterns in the region are driven by a seasonal monsoon system originating in the Indian Ocean during the wet season (May through October) and by dryer weather from the Pacific Rim during the rest of the year (November through April). Annual temperature and rainfall patterns are summarized in Figure 2-2. Several high mountain ranges intercept monsoon rains during the wet season resulting in a marked difference in precipitation patterns from the southwest to the northeast (van de Bult 2003).

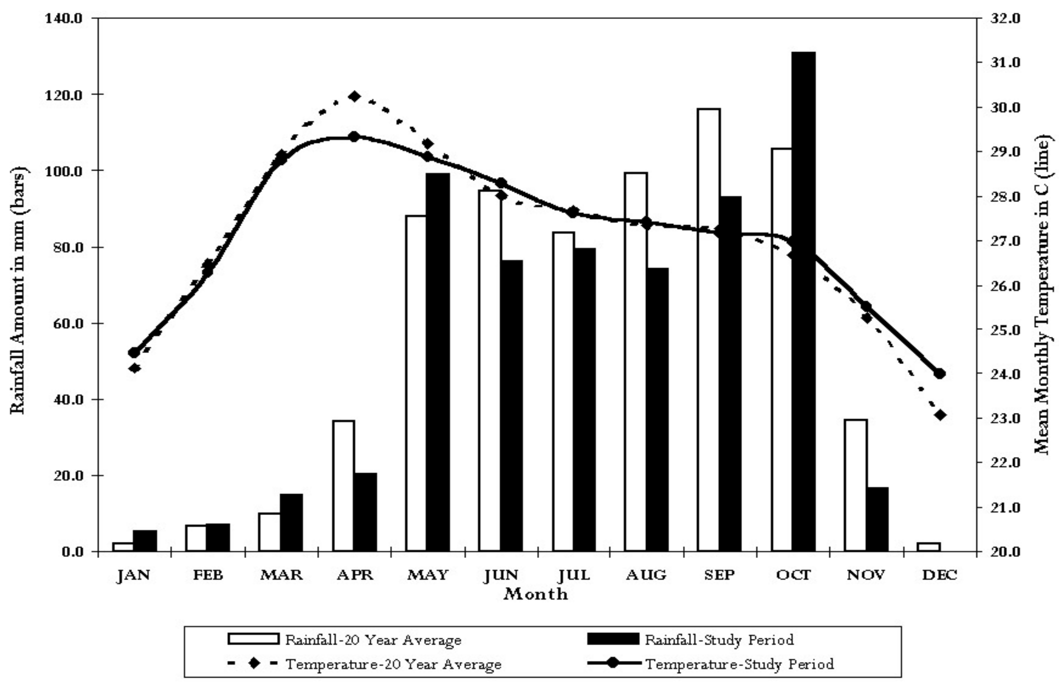

Figure 2-2. Weather patterns in the study area. Data averaged from 11 weather stations surrounding the study area. (Data from the Thailand Meteorological Department).

The vegetation pattern within the study area is a mosaic of evergreen and deciduous forests. Evergreen forests are often separated into semi-evergreen (or seasonal evergreen) and hill evergreen types and deciduous forests into tropical mixed deciduous and dry deciduous (or dry dipterocarp) types (Bangkurdpol 1979; Cubitt & Stewart-Cox 1995; Lekagul & McNeely 1977). Stands can differ markedly in terms of both species composition and structure; few areas exhibit clear edges and most stands are intermediate among the described primary vegetation types. Interspersed with forested areas are smaller patches of natural grassland, savannah woodland, and cultivated fields.

Although semi-evergreen forests (SEF) once occurred extensively at lower elevations, clearing and fire have now relegated this type to the moister higher elevations that retain well-developed soils. SEF is a mix of evergreen and deciduous species with the upper canopy dominated by large diptercarps—rimarily *Dipterocarpus* and *Hopea*. The SEF canopy is the tallest in the region with an upper canopy of more than 30 meters and emergent trees sometimes reaching 40 meters. Epiphytes and lianas thrive in the almost total shade and higher moisture of the canopy. At ground-level, rattans (*Calamus* spp.), moisture loving forbs, and ferns are often present but grasses and smaller trees are noticeably absent. The midstory is often poorly developed with treefalls and other natural break events providing the primary opportunities for the recruitment of younger trees.

Hill evergreen (or *montane*) forests occur at elevations above 900-1200 meters (depending on local factors such as soil type) where average temperatures are lower, the daily temperature regimes more cyclical, and humidity higher.

In the lower montane areas (~1200-1700 m), the tallest trees reach to about 35 meters and the canopy is dense. Oaks and dipterocarps dominate this zone and rhododendrons and laurels can be found in the understory. In the upper montane areas (usually found above 1700 m), trees appear stunted and the canopy occurs at about 20 meters above the ground. Epiphytes and mosses are noticeably more abundant due to the fact that this zone is often shrouded in clouds.

Tropical mixed deciduous forests (MDF) occur on relatively rich soils where annual rainfall is lower. Median canopy height is quite variable (ranging between 20 and 35 meters) as are emergent crown heights at any given site. The canopy is significantly more open than in SEF. During the leaf-off part of the year, scattered evergreen trees provide the only shade on the forest floor—often resulting in a thick understory layer of hearty, woody shrubs and seasonal emergent forbs such as wild gingers (Zingiberaceae) and aroids (Araceae).

A grassland-woodland mosaic dominates a few sites in the study area. Sedges are common in these areas and cycads (*Cycas siamensus*) are the predominant trees.

Patches of secondary vegetation occur in all forest types where anthropogenic events or the foraging activities of elephants have altered primary structure and composition. The structure and composition of secondary patches vary widely: some are dominated by high imperata grasses and shrubs while others have developed larger trees or bamboo.

Bamboo (primarily *Bambusa* and *Dendrocalamus* spp.) is common and can form large stands in both SEF and MDF forests. Bamboo distribution patterns are frequently associated with disturbance (e.g. annual fire patterns, forest clearing, livestock grazing and elephant foraging).

Zoogeographically, the area falls within the Indochinese subregion of the Oriental region. The tiger is the largest carnivore in the region and occurs sympatrically with leopards (*Panthera pardus*) in parts of the study area (Rabinowitz 1990). Other large carnivores include the Asiatic wild dog (*Cuon alpinus*), Asiatic jackal (*Canis aureus*), Asiatic black bear (*Ursus thibetanus*), and Malayan sun bear (*Ursus malayanus*). Larger herbivores include gaur (*Bos gaurus*), banteng (*Bos javanicus*), sambar deer (*Cervus unicolor*), barking deer (*Muntiacus* spp.), and wild pig (*Sus scrofa*). Elephants (*Elephus maximus*) are present in relatively large numbers and are responsible for maintaining some of the area's vegetation patterns (Lekagul & McNeely 1977).

Ethnic Karen and Hmong populations have lived in villages within the boundaries of the protected areas for at least 200 years. Although some villages have been relocated over the last 30 years as part of protected area management efforts, approximately 4000 people (mostly Karen) still live at about 35 village sites—most near the Thai/Myanmar border. Additionally, over 70 permanently staffed forest protection stations in and around the area house over 300 people. Most villages practice a rotating crop system with dry-farmed rice as their staple food although an increasing number of villages are moving to paddy rice cultivation with sometimes elaborate, semi-permanent irrigation systems. Outside of protected area boundaries, human population densities increase immediately. Although officially restricted, activities such as the collection of forest products, hunting, fishing and logging—originating from villages both inside and around the area—take place to some degree throughout most of the area.

Methods

I used sign occurrence data collected over four years to explore the utility of both basic and multi-state model types for estimating tiger occurrence and abundance patterns over the study landscape. In the basic detection / non-detection occupancy model, I used sample data to estimate occupancy probabilities at the resolution of ecological survey units (see Chapter 1). Occupancy patterns were modeled with data collected from the core of the study landscape. Correlation with covariates was explored to extrapolate these patterns to the larger landscape. In a second model, I applied a multi-state extension of the basic occupancy model which distinguished occurrences as "breeding" or "non-breeding". Finally, to explore tradeoffs in survey design, I developed a simulation model based on the basic occupancy approach to estimate the power to detect trends under different survey conditions.

I treated the four-year dataset as representing a single, closed survey period (i.e., the state of tiger occupancy and abundance in any given survey unit was assumed to be constant throughout all 4 years of sampling). This length of time might be excessive (e.g. possibly violating the closure condition assumed by most occupancy models (see explanation below)) if the data were used for formal estimation. However, given the goals of this analysis (e.g. comparison of prospective model utility for monitoring), and that tiger occupancy in the area is characterized by rapid reoccupation of vacated territories, I considered this time period appropriate.

Since several aspects of survey design and data collection techniques relate to all of the analyses, I briefly discuss these below. I then discuss the structure of each model and the methods used to implement them with the sample data.

Sampling Framework

Two key assumptions in occupancy analyses are: 1) that of "closure": that the status of the target phenomena (e.g. occupied vs. unoccupied) does not change with regard to the sampling units within the set of surveys used to estimate detection probability, and 2) that of independence of detections between sampled sites (MacKenzie et al. 2006; MacKenzie et al. 2004b; Tyre et al. 2003). Violations of either can lead to unreliable inferences about occupancy, changes in occupancy over time, and the relationship between occupancy and other covariates (MacKenzie et al. 2006; Thompson et al. 1998). Although these assumptions are rarely completely satisfied in practice, survey designs in which they are better satisfied will provide more accurate estimates of occupancy patterns. As the interplay of the movements of the target animal and the design of survey plots can impact how well both assumptions are met, I considered the design of survey units (i.e. size and shape) carefully. In particular, I evaluated issues relating to tiger ecology, survey logistics, management expediency, and the interpretation of data resulting from surveys.

While the distribution, abundance, and detectability of some species allow for a "grid-based" sampling approach, this approach can be problematic for surveys over complex terrain where ease of access varies greatly and where this complexity is likely related to the distribution of the species in question. Instead, I proposed a system of contiguous spatial units as the basic framework for measuring and analyzing tiger occupancy and how this pattern changes over space and time.

Survey Unit Shape

A grid-cell approach is perhaps the most common survey unit configuration for terrestrial mammal surveys. When no information is available about how the movements of a target animal relate to other features on the landscape, this configuration may be reasonable. However, when there is additional information available about target animal movements, this information can be used to reduce the likelihood of violating both closure and independence assumptions and therefore improve the accuracy of model estimates.

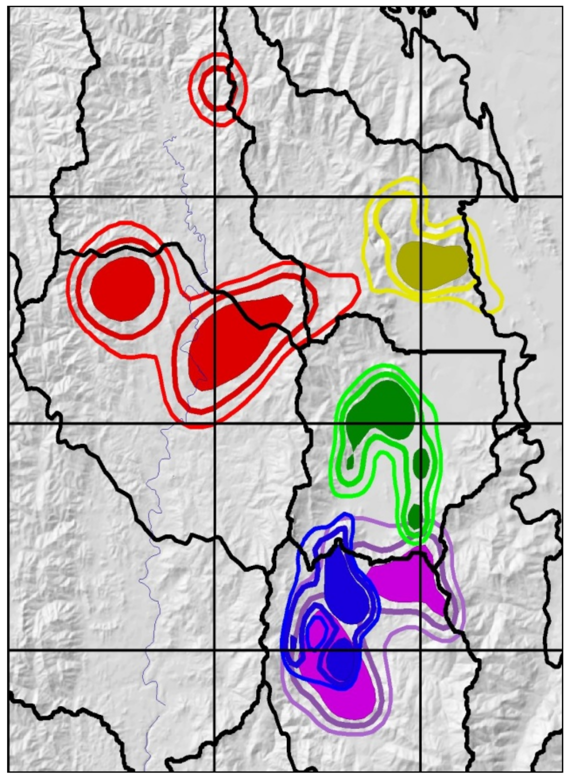

Figure 2-3. Home ranges of five tigers in Huai Kha Khaeng Wildlife Sanctuary showing grid-based survey units (narrow black lines) and ecologically-derived survey units (ESUs (thick black lines)). Movement patterns of individual tigers fall mostly within ESU boundaries whereas arbitrary grid boundaries (here alligned with the closest whole number lat/long intersection) are more likely to bisect home ranges –leading to more frequent violation of closure assumptions in many models and inflated estimates of occupancy or abundance. ESUs also facilitate efficient survey, analysis, and management action.

High resolution studies of tiger movement in the study area demonstrate that while tigers frequently move throughout large areas of low slope habitat, they rarely use midslope areas and ridgetops and even more rarely regularly cross over high ridges in their movements (Saksit Simcharoen, pers. comm.). The result of this is that home range areas tend to be bounded by, rather than intersect, ridges. Although tigers are capable swimmers, there is likely an upper limit to the size of waterway that they will readily traverse as part of their daily movements, (Barlow et al. 2008). I therefore concluded that sufficiently deep, wide and fast-flowing streams represent "soft" boundaries to tiger movement in that tigers are unlikely to extablish home ranges bisected by such streams. They would probably present a risk to an adult animal trying to cross and would certainly be dangerous to an adult moving with cubs. These 'semi-permeable' barriers to tiger movement thus tend to define home range boundaries more often than not. Any survey configuration integrating these boundaries will thus have a higher likelihood of satisfying closure assumptions and will therefore yield better estimates within an occupancy analysis framework. With this in mind, I used high ridges and large, fast-flowing streams as boundaries in delineating survey units for this analysis. Where survey units defined by these boundaries were larger than a target size range (see below), I used administrative boundaries or partial ridgelines to further subdivide units.

Specifically, I first used a digital elevation model and topographic algorithms available in standard GIS software (ESRI 2002) to identify watershed units larger than 100 km^2. Where these calculated watersheds were larger than 300 km^2, I further divided them along such features as partial ridgelines, wide, permanent streams (which present a barrier to both wildlife and human movement), and/or protected area boundaries to achieve spatial units of approximately 150 km^2. This target size was selected to roughly reflect the size of male tiger home ranges in this area (estimated at 168 km^2 based on a long-term study of radio-collared individuals (Saksit Simcharoen, pers. comm.)). Proceeding in this way, I delineated contiguous 'ecologically-derived' survey units ('ESUs') covering the entire Western Forest Complex.

While somewhat subjective in their delineation, ESUs have several desirable qualities in the contexts of survey logistics, data analysis, and management action. From an analysis and interpretation standpoint, ESUs are more likely to encompass the full home ranges of many large mammals (particularly tigers) and therefore tend to minimize violations of closure and independence assumptions critical to many inventory and monitoring techniques. Logistically, ESUs provide an efficient framework for surveys because they are typically oriented around logical access routes to an area (such as streams or forest roads), thus facilitating efficient planning and execution of surveys. Also, because ESU boundaries are usually readily identifiable physical features, effort tracking and concise reporting of survey data are possible without continual reference to unnatural boundaries imposed by a grid or other arbitrary configuration. Finally, by utilizing both natural and, in some cases, administrative boundaries, ESUs are more appropriate units for the application and measurement of management actions that tend to share these boundaries.

Survey Unit Size

Decisions about survey unit size relate to survey objectives and the biology of the target species. When probablility of occupancy is of interest, survey units that are smaller than the range of movements of the target organism (i.e. do not effectively "contain" the movements of individuals) will tend to violate the independence assumption and lead to exaggerated occupancy estimates. On the other hand, units that are very large with respect to the target animal's distribution and movements can fail to provide information at sufficient resolution to be useful for answering questions of interest (i.e. sites remain occupied whether there are 10 or 2 tigers present, and occupancy therefore fails to provide meaningful information on the magnitude of population change). Choices about survey unit size must therefore balance these two contrasting effects. I addressed this by grouping or splitting survey units described above such that all units ultimately ranged between 100 and 250 km^2. This ensured that units are thus approximately equal to the range of estimates of male tiger homeranges in the area and thus there should be an upper limit to the number of breeding individuals that can potentially occupy a given unit. Because survey unit size was not held constant and occupancy is expected to increase with ESU size (all other things constant), I explored ESU size as a covariate in several models.

Detecting Tigers

Initially, I experimented with a photo-trapping survey approach as a means of detecting tigers in a given area (Karanth & Nichols 1998; Lynam et al. 2001; Moruzzi et al. 2002). To evaluate the utility of that approach to my survey, Trailmaster® brand passive infrared photo-trap kits were set up in six locations in an area of approximately 60 km^2 for a total of 53 trap nights over a two week period. The area selected for this trial is widely considered to have one of the highest densities of tigers in Thailand and traps were located at sites selected by the presence of tiger tracks, scrapes, and other signs to be along tiger travel routes. Although the overall capture rate for large mammals was promising (11 photo-captures including leopard, Asiatic wild dog, large Indian civet, common palm civet, sambar deer, barking deer, banteng, and tapir), no tigers were photographed. In contrast, walking surveys of trails and dirt roads transecting the same area during the photo-trapping period resulted in numerous detections of unambiguous tiger sign (including tracks, scrapes, and scat) with enough variation in some of the track sizes to conclude that at least 3 tigers were utilizing the area. As the primary goal of the analysis was to establish the presence or absence of tigers within survey units over a very large (~20,000 km^2) area, photo-trapping was dismissed in favor of a track-based survey approach.

Before beginning field surveys in an area, likely tiger travel routes (e.g. roads, trails, ridgelines, and stream courses) were identified using 1:50,000 scale topographic maps, existing GIS information, and by consulting with local residents and protected area managers. Tigers utilize these features disproportionately in their movement (Smith et al. 1989; Sunquist 1981b) and leave various signs such as tracks, feces, scrape-marks, urine sprays, prey remains, and claw marks on trees (Schaller 1967; Smith et al. 1989).

Survey units were selected from a "core" area of Thailand's Western Forest Complex consisting of four wildlife sanctuaries and one national park (Figure 1-1). In the field, identified routes in a given survey unit were walked by teams of 3 or more people in the following order of priority: maintained dirt roads, old dirt roads, sections of streams with sandy banks, large foot trails, dry streambeds, ridgelines, and other stream banks. Efforts were made to survey each unit sampled at an intensity of at least 10 linear km surveyed for every 100 km^2 of area.

Survey routes were recorded by acquiring frequent positions along each route with a handheld GPS[2]. Where tiger sign was encountered, information on the type and details of sign (including detailed track and scrape measurements), general forest type, and other details were recorded on standardized field data forms. In addition, survey teams attempted to document all occurrences with photos, plaster casts, or by collecting spoor.

The following criteria were used to define individual encounters:

1) **Condition/apparent age of sign**: The condition of sign (e.g. moisture level of feces or deposition of tracks in relation to vehicle tire marks) was used to distinguish the relative age of sign. Where relative condition was clearly different, sign occurrences were considered unique.
2) **Track size**: In cases where track size clearly differed between nearby tracks (i.e. by more than 0.5 cm in pad width, track width, or track length on clear track

[2] Two types of GPS were used for field surveys: the Garmin GPS 12 and Garmin E-Trex Summit models. The accuracy of positions acquired using the GPS varied from an estimated accuracy of "within 100m" prior to the May 1, 1999 shut-off of the *Selective Availability* intentional degradation of GPS signals to "within 15m" after that date.

impressions), sign were considered to have been deposited by different individuals.

3) **Direction of travel**: When the direction of travel of two or more sign occurrences was clearly different (as assessed by the alignment of tracks or scrape-marks, for example), occurrences were considered unique.
4) **Proximity**: If signs were similar by all of the above criteria—yet separated by 20 meters or more, they were also considered a unique occurrence.

By the above criteria, the continuous presence of similar sign occurring for more than 20 meters along a linear route would be considered a single occurrence as long as the sign was not interrupted by a sign-free interval of more than 20 meters.

Various characteristics of tiger sign have been used as evidence detected individual(s) represent a portion of the population capable of breeding. Such evidence includes tracks of an adult moving with cubs (Barlow et al. 2008; Gurung 2002; Karanth et al. 2002) and the recurrent detection of occupancy throughout the year (Gurung 2002). For the purposes of model exploration, I assigned breeding status to survey units where 1) I recorded an adult moving with cubs, 2) where tigers were consistently encountered on repeated surveys at least 3 months apart, and 3) where other survey efforts have documented consistent tiger occurrence throughout the year.

Ancillary Data

Continuous landscape-scale data were provided by the Department of National Park, Wildlife and Plant Conservation (DNP), the Department of Community Development, Kasetsart University, and the World Conservation Monitoring Center (WCMC).

Throughout the course of the investigation, a geographic information system (GIS) was used as a repository for all data collected both in the field and from other sources that had an explicit spatial component. The GIS platform allowed for data correction, georectification, and attribution.

Analysis

Basic Occupancy Model

I used an occupancy modeling approach and data from the sample dataset to generate estimates of occupancy and detection probability within discrete ecologically-bounded survey units (see above). In addition, I assessed the strength of the association between occupancy and several covariates including size of survey unit, elevation, ruggedness, distance to nearest village, and percent of “open” land cover types in each survey unit.

Modeling was carried out using the “occupancy estimation” modeling mode of the program Mark (White & Burnham 1999). The basic structure of the model is the following function:

$$L(\Psi, p) \mid u_1 ... u_T, u.) = \left[\Psi \prod_{t=1}^{T} p_t^{U_t} (1 - p_t)^{u. - u_t} \right] \left[\Psi \prod_{t=i}^{T} (1 - p_t) + (1 - \Psi) \right]^{U - u.} \quad \textit{(Equation 2-1)}$$

Where the term on the left is the likelihood of a situation defined by a given occupancy rate (Ψ) and probability of detecting the species of interest during each search occasion (*p*) at a number of sites ($u_1...u_T$), *T* is the number of repeat searches at each location, *u.* is the number of locations where the species was detected at least once, and u_t is the number of sites where the species was detected during the t^{th} search occasion (MacKenzie et al. 2004b). Program Mark uses an optimization algorithm to maximize the likelihood term by changing values of Ψ and *p*. These values can then be considered maximum likelihood estimates of these parameters.

This basic model can be extened to include covariates using the following logistic model structure:

$$\theta_i = \frac{\exp(X_i \beta)}{1 + \exp[X_i \beta]} \quad \textit{(Equation 2-2)}$$

Where θ_i is the probability of interest for a given site, *i* (e.g. either occupancy or probability of detection), X_i is the row vector of covariate values for site *i*, and β is the column vector of coefficients to be estimated (MacKenzie et al. 2006). I used Mark to implement this equation to quantify the strength of association with various covariates. I then used significant associations to inform estimated occupancy at individual sites within and beyond the sample area.

Detection histories with missing observations in this and in the two following models are accommodated by inserting a zero value for the probability of detection at that vector element, a fair reflection of “the fact that no information regarding the detection (or non-detection) of the species has been collected from that site at that time” (MacKenzie et al. 2006). Thus, while complete histories are desireable and will usually decrease the variance around detection probability estimates, their omission will not bias estimation of the means of these parameters.

Key assumptions of this model are: 1) that sites remain closed (i.e. the underlying occupancy state of each unit does not change) during the period that repeat searches are conducted, 2) that there is no heterogeneity in occupancy rates unaccounted for by covariates, 3) that there is no heterogeneity in detection probabilities unaccounted for by covariates, and 4) that detection events are independent (i.e., the probability of detecting an organism at any given site is independent of prior detections). Non-independence could occur within sites if investigators were more diligent about searching for sign if they found sign during the previous survey, and it could occur across sites if investigators followed the same tiger trail from one ESU into an adjacent ESU.

Multi-state Occupancy Model

Understanding geographic patterns relating to the status (e.g. breeding or non-breeding) of individuals in a population or subpopulation can be useful for many types of analysis (Gilpin & Hanski 1991; Gilpin & Soule 1986; Noss et al. 1999; Smith et al. 1998; Smith & McDougal 1991). One useful extension of the basic occupancy model described above is one in which two or more occupancy "states" are explicitly modeled (Nichols et al. 2007).

To describe this more complex structure, the multi-state model involves the estimation of a larger set of parameters. These are:

Ψ_i^1, the probability that a site is occupied, regardless of the occupancy state;

Ψ_i^2, the probability that a site is occupied by a breeding individual, conditional on the site being occupied in the first place (e.g. Ψ_i^1 = 1);

p_{it}^1, the probability that occupancy is detected, conditional on the site being occupied by an individual of any state (e.g. Ψ_i^1 = 1);

p_{it}^2, the probability that breeding is detected, conditional on the site being occupied by a breeding individual (e.g. Ψ_i^2 = 1) and occupancy having been confirmed (p_{it}^1 = 1); and

δ_{it}, the probability that breeding state is correctly inferred, conditional on the site being occupied and occupancy having been detected.

The number and form of the individual probability statements will depend on the structure of surveys and resulting data. I present the most complex of these (i.e. the one with the most parameters) below as an example of how the parameters above contribute to probabilities at a given site, searched on four occasions, where the species is detected (but with no evidence of breeding) on occasions 2 and 4:

$$\Pr(h_i = 0101) = \Psi_i^1[(1-\Psi_i^2)(1-p_{i1}^1)p_{i2}^1(1-p_{i3}^1)p_{i4}^1 +$$
$$\Psi_i^2(1-p_{i1}^2)p_{i2}^2(1-\delta_{i2})(1-p_{i3}^2)p_{i4}^2(1-\delta_{i4})] \quad \textit{(Equation 2-3)}$$

Using this and other probability functions (described in detail in Nichols et al. (2007) and implemented in program Mark, I fitted a multi-state model using detection histories generated from the sample data (i.e. detection vs. non-detection) but with detections representing breeding indicated by a "2" in the input data.

Assumptions for this model are the same as for the basic occupancy model presented above.

Monitoring Simulation Model

To explore the relationship between survey design variables and the power of monitoring to detect trends in occupancy, I developed a stochastic simulation model based on the basic occupancy model described earlier to compare modeled data from two survey periods, $\mathbf{t_0}$ and $\mathbf{t_1}$ over many iterations.

To simulate sign survey histories, I modeled the number of signs encountered in a given survey unit by generating a random variate from a negative binomial function described by a mean, $\boldsymbol{\mu}$, and a "clumping parameter", ***k***. I based the value of μ on a number of tigers occupying each of 157 units, the size of the unit, and a specified amount of survey effort in terms of the number of km surveyed within each unit. To simulate a plausible starting condition for tiger occupancy, I used parameter estimates from the above tiger abundance model. The specific equation used was:

μ = (baseline number of tigers / 15) * (150 / area of unit) * # of km surveyed

For all simulations, the clumping factor was set equal to the mean of such values calculated from the empirical data collected in 59 units. Simulated sign detection values for each unit "surveyed" thus took a value of zero (0) for any units with no tigers and a random variate from this negative binomial distribution for all units in which tigers did occur (potentially ranging from zero in units where tigers were present but not detected to much higher values). Detection histories were then generated for each of ***n*** units and for each of ***s*** surveys (as defined in the particular model run) during an initial survey "season" (t_0). A corresponding set of survey data were calculated to represent sign encountered at $\mathbf{t_1}$ after conditions (e.g. numbers of tigers in each survey unit) had changed to one of four states representing plausible changes in tiger abundance and/or occupancy between t_0 and t_1. Values were then converted to the binary detection histories (e.g. 1 for values > 1, otherwise 0) used for input into basic occupancy models (MacKenzie et al. 2002).

I used an approach similar to that described by Field et al. (2005) to calculate trend detection power for a given simulation. Specifically, I used visual basic code and Excel spreadsheet commands to program a looping function to iteratively compare sign encounter histories from the two modeled periods with two possible models:

- A model in which occupancy was constrained to a single value between $\mathbf{t_0}$ and $\mathbf{t_1}$ (i.e., no change),
- an alternative model in which occupancy was allowed to vary between $\mathbf{t_0}$ and $\mathbf{t_1}$

Within a given iteration, I used the following formulas to represent raw likelihood values for each unit and time period:

For any survey history where sign was encountered at least once, and:

$$L\ (s>0) = \Psi\binom{m}{s} p^{s} (1-p)^{m-s}$$

(where Ψ = probability of occurrence and p = probability of detection)

…representing the probability of ***s*** successful sign detections over ***m*** survey occasions (a binomial distribution) multiplied by Ψ,

…and, for any survey history in which sign was never encountered:

$$L(s=0) = (1-\Psi) + \Psi(1-p)^{m}$$

…representing the probability that the site was unoccupied by tigers plus the probability that tigers were there but that their sign was undetected over ***m*** survey occasions.

I then used the ***Solver*** function in Microsoft Excel (Fylstra et al. 1998) to find values for Ψ and p that would minimize the summed negative log likelihood (-ln*L*) values over all units and survey occasions within each time period.

To determine whether a trend would be successfully detected during a given iteration of a particular simulation run, I subtracted the quantity 2*(-ln*L*) of a model where occupancy was constrained to a single value between $\mathbf{t_0}$ and $\mathbf{t_1}$ from the same quantity of an alternative model in which occupancy was allowed to vary between periods. The resulting value represents a likelihood ratio test statistic (LRT) appropriate for comparison with a chi quare distribution for hypothesis testing (Lebreton et al. 1992). I thus compared this LRT to a chi-squared distribution (with *df*=1). If the likelihood of the constrained model (e.g. Psi constant from $\mathbf{t_0}$ to $\mathbf{t_1}$) was significantly higher than the likelihood of the unconstrained model (at the significance level specified for that simulation run), then I considered the modeled trend successfully detected.

I programmed a variable to keep track of successful trend detection events as the simulation proceeded. Finally, I interpreted the proportion of times a trend was successfully detected over the total number of simulated survey events within a given program run as representative of power. The above procedure is reflected in the pseudo-code below:

1) Define a plausible starting condition (e.g. distribution and abundance of tigers in discrete survey units) for tiger occurrence over the landscape.
2) Define a subsequent condition representing a plausible change in tiger numbers in one or more units.
3) Generate a simulated 1st season detection history for the hypothesized "starting condition" of tiger occurrence by generating random variables (from the negative binomial distribution described above) representing signs encountered at each of ***n*** units and each of ***s*** surveys. Where ***n***, ***s***, and distance surveyed (***d***) are specified to explore a specific survey design.
4) Keeping all other variables constant, generate a simulated 2nd season detection history for a modeled change in underlying tiger numbers (e.g. some tigers are taken out of or added to the the underlying starting condition).
5) Convert modeled numbers of tiger sign detections to binary (e.g. 1 or 0; detected vs. not detected) format.
6) Use the Solver algorithm in excel to find maximum likelihood estimates for **Psi** and **p** for both of the above histories by finding values of these variables that minimize the summed negative log likelihood values over all unit-wise outcomes in a given survey period.
7) Combine these into a single binary detection history representing 2 survey periods with s surveys during each period.
8) Use this history to fit two models: one constraining occupancy rates to be constant over the two years and one allowing occupancy to vary.
9) Compare the likelihood of the two models. Where the likelihood of the unconstrained model is greater than the likelihood of the constrained model (at a

specified probability), then consider the trend successfully detected for that particular model run.

10) Tally successful trend detection events over many simulated iterations and interpret this as power (expressed as the % of modeled surveys in which a trend was successfully detected).

To compare the effectiveness of different survey configurations, I systematically varied the following survey parameters:

- ***α***(the desired confidence level at which trends are to be detected; 0.01, 0.05, 0.10, or 0.15)
- ***n*** (the number of survey units searched for sign)
- ***s*** (the number of repeat surveys to be carried out within a given survey period)
- ***d*** (the total number of kilometers walked within each survey unit in an effort to detect signs)
- ***unit selection strategy*** (whether units surveyed are selected at random or are based on an strategic schedule that attempts to balance the selection of units where tigers are predicted to occur with a geographically representative pattern)

Furthermore, to explore trend detection power under different change scenarios, I held the above parameters constant while changing the modeled trend (Table 2-1). I constructed change scenarios by manually reducing numbers in cells in an ad-hoc manner until desired conditions related to occupancy and overall population were achieved. Basic decline scenarios included declines of 10 % and 20 % of both occupancy and population. A scenario with 0% change in occupancy but 20% change in population explored whether smaller numbers in many occupied units (and thus a smaller amount of sign created) could be consistently detected.

Table 2-1. Trends in occupancy and abundance used in exploring the monitoring model.

Trend Name	**Change in Occupancy**	**Change in Total Individuals**	**Insight Sought**
-20/-20	-20%	-20%	Compare power to detect larger trend
-10/-10	-10%	-10%	Test power to detect a decline in occupancy
0/-20	0	-20%	Test power to detect a decline in numbers with no change in occupancy
+20 /+20	+20%	+20%	Test power to detect an increase

Results

The survey unit delineation process resulted in 157 units covering the entire study landscape and ranging in size from 88 km^2 to 251 km^2 with a mean size of 152.24 km^2 (see Chapter 1, Figure 1-19). Surveys were conducted over a four year period in 59 units representing the core of this area (Figure 2-4). Twenty-seven sites were surveyed 1 year only, 14 sites surveyed twice over 2 years, 5 sites twice over 3 years, and 1 site twice over 4 years. Two sites were surveyed thrice over 3 years, 6 sites thrice over 4 years, and four sites four times over 4 years.

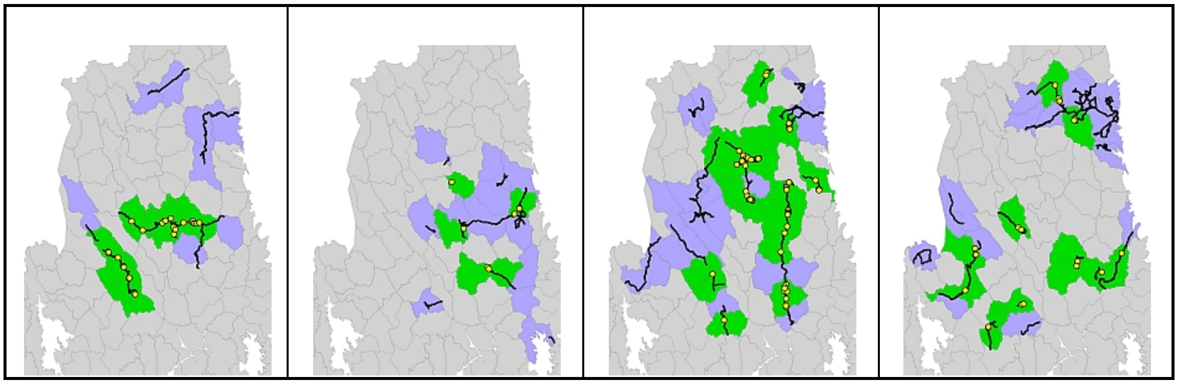

Figure 2-4. Summary of four consecutive years of sign surveys. Dark lines are survey routes, blue areas were surveyed with no detection of sign, green areas are where tigers were detected and yellow dots are tiger detection points.

Basic Occupancy Model

The results of nine models compared in the basic occupancy framework are shown below. Log transformed survey route distances improved model likelihood dramatically and were retained throughout. Of four covariates assessed, only relative prey abundance and distance to village led to improvements over models that estimated occupancy as constant over all sites.

Table 2-2. Comparison of nine models fit using the basic occupancy modelframework.

Model #	Model form	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par
1	{p(.+log(dist)) Psi(.+prey)}	107.8383	0	0.70899	1	4
2	{p(.+log(dist)+area) Psi(.+prey)}	110.2155	2.3772	0.21599	0.3046	5
3	{p(.+log(dist)) Psi(.+dist2vill)}	112.3305	4.4922	0.07502	0.1058	4
4	{p(.+log(dist)) Psi(.)}	137.0341	29.1958	0	0	3
5	{p(.+log(dist)+area) Psi(.)}	137.4461	29.6078	0	0	4

6	**{p(.+log(dist)) Psi(.+forest)}**	139.0565	31.2182	0	0	4
7	**{p(.+log(dist)) Psi(.+ruggd)}**	139.2189	31.3806	0	0	4
8	**{p(.) Psi(.) PIM}**	149.7652	41.9269	0	0	2
9	**{Full}**	155.3028	47.4645	0	0	5

The second model includes the uninformative variable area.

Parameter estimates for the best supported model are shown below.

Parameter	Estimate	SE	LCI	UCI
P (Occasion 1)	0.739051	0.062341	0.60048	0.842191
p (Occasion 2)	0.767816	0.06135	0.627504	0.866518
P (Occasion 3)	0.78686	0.060665	0.644999	0.88237
P (Occasion 4)	0.848678	0.057013	0.701434	0.930501
Psi (Occupancy)	0.519153	0.143486	0.259238	0.7691

Given support for a model including relative prey quality values, I used this covariate (for which values had been calculated over the entire study landscape) as a means to extrapolate occupancy probalities to all survey units. The results of this procedure are shown in Figure 2-5.

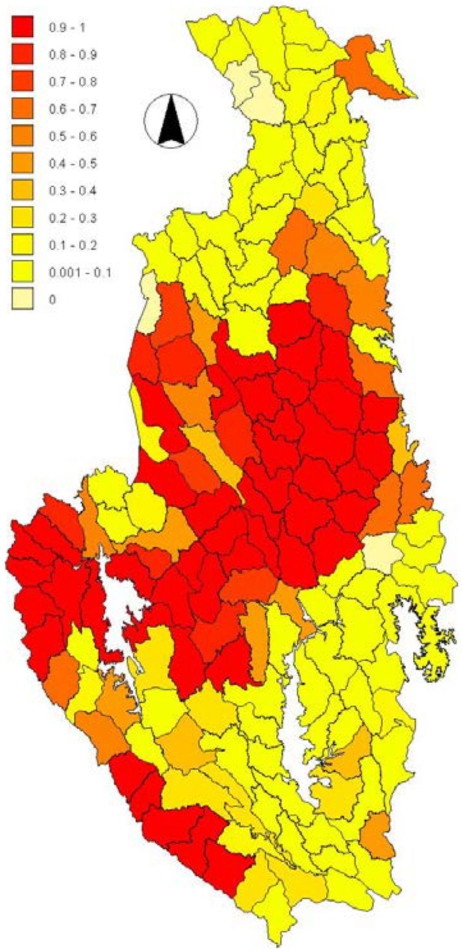

Figure 2-5. Occupancy probabilities extrapolated based on a prefered model and prey relative quality values summed by survey unit.

Multi-state Model

A total of 16 models were compared in the multi-state modeling environment. Given the support for log transformed survey route distances in the basic model, I retained this transformation in all cases where survey distance was used. Of four site-wise covariates assessed (e.g. area, ruggedness, percent of closed forest types, and relative prey quality index), prey index values were again strongly supported.

Table 2-3. Comparison of 16 models fit with the multi-state model personality where 3 states represent "breeding occurrence", "non-breeding occurrence", and "not occupied".

Index	Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
1	{[Psi1+prey],Psi2,[p1(.),p2(.),delta]+log(dist)}	163.789	0	0.26691	1	7	147.593
2	{[Psi1+Psi2],Prey,[p1(.),p2(.),delta]+log(dist)}	164.566	0.777	0.18099	0.6781	7	148.3699
3	{[Psi1+prey],Psi2,[p1(.),p2(.),delta]+log(dist)+forest}	165.0443	1.2553	0.14249	0.5338	8	146.1643

4	{[Psi1+dist2vill+prey],Psi2,[p1(.),p2(.),delta]+log(dist)}	165.5948	1.8058	0.1082	0.4054	8	146.7148
5	{[Psi1+log(area)+prey],Psi2,[p1(.),p2(.),delta]+log(dist)}	165.9168	2.1278	0.09211	0.3451	8	147.0368
6	{[Psi1+prey],[Psi2+prey],[p1(.),p2(.),delta]+log(dist)}	166.1414	2.3524	0.08233	0.3085	8	147.2614
7	{[Psi1+Psi2],Prey,[p1(.),p2(.),delta]+log(dist)+log(area)}	167.0434	3.2544	0.05244	0.1965	8	148.1635
8	{[Psi1+Psi2],Prey,[p1(.),p2(.),delta]+log(dist)+area}	167.0967	3.3077	0.05106	0.1913	8	148.2167
9	{[Psi1+dist2vill],Psi2,[p1(.),p2(.),delta]+log(dist)}	168.6525	4.8635	0.02346	0.0879	7	152.4565
10	{[Psi1,Psi2,[p1(.),p2(.),delta]+log(dist)}	192.865	29.076	0	0	6	179.2496
11	{[Psi1+forest],Psi2,[p1(.),p2(.),delta]+log(dist)}	195.123	31.334	0	0	7	178.9269
12	{[Psi1+ruggd],Psi2,[p1(.),p2(.),delta]+log(dist)}	195.2995	31.5105	0	0	7	179.1035
13	{[Psi1,Psi2,[p1(.),p2(.)]+log(dist),delta}	198.7636	34.9746	0	0	6	185.1482
14	{[Psi1,Psi2,[p1(.),p2(.)]*log(dist),delta}	201.0939	37.3049	0	0	7	184.8979
15	{[Psi1,Psi2,p1(.),p2(.),delta}	212.2413	48.4523	0	0	5	201.1092
16	{Full}	215.0089	51.2199	0	0	11	187.3919

The top model is superior in terms of AIC value. However, an examination of parameter estimates for model 2 (a model associating the prey covariate with occupancy probabilities for both breeding and non-breeding occurrences) shows that several parameters failed to converge, an indication that data on breeding status was insufficient for the model to provide accurate estimates. Parameter estimates for the best performing model are shown in Table 2-4.

Table 2-4. Parameter estimates for the best-performing multi-state occupancy model.

Model	**Parameter**	**Estimate**	**SE**	**Lower CI**	**Upper CI**
{[Psi1+prey],Psi2,[p1(.),p2(.),delta]+log(dist)}	Psi1	0.520626	0.144066	0.259445	0.770998
	Psi2	0.724974	0.243268	0.194334	0.966451
	p1	0.855106	0.102792	0.537214	0.967746
	p1	0.875238	0.091952	0.573861	0.973366
	p1	0.888137	0.084669	0.599045	0.976847
	p1	0.927034	0.060848	0.685434	0.986681
	p2	0.701196	0.090832	0.500824	0.845888
	p2	0.736114	0.085904	0.539687	0.869057
	p2	0.759443	0.082382	0.566058	0.884267
	p2	0.834765	0.069031	0.654496	0.930907
	Delta	0.337433	0.166671	0.105654	0.68706
	Delta	0.377097	0.175089	0.123158	0.722938
	Delta	0.406579	0.180199	0.136816	0.747578
	Delta	0.52299	0.19061	0.196941	0.830556

The association between prey index values and general occupancy in model 1 was used to map values for occupancy over the full study landscape, producing a pattern similar to that of the basic model above.

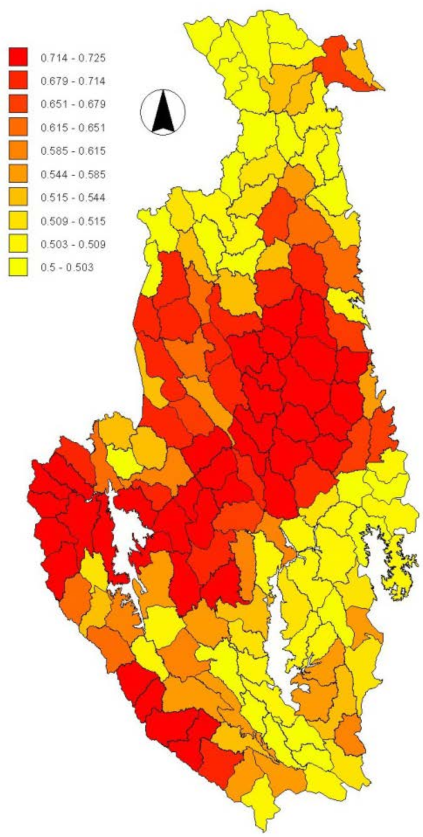

Figure 2-6. Occupancy probabilities predicted by the multi-state model.

Detailed Monitoring Model

Alpha Values

The alpha level chosen for significance testing had a significant effect on power to detect trends (Figure 2-7). However, at alpha values of .10 or more, power cooonverged to 1 under most conditions.

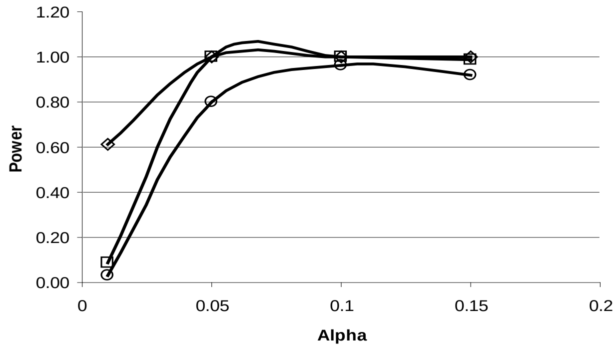

Figure 2-7. Change in power to detect a 20% decline in occupied units as a function of the alpha level chosen for testing. Circular points are the case with 2 repeat surveys, squares are with 3 repeat surveys and diamonds are with 4 repeat surveys.

Number of Survey Units Visited

The number of survey units visited had a significant impact on power to detect trends (Figure 2-8). However, most of the increased power was masked by the much stronger effect of simply conducting three or four repeated surveys rather than two. The shape of the lines, especially that of the one representing 2 repeat surveys, indicates that the number of simulations was likely insufficient to reflect the expected monotonicly increasing trend.

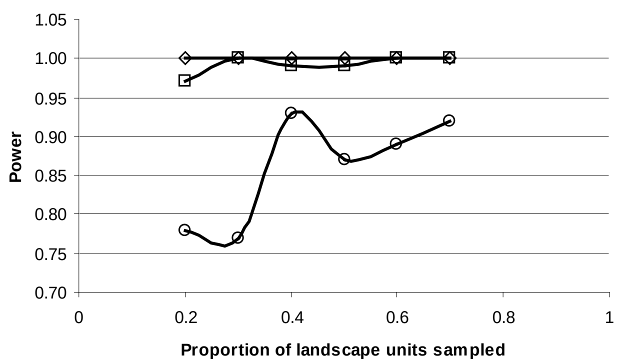

Figure 2-8. Change in power to detect a % decline in occupied units as a function of the proportion of overall survey units sampled. Circular points are the case with 2 repeat surveys, squares are with 3 repeat surveys and diamonds are with 4 repeat surveys.

Number of Replicate Surveys

Under a wide variety of simulated conditions, there were typically large gains in trend detection power resulting from conducting three vs. two surveys per study plot, but only marginal gains from conducting four replicates instead of three. Given the added cost and time, managers would want to consider conducting four surveys only under a very limited set of circumstances.

<u>Survey Effort</u>

Survey effort (here expressed in terms of distance walked along likely tiger travel routes by equally competent teams of surveyors) only affected power when distances searched were lower than about 5 kilometers. It appears that, under conditions of the model, the presence of any tiger within a unit will likely be detected early in the course of surveys.

<u>Survey Strategy</u>

This factor had a strong impact on power to dectect trends. When units for survey were selected at random (resulting in a relatively high number of empty cells, power to detect trends in occupancy was greatly reduced. In contrast, when surveys focused on core areas, the number of occupied cells was higher and resulted in higher rates of power. However, when only a small proportion of "strategically selected" units were surveyed, power was low; likely due the very low rate of any empty units that might otherwise provide contrast from one time to another.

Discussion

By exploring conditions likely to be encountered by surveyors working in the study area, I have attempted to provide useful insights for planners and managers attempting to address key questions about trends in tiger distribution and abundance throughout the study landscape. While I report on results and simulations that attempt to mirror conditions found in Thailand's Western Forest Complex, many of the patterns encountered with these sample data should be applicable to other areas where monitoring efforts are challenged by issues of spatial scale and variablility.

Means of Tiger Detection

Presence-absence survey methods are relatively easy to apply and do not require a large initial investment in equipment and training. They can be implemented on a landscape scale at a relatively low cost. A thorough record of survey effort and the types of features surveyed (e.g. roads, streams, ridges, etc.) is likely to be a critical component of this method as it facilitates the comparison of data from diverse efforts.

A useful feature of the occupancy-based parameter estimation framework used in this analysis is that different methods of detection can be used and explicitly integrated into a single occupancy model. Given a sufficient number of survey units and repeat surveys, independent detection probabilities can be estimated for different detection methods thus informing future choices about the effectiveness and efficiency of a variety of methods. With this in mind, it is important that existing datasets on tiger detection using different methods be combined and compared in this framework.

Survey Unit Configuration

The "ecologically-bounded" survey units or ESUs proposed here have several characteristics that make them valuable and appropriate for tiger survey, monitoring, and management efforts at the landscape scale. They:

- can be readily identified in the field through reference to distinct topographic and other natural features;
- roughly reflect patterns of resource use and movement patterns of many large mammal species (e.g. heavier use in lower areas, lighter use in higher areas);
- parallel human impact patterns (e.g. higher impacts and more travel routes in lower areas); and
- leverage the value of limited surveys to uncover significant trends in both animal abundance and distribution and threats to the survival or maintenance of target species populations.

Rectangular survey units have been proposed as a basis for organizing and reporting data on landscape-scale tiger distribution (Karanth & Nichols 2002a). However, I found irregular, ecologically-bounded survey units (ESUs) to be more practical for planning and carrying out fieldwork and more meaningful in linking biological data with patterns of tiger distribution.

ESUs were readily discernable in the field - especially in areas of rugged terrain, and natural and man-made travel routes coincided with catchment topography. Large mammal distributions and human impact patterns are often focused on the central drainages of catchments (typically the most convenient access route) and surveys that focused on these features therefore tended to maximize the efficiency of our time in the field. The size of ESUs used here proved to be appropriate for planning purposes in that units could be adequately covered in a 2-3 day field trip.

From an analytical standpoint, ESUs of the size outlined here can be a useful unit of analysis for quantifying and monitoring distribution patterns over large areas. Another practical advantage of the ESU approach is that it provides a consistent platform on which to evaluate tiger survey data from year to year. Potential disadvantages of an ESU approach are that 1) an additional parameter (e.g. size) is needed to to deveop accurate models; and 2) their inconsistent sizes mean that converting occupancy to density requires more work (although this work will likely produce more accurate maps).

Occupancy Models and Implications for Monitoring

Occupancy as a state variable can be practically applied over large areas and could form an important part of an integrated monitoring strategy in this area. The monitoring strategy described here should be seen as part of an adaptive approach that is flexible enough to respond to new insights derived from the ongoing survey and monitoring process. I have detailed the steps in estimating key parameters necessary for making monitoring projections. These parameters are likely to become more stable with each monitoring cycle and it is important that each successive survey dataset be seen as an opportunity to reassess monitoring strategies and effectiveness.

PART II

Conservation Planning in Cambodia

CHAPTER 3. MAPPING CAMBODIA'S BIODIVERISTY

Cambodia's biological diversity is unique in many ways and has significant economic and other values. The Cambodian government has taken important steps to document and conserve this biodiversity through the establishment of a number of dedicated government agencies and an extensive protected area system. Cambodia has supported a national level gap analysis to identify options for improving the effectiveness of it's protected area system in representing and conserving the country's biological diversity. This analysis represents a key aspect of that larger process by mapping distributions of both coarse filter (e.g. biogeoclimatic zones and distinctive ecological communities) and fine filter (e.g. species, subspecies, and populations) and assessing the status and viability of these occurrences.

Introduction

Cambodia falls within the Indo-Burma ecological region which is noted for its biological diversity. This region encompasses five of the 'Global 200' ecosystems – the most biodiverse areas in the world as well as extensive, relatively intact natural landscapes. Vertebrate species new to science are regularly discovered and islands of habitat such as isolated mountains and mountain ranges have been shown to be hotspots for endemic species and natural communities.

A number of highly distinctive ecological systems occur in Cambodia including the globally unique Tonle Sap lake, extensive intact mangrove forests, and the largest remaining block of lowland humid (e.g. evergreen or semi-evergreen) forest in Southeast Asia (Ashwell et al. 2004).

From a species diversity perspective, many of Cambodia's native taxa are poorly studied, and a clear understanding of the diversity and distribution of larger taxonomic groups is currently limited to mammals and birds. Recent surveys have contributed substantially to a more complete picture of reptile diversity (Platt et al. 2008; Platt & Tri 2000; Stuart et al. 2000) but distribution patterns remain poorly understood. With the exception of a few targeted surveys in recent years, overall knowledge of amphibian diversity also remains weak although preliminary data suggest that rates of endemism may be high for this group (Daltry & Momberg 2000). Focused studies on invertebrates, while valuable in many ways, have been restricted to local sites and are therefore of limited value in expressing diversity patterns across the entire country.

With more than 500 documented and likely more than 600 total species of birds (Poole 2001), Cambodia has a particularly high rate of avian diversity. The country's unique hydrology provides critical breeding and feeding habitat for many species. Although only one endemic bird is known from the country (Chestnut-headed Partridge), Cambodia hosts the most viable populations globally for many species (including Giant Ibis, Bengal Florican, Slender-billed Vulture, White-rumped Vulture, and Spot-billed Pelican) and the most viable populations regionally for many others (including Greater Adjutant, Sarus Crane, and Manchurian Reed Warbler) (Hout et al. 2003).

Compared with its neighbors, Cambodia has the highest occurrence rate of globally threatened species (per unit area) in the region for mammals, birds and fish (Tordoff et al. 2005a). The occurrence of relatively extensive, intact tracts of habitat demonstrates that the country has a potentially pivotal role in global conservation efforts targeting these species.

Cambodia's natural landscapes were significantly impacted during periods of widespread conflict from the mid-1960s through the early 1990s and then during a period of intensive commercial logging during the 1990's and early 2000's. In addition, hunting, snaring, egg collection, and other direct impacts have taken a heavy toll on wildlife in recent years (Bettinger 2004). These focused impacts present a particular challenge in conservation planning as these threats are difficult to impossible to monitor and map comprehensively.

As a signatory to the Convention on Biological Diversity (CBD), Cambodia is committed to pursuing the various "Programmes of Work" agreed on by participating countries. Of particular relevance to native biodiversity protection is decision VII/28 and its associated programme of work developed in 2004 in Kuala Lumpur (Secretariat of the Convention on Biological Diversity 2005). The first goal of the first programme element is "to establish and strengthen national and regional systems of protected areas integrated into a global network as a contribution to globally agreed goals". To achieve this goal, the programme recommends that parties undertake ***gap analyses*** to:

- identify sites of global and national biodiversity significance,
- identify which sites and features are currently not adequately represented or adequately managed in protected area systems, and
- prioritize conservation actions to undertake at these sites.

This analysis is an attempt to satisfy the first of these explicit recommendations and facilitate the second and third.

In particular, the programme of work specifies that:

> *"Gap analyses should take into account Annex I of the Convention on Biological Diversity[3] and other relevant criteria such as irreplaceability of target biodiversity components, minimum effective size and viability requirements, species migration requirements, integrity, ecological processes and ecosystem services."*

Guided by widely used strategies and procedures for selecting appropriate representative biodiversity surrogates and in broad consultation with stakeholders, this analysis attempts to provide the biodiversity maps required for this gap analysis and for a wide variety of conservation planning needs in Cambodia.

Background

A number of valuable efforts have attempted to inventory Cambodia's biodiversity in some way. These exercises provide an essential foundation for this and future work to characterize and quantify the patterns and processes that define the country's biodiversity.

One of the most important contributions was David Ashwell's *Cambodia: A National Biodiversity Prospectus* (Ashwell 1997). Based on exhaustive research into previous geological, botanical, and other seminal survey work and aerial surveys and ground visits to many areas around the country, this detailed profile still provides essential background for understanding biodiversity patterns throughout the country.

[3] Annex 1 of the Convention on Biological Diversity: Identification and Monitoring "1. Ecosystems and habitats: containing high diversity; large numbers of endemic or threatened species, or wilderness; required by migratory species; of social, cultural or scientific importance; or, which are representative, unique or associated with key evolutionary or other biological processes; 2. Species and communities which are threatened; wild relatives of domesticated or cultivated species; of medicinal, agricultural or other economic value; or social, scientific or cultural importance; or importance for research into the conservation and sustainable use of biological diversity, such as indicator species; and described genomes and genes of social, scientific or economic importance."

In 2001, a diverse team of contributors produced "Biodiversity: the life of Cambodia" (Smith 2001)which in many ways complements Ashwell's prospectus by presenting a profile of both wild and domesticated biodiversity (e.g. cultivars, livestock varieties, etc.). This compendium also summarized much recent work on the status and distribution of the country's vegetation patterns and wildlife species.

In 1999, WWF initiated a large scale planning effort to characterise landscapes and identify conservation priorities in the forested areas of the Lower Mekong Region (Baltzer et al. 2001; WWF Indochina 2000) which contains four of WWF's Global 200 priority biodiversity conservation. Spanning all of Cambodia, Vietnam, and portions of Laos, the assessment took stock of the biological uniqueness and threats to the Greater Annamites, Central Indochina Dry Forests, Lower Mekong Floodplains, and Cardamom Mountains ecoregions.

On the scale of the entire country, BirdLife International and several partners applied their widely-used 'Important Bird Areas' (IBAs) methodology to identify important areas for bird conservation throughout Cambodia (Hout et al. 2003). IBA methods use four categories of species to focus conservation efforts: endangered species, restricted-range species, biome restricted species, and species that form congregations during all or part of the year.

These larger scale assessments led to a more focused effort to understand and conserve biodiversity within the Central Indochina Dry Forest Ecoregion (Tordoff et al. 2005b). A strategic plan for that region has been drafted (WWF Greater Mekong Programme 2005) and is being promoted as a framework to link the conservation efforts of stakeholders throughout the region.

The recent Indo-Burma Ecosystem Profile (Tordoff et al. 2005a) prepared as a planning document for the soon-to-be activated Critical Ecosystem Partnership Fund[4] covers a large region inclusive of Thailand, Cambodia, Laos, Vietnam, and portions of southern China. Among other contributions, the profile builds on and expands the Important Bird Area work in each of these countries by applying the concepts used to define IBAs to a broader range of taxa.

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[4] http://www.cepf.net/xp/cepf/

While the assessments above have provided invaluable information to policy-makers and conservation practitioners, none has attempted to produce the types of maps required for explicit gap analyses and other elements of conservation planning. Such maps are a critical component of these efforts (Dudley & Parrish 2006).

Techniques related to conservation planning and implementation have undergone sweeping advances in recent years. As projects and objectives have grown in both complexity and geographic scope, concepts and tools from the fields of decision theory, operations research, and computer science have been adapted to address complex modeling, decision-making, and communication challenges (Sarkar et al. 2006).

Many of these tools require spatially explicit data to yield meaningful outputs for conservation planning and management. Geographic Information Systems (GIS) have become an indispensible tool for storing, manipulating, and visualizing such data. At various points in the process, employing spatially explicit data can increase the power and efficiency of exploring options, increase the level of participation and transparency, and provide a crucial bridge between normative and positive aspects of conservation planning and implementation.

Objectives

The objective of this analysis is to provide the biodiversity information products necessary for carrying out the explicit gap analysis called for by the CBD. In broad terms, the analysis consists of two important steps: the selection of focal biodiversity features and a detailed evaluation of the distribution and conservation status of these features.

I begin with a summary of Cambodia's broad biodiversity patterns to provide context to both of these steps. This is followed by a description of methods used to select representative biodiversity features and produce maps and associated data for use in gap analyses and other aspects of conservation planning.

Finally, I review the results of the selection and assessment process and discuss how these products can be utilized and refined in a practical and systematic way.

Study Area and Biodiversity Overview

The broad geographic extent of this analysis includes all terrestrial portions of Cambodia (~181,370 km^2) as well as a marine zone extending approximately 40 km from the country's coastline (~13,651 km^2) and including all major coastal islands.

The sections below attempt to provide an overview of Cambodia's biodiversity. I first summarize the country's physical geography in terms of the physiographic features, geology, hydrology, and climate patterns that provide the backdrop to all other elements of the country's biological diversity. I then present overviews of the diversity and status of Cambodia's terrestrial, freshwater, and marine ecosystems in the context of the broader Indo-Burma ecoregion.

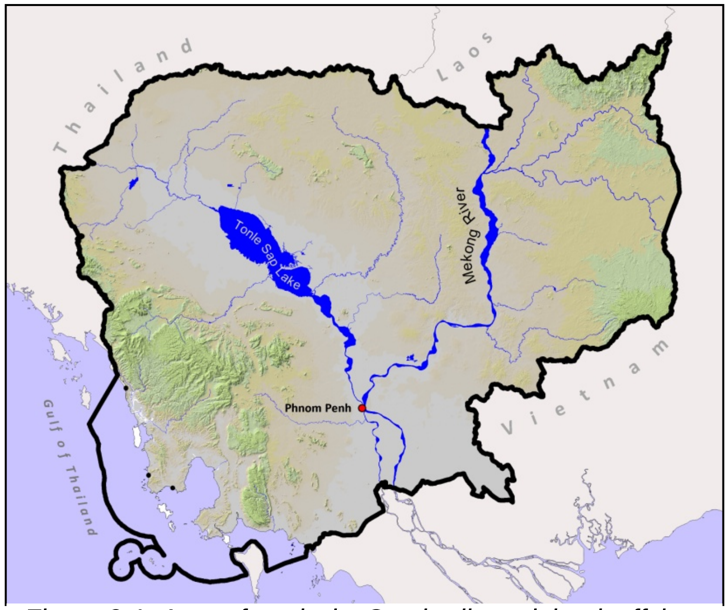


Figure 3-1. Area of analysis: Cambodia mainland, offshore islands, and marine zone.

Climate and Geophysical Context

<u>Physiography</u>

At the most basic level, Cambodia's physiography is that of extensive lowland areas punctuated by a few areas of higher relief. Lowland areas were once covered by ocean and have subsequently been shaped by the action of several major rivers, including the Mekong which still dominates the country's defining hydrology.

<u>Geology</u>

Geological patterns have been created by three major forces: ancient volcanic activity forming the rugged mountainous areas, sandstone deposits of the ancient ocean, and the action of major drainages which have served to both carve away some of the ancient sandstone deposits and deposit their own load of silt and other materials.

Lowland areas (primarily below 100 meters above sea level(masl)) can be described as five major formations:

- extensive alluvial plains bordering the Mekong River-Tonle Sap wetlands system at elevations between 5 and 30 metres, much of which receive an annual increment of alluvial silt,
- basaltic areas in the vicinity of Kompong Cham province in eastern Cambodia,
- fertile soils of the Battambang plain in western Cambodia,
- alluvial soils associated with the upper (Cambodian) portion of the Mekong Plain, and
- vast areas of northern-eastern and northern Cambodia featuring either flat sandstone plains or rolling terrain on ancient alluvial deposits punctuated by volcanic outcroppings.

Areas above 100 masl consist of:

- the primarily sandstone and granitic Cardamom and Elephant Mountains (including the country's highest point, Mt. Aural at 1,771 masl),
- colluvial slopes along the northern and eastern edges of the Cardamom and Elephant Ranges,
- northeast mountainous areas representing an extension of the metamorphic and sedimentary rocks of the Kontoum Plateau (Annamite mountain range),
- the basalt based Bokeo (Rattanakiri) and Chhlong Plateaus, and
- the steep escarpment of the Dongrek Range which defines the northern limits of the northern plains and rises to the extensive sandstone plateaus of northeastern Thailand.

Closely associated with the country's geology are its soil patterns. These can be summarised as:

- alluvial lithosols forming around the Tonle Sap Lake, Mekong floodplain, and other major riverways,
- older hydromorphics along the higher ancient floodplains and drainages,
- podzols occurring on undulating lower slopes,
- basalt-derived latisols of some of the extensive lower plateaus,
- distinctive coastal formations arising from older tidal deposits, and
- lithosols of the rugged higher elevations.

The most productive areas of the country in terms of both natural and agricultural vegetation are those situated on the relatively rich alluvial deposits and on the basalt derived soils of several extensive plateaus (Ashwell et al. 2004).

Hydrology

The Mekong River/Tonle Sap system dominates the hydrology of Cambodia (Figure 3-2). Originating in the Tanghla Shan Mountains of the Tibetan Plateau, the 4,200 km-long Mekong passes through China, Burma, Laos, Thailand, Cambodia and Vietnam before draining into the South China Sea. Approximately twenty-five percent of the total water flow in the Mekong River is derived from Tibet and China, fifty percent is derived from northeast Thailand and Laos, a further twenty percent from the catchment of the Sekong, Sesan and Sre Pok rivers, with the remainder coming from rivers that drain northeast and central Cambodia via the Tonle Sap Lake (Pantalu 1986).

Cambodia's other major rivers include the the Sekong, Sesan and Sre Pok which flow into the Mekong and drain much of the country's extensive eastern plateau as well as adjacent parts of Laos and Vietnam. The Stung Sen and Stung Chinit drain much of northern Cambodia whereas the Stung Sangké and Stoeng Poursat drain major portions of western Cambodia and the northerly slopes of the Cardamom Range. Rivers draining the southerly slopes of the Cardamoms are among of the region's most dramatic and pass through some of Cambodia's roughest topography before draining into the Gulf of Thailand.

Central to much of Cambodia's hydrological system is the Tonle Sap or "Great Lake", a globally unique hydrological phenomenon that has helped shape Cambodia's landscape and culture. Each year, the floodwaters of the swollen Mekong and other rivers surge into the lake causing it to rise 8 meters in some areas and more than quadruple in size (Campbell et al. 2006). Later in the year, as the flow decreases in the Mekong, these waters recede - and the Tonle Sap river reverses direction; flowing back into the Mekong. A topographical rise at the south-eastern end of the Great Lake forms a massive natural dyke and prevents the lake from emptying completely during the dry season (Bardach 1959; Fontaine & Workman 1978).

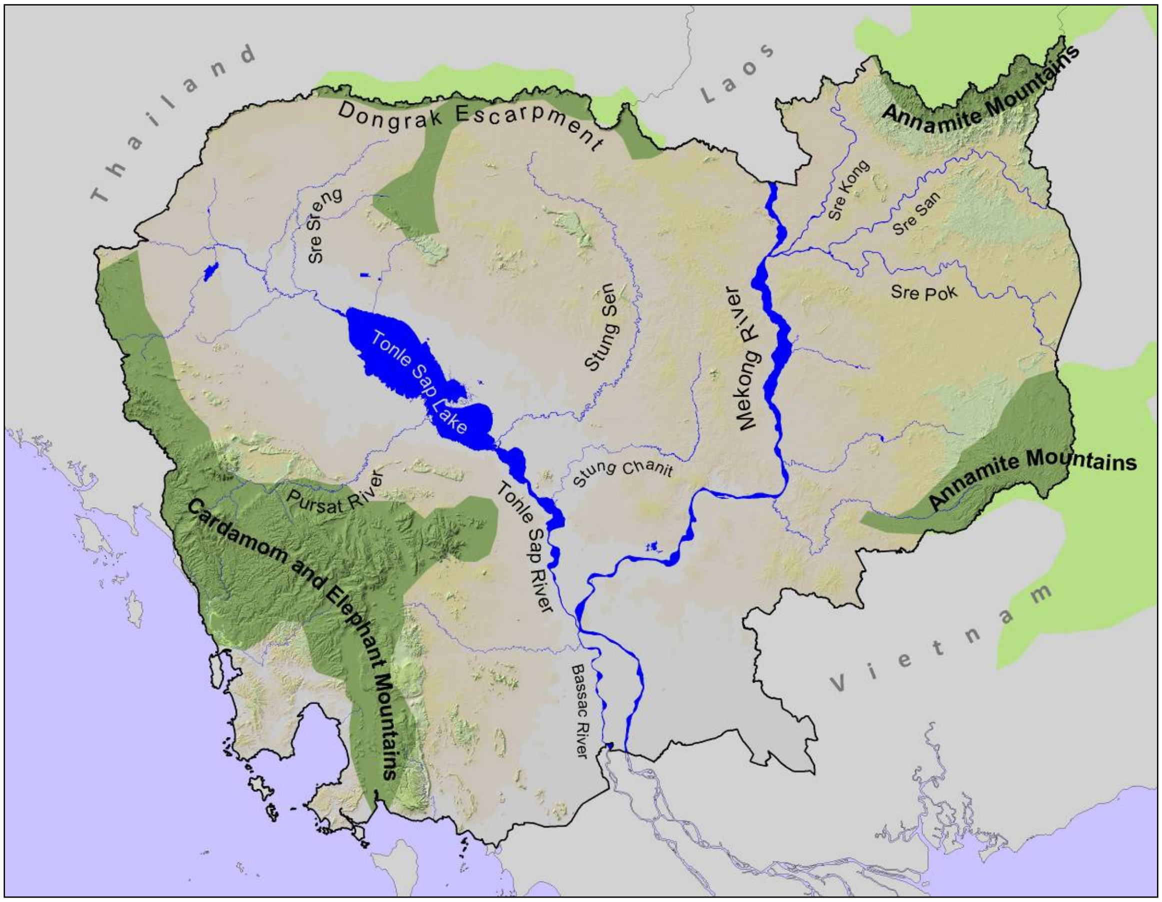


Figure 3-2. Map of Cambodia showing topography, major hydrological features, and areas of high plant endemism in Indochina. Light green areas are endemic-rich areas outside of Cambodia and dark green areas are (green areas). (After Schmid (1989)).

Climate

Cambodia's climate is an annual monsoon pattern with the heaviest precipitation arriving from the Southwest between May and early October. A shift in the prevailing winds from the Northeast prelude a relatively cool season extending from November until January. February through April is relatively hot and dry.

Average annual rainfall is generally between 1,200 and 1,875 mm over most of the country's lowlands but can reach 5,384 mm during up to 223 rain days per year (Dy Phon 1982) in the coastal Cardamom range. In the higher elevation areas of the south-west and north-east the dry season is shorter and less pronounced.

Average annual temperatures vary between 25°C and 30°C for most of the country except at higher elevations such as Phnom Bokor (1050 m) where the average temperature is approximately 20°C. March, April and May are the hottest months. Fontanel (1972) defines three major bioclimatic regions for the country:

- coastal and mountain areas of the south-west;
- central plains encompassing the Great Lake, the Mekong Plain and contiguous areas; and
- northern and north-eastern.

The coastal and mountainous regions of the southwest show the least seasonal periodicity in climate. Humidity in these areas is relatively high throughout the year.

The central plains show the most seasonal variation in average temperatures (25-30°C) although relatively uniform patterns occur in some areas. Annual rainfall spikes in September and October and again in May and June. The number of rain days varies between 110 and 130 days per annum.

In northern and northeastern areas, a more continental climate regime features distinct seasonality with average daily temperatures reaching 41°C in some areas during the hottest month (April) and falling to below 25°C during the cooler part of the year. Rainfall patterns follow local topography with the average number of rain days varying between 110 and 130 days per year.

Habitat Diversity

Terrestrial Ecosystem

Nearly 70% of Cambodia's land area is below 100 masl. Large portions of these low-lying areas occur within the vast floodplains of the Tonle Sap Lake and the Mekong River and are thus subject seasonal inundation. Higher areas of the country consist of the Cardamom and Elephant Mountain Ranges in the southwest and an extensive eastern plateau flanked on the north and south by portions of the Annamite mountains. Patterns of terrestrial vegetation diversity in Cambodia and the region are covered in detail in several recent reviews (Ashwell 1997; Ashwell et al. 2004; McDonald 2004; Rundel 1999, 2001).

Human impact on vegetation patterns throughout the Indochinese peninsula began long ago (Vidal 1978; Wharton 1968) and the northern and eastern plains of Cambodia are an example of a landscape significantly modified by a longstanding pattern of fire that has eaten away at evergreen formations while facilitating the extension of deciduous species

(Ashwell 1997; Wharton 1968). These influences resulted in vast areas of relatively open, deciduous forest throughout the north and east of the country.

Freshwater Ecosystem

Cambodia's freshwater habitats comprise the country's most biologically diverse and threatened areas (Smith 2001). In addition to the diverse array of plant and animal life represented in this ecosystem, the country's hydrologic patterns and dynamics are globally unique and therefore warrant special consideration in protection and management activities.

The dominant features of Cambodia's freshwater ecosystem are the Tonle Sap Lake, Mekong River, and the Mekong's major tributaries. Central to the maintenance of the Tonle Sap are the adjacent seasonally inundated forests, shrublands, and grasslands. Altogether, these seasonally inundated areas cover 1.2 million hectares (Ashwell 1997).

Natural seasonal changes in hydrology as well as annual variation in the extent, timing, and duration of flooding translate into a tremendous variety of hydrological conditions and are thus important for maintaining the region's high rate of aquatic diversity (Ashwell 1997; Coates et al. 2003).

Other distinctive freshwater habitats include smaller river systems, marshes, fens, permanent and seasonal ponds, lakes, and reservoirs representing a wide variety of limnological conditions.

Simplification of hydrological systems through channelization, dredging, and other activities has been identified as the primary threat to sustaining Cambodia's freshwater biodiversity (Coates et al. 2003). Other major threats include the construction of dams and unsustainable fish harvest. Whereas many threats can be addressed domestically, the construction of dams at upstream locations outside of Cambodia highlights the need for regional planning and dialogue with regard to the region's freshwater resources.

Marine/Coastal Ecosystem

Cambodia's entire coast and sovereign marine zone occurs along the relatively shallow Gulf of Thailand (only 80 m at its deepest point). The total length of Cambodia's mainland coastline is approximately 530 kilometers (including island shorelines) and features a number of interrelated vegetation formations and other distinctive habitats. Among these are some of the most extensive and intact mangrove forests in Southeast Asia, Melaleuca-dominated swamp forests (often referred to as ‘rear mangrove’), and estuarine systems extending more than 30 km into the mainland in some cases.

Coral formations line some of the relatively shallow coastal waters and ring many of the 50 islands occurring off the coast. Several areas support vast seagrass communities that provide food and shelter for globally threatened sea turtles, dugongs, and diverse fish and invertebrate communities (Hines et al. 2008; Wildlife Conservation Society & Cambodia Department of Fisheries 2002). Cambodia’s open ocean areas area within the relatively shallow and productive Gulf of Thailand.

The distinctive moist evergreen forests of the steep slopes of the Cardamom and Elephant Ranges are fed by the heavy rains of the south-west monsoon (annual rainfall is between 2,000 and 5,500 in the coastal ranges). As a consequence, the rivers that drain this area deliver a high organic load to coastal estuaries and the gulf of Thailand. It is this rich seasonal nutrient injection that many credit for the high productivity of Cambodia’s coastal fisheries (Scripps Institute of Oceanography 1961).

Although they have been substantially reduced and impacted in recent years, Cambodia’s mangrove forests are perhaps the most extensive and intact in the region. Coastal mangrove formations, dominated by *Rhizophora*, *Brugiera*, and *Ceriops* spp. occur directly on the coastline and along the wide mouths of coastal estuaries. Inland from these mangrove forests is a community dominated by *Melaleuca leucadendron*, (formerly *M. cajuputi*), though with some trees and shrubs characteristic of mangroves and, frequently, distinctive large tree-ferns (*Acrostichum* spp.). Some palms, notably the highly useful and marketable *Nipa fruticans* may also be present. While frequently flooded by run-off, these areas are usually above the high-tide line, although they are subject to periodic salt water inundation due to storms and extreme “spring tides”. Finally, inland from this secondary band of coastal vegetation are 'swamp forests' that may develop in depressions of muddy alluvial soils (Vidal 1978).

Limited coral communities occur near the mainland coastline but coral is distinctly more extensive and well developed around offshore islands such as Koh Tang, Koh Dong, and Koh Pring. A number of cetaceans have been documented in the coastal zone (Wildlife Conservation Society & Cambodia Department of Fisheries 2002) including populations of the Irrawaddy Dolphin—better known regionally for its distribution in portions of the Mekong, Irrawaddy, and other freshwater areas.

Major threats facing marine ecosystems include pollution from coastal development and industry, overharvesting of fisheries, and unsustainable harvesting in mangrove and rear mangrove communities. Although Cambodia's mangrove communities are of key biological and economic significance both nationally and regionally, rapidly growing coastal communities continue to reduce the extent of these fragile formations.

The relatively unregulated development on many of the large near-shore islands in recent years has resulted in large areas of complete deforestation and erosion which in turn has likely had a negative impact on surrounding benthic communities.

Species Diversity and Endemism

Plant Diversity

Cambodia is located within the Indo-Malayan biogeographic realm. The flora of lower altitudes is typical of the Indochinese floristic province and so contrasts with that of the Chinese, Indo-Burman and Indo-Malayan floristic provinces. The flora of the higher altitudes shares a close affinity with those of the Indo-Malayan floristic province (Dy Phon 1982).

Forested areas of Cambodia are typically a mix of evergreen and deciduous species but can be almost entirely composed of one or the other at extreme ends of the spectrum. Often, single families such as Dipterocarpaceae, Leguminosae, Lythraceae and Fagaceae dominate a given community while in others, species from multiple families occur much more evenly.

A systematic list of Cambodia's vascular flora has never been published. Of an estimated 15,000 species of plants in all of Indochina (McDonald 2004), Dy Phon (1982) lists 2,308 occurring in Cambodia consisting of:

- 1,806 Dicotyledons in 626 genera,
- 488 Monocotyledons in 219 genera, and
- 14 Gymnosperms in 7 genera.

While approximately 214 of these species (9.3 percent of the total number of species) are endemic to Cambodia, there are no known endemic families or genera of vascular plants.

The rate of newly recorded botanical occurrences over the last several decades suggests that many more species await discovery and the full flora of Cambodia is expected to exceed 3,000 species (Ashwell 1997).

Fortunately, areas of highest plant endemism are also those in the more remote, mountainous areas of the country and therefore benefit from a high degree of natural protection. However, as few detailed floristic investigations have been carried out in Cambodia, the biodiversity implications of degradation or conversion in more threatened areas such as lowland evergreen forests and wetlands remains unclear.

Animal Diversity

Although relatively little systematic survey and taxonomic work has been invested in Cambodia's invertebrate fauna, both invertebrates and vertebrates have received increasing attention in recent years. However, survey coverage is still quite patchy making it hard to report on national-scale patterns of occurrence. Birds are certainly the best-documented group in terms of inventory and distribution and mammals (with the possible exception of rodents) are also quite well-documented. New country records of known species of reptiles, amphibians, and fish are not infrequent and indeed, there have been numerous new species discovered in all of these groups over the last several years.

While no single source has the most up-to-date inventory of animal diversity in Cambodia, Table combines information from a variety of sources to summarize numbers of documented species for most major groups.

Table 3-1. Animal species diversity summary data for Cambodia. All data are from the EarthTrends Environmental Information Database (UNEP-WCMC 2004) unless otherwise noted.

Taxon	# of Documented Species	Estimated Total # of Species	# of Endemic Species	# of Threatened Species	***Comments***
Mammals	127	-	0	37[d]	
Birds	530[a]	~600[a]	5	25[d]	*183 bird species are known to breed in Cambodia*
Reptiles	116	-	3	12[d]	
Amphibians	11	-	3	3	
Fishes	872 (Freshwater = 488; Marine = 410)[c]	850-1200 (Freshwater only) [b]	1[c]	22[c]	

***Other sources of data**: a) Directory of Important Bird Areas in Cambodia (Bird Conservation Society of Thailand 2004); b) Biodiversity: The Life of Cambodia (Smith 2001); c) FishBase (Froese & Pauly 2003) d) IUCN Red List (IUCN 2008)*

Methods

General Organization of the Analysis

Coarse filter (e.g. distinctive habitats and natural processes) and fine filter (e.g. individual species) focal biodiversity features (Dudley & Parrish 2006; Jennings 2000; Noss 1990; Scott et al. 1993) were selected to produce a representative set of biodiversity features. To facilitate the efficient application of similar analytical techniques, data relating to fine filter features were handled as a set, whereas data on coarse filter features were categorized into terrestrial, freshwater, and coastal/marine ecosystems; each received focused analysis. While there are rarely hard lines to be drawn between these broad ecosystems, they each possess fundamentally distinctive features and tend to relate to discernable subsets of overall biodiversity (Groves et al. 2000). From a practical standpoint, they also tend to serve as the basic structure for disparate field biodiversity assessments and thus provide a natural organizing structure for relevant information. Furthermore, conservation intervention and ongoing management are often aligned along the lines of these broad ecosystems.

A "human footprint" (sensu Sanderson et al (2002a)) map was developed to represent levels of impact and vulnerability based on an area's proximity to human population centers, transportation routes, and other mapped sources of impact. The intersection of focal biodiversity elements and these modelled vulnerability patterns provided the primary mechanism for characterizing the conservation status and vulnerability of mapped element distributions.

Data Compilation

Data related to the distribution and conservation status of selected focal features were compiled from diverse sources including the primary literature, grey literature, government and non-governmental organization databases, and consultations with a range of professionals with specialist knowledge of particular patterns. This process resulted in the compilation of a project library with both physical document and electronic components. All sources were tracked using bibliographical database software.

Of central importance to the analysis was a central geographic database consisting of documented records of the occurrence of various conservation features. Habitat data were primarily in the form of digitized maps of the extent of various vegetation assemblages and other broad habitat types. Species data were primarily in the form of point location records based on direct field observations (of living organisms, their distinctive signs, or their remains), or the detection of individuals by automated camera traps.

Screening of Potential Biodiversity Elements

Gap analyses are often viewed as ongoing processes in which a focal subset of representative ‘elements’ of biodiversity is continually revised and re-evaluated in light of new data or better models of how a necessarily limited set of biodiversity elements might be more representative of biodiversity as a whole. For example, ongoing gap analyses conducted at the state, regional, and national level in the US began with a focus on ” vegetation alliances along with all native species of amphibians, birds, mammals, and reptiles as surrogates for biodiversity” and over time, have come to include such elements as ant, mussel and plant species distributions (Jennings 2000). Gap analyses conducted in other parts of the world have included such diverse conservation elements as modelled bird distributions (Boone & Krohn 2000), marine species assemblages (Ward et al. 1999), and “functional ecosystems” (Ibisch et al. 2006). There is active debate about focal element selection theory and procedures (Margules & Sarkar 2007; Pressey 2004) and uncertainty and subjectivity are hallmarks of the process (Margules & Pressey 2000). Ultimately, decisions are often dictated by the opposing challenges of maximizing representation of biodiversity while operating within the constraints of data limitations and time (e.g. the need to provide meaningful results within realistic planning horizons) (Dudley & Parrish 2006; Jennings 2000).

Faced with this uncertainty, Pressy suggests that “conservation planning is more about explicitness than objectivity” (Pressey 2004). In other words, we can never know exactly how good the choices we make about focal features are but if we document the process carefully, these choices can be the foundation for subsequent efforts.

To select biodiversity elements, I followed a combination of guidelines from two sets of procedures widely used in ecoregional planning and gap analysis. Specifically, I followed Groves et al. (2000) in selecting (insofar as adequate data were available) communities within the terrestrial, freshwater, and marine realms as well as a selection of species aimed at complementing these coarse filter features.

Based on an evaluation of the comprehensiveness and apparent biases of the available data, only a subset of features consisting of selected habitat types and species were retained for further detailed analysis. For habitats, only natural or semi-natural types were retained.

In screening for species for potential inclusion in the fine-filter part of the analysis, seven broad taxonomic groups of organisms were considered: plants, invertebrates, fish, amphibians, reptiles, birds, and mammals. In consultations with taxonomic experts working in the region, I sought to determine whether recent surveys (within the previous 10 years) provided a minimally representative picture of the country-wide occurrence of the species or higher taxa from that group. Surveys for a particular taxon as "minimally representative" if they represented efforts to locate that taxon somewhere within any of eight national biodiversity management zones (Figure 3-3) where the taxon might potentially occur. For taxa satisfying this first criterion, experts were consulted to determine how representative these taxa were be of the distribution patterns of related taxa within that group.

Species were included in the focal species set if a) one or more explicit criteria identified by Groves et al. (2000), Eken et al. (Eken et al. 2004), or (in one case) established by this project, and b) if the species would potentially not be adequately represented by efforts to conserve the previously identified set of focal habitats. Table 3-2 summarizes focal species selection criteria.

Table 3-2. Criteria used in the selection of focal species for gap analysis and other conservation plannning activities in Cambodia.

Criterion	Explanation	References
Globally Threatened	Species currently listed as Critically Endangered, Endangered, or Vulnerable by the IUCN	a,b
Vulnerable	Species for which any of following apply: • exhibit significant, long-term declines in habitat and/or numbers, • have well-documented relatively high rates of collection, offtake, or confiscation in Cambodia, • are particularly rare in the wild, • that have unique habitat or behavioral requirements that expose them to great risk, or • have long generation time (i.e. more than 3 years)	a
Endemic	Species are restricted to a single ecoregion or species for which Cambodia represents more than 50% of the historical or current known range	b
Restricted in Range	Species for which the global breeding range is thought to be less than 50,000 km^2	b

Criterion	Explanation	References
Congregatory	Occurring in congregations of ≥1% of the estimated global population	a, b
International/Regional Priority Occurrence	Species for which one or more occurrences in Cambodia are among the 5 most viable occurrences either globally or in the Indo-Burma region	c

***References**: a) Groves et al. 2000; b) Eken et al. 2004 c) Developed for this assessment.*

Figure 3-3. Map of biodiversity management regions in Cambodia (after Ashwell (1997)). Representing highly distinctive geomorphology and climate patterns, these zones have been recommended as an essential basis for biodiversity gap analyses and other conservation planning activities (ICEM 2003).

Analysis and Mapping of Focal Habitats

A suite of representative habitats was defined for each ecosystem based on published maps and other inventories. All classes were mapped based on the most recent available data. Within each ecosystem, the classification process attempted to maximize the following:

- Ecological distinctiveness at a resolution appropriate for reflecting major patterns in biodiversity at a national level
- Consistency with published literature
- Consistency between the habitats defined and available mapped data

- Consistency with existing classification systems

Terrestrial Habitats

The delineation of terrestrial habitats was conducted by stratifying general vegetation cover classes on the basis of broad climate and physiographic zones, and surface geology. This was achieved by from three relevant maps: a recent national land cover classification, a map of physiographic/climate zones resulting from a detailed study of the country's chief floristic zones, and a detailed map of the country's surface geology.

The land cover map (referred to as the "JICA map" below) was produced by the Ministry of Land Management, Urban Planning and Construction (MLMUPC) in association with the Japanese International Cooperation Agency (JICA) as part of a long-term national level mapping project (Ministry of Public Works and Transportation & JICA 2003). The project used manual interpretation of LandSat and SPOT satellite imagery and conventional aerial photos acquired between 1997 and 2002 to assign all terrestrial parts of Cambodia to one of over 30 land cover categories. It was selected as a basic starting point for delineating terrestrial habitats on the basis of providing sufficient detail in land cover classes, high accuracy in identifying vegetation boundaries, and because it was one of the most up-to-date vegetation cover maps of Cambodia.

Several of the extensive natural and semi-natural vegetation cover classes from the JICA map were subdivided to reflect a long appreciated split in floristic affinities between the moist mountainous areas of southwest Cambodia from the drier, more seasonal northern and eastern regions. Blasco et al. (1997) mapped this geographic zonation and demonstrated its physiographic and climatic basis and we used their maps as the basis for this key distinction. Although surface geology and associated soil complexes have been shown to be a major determinant in shaping many of the country's distinctive vegetation associations (Ashwell 1997; Ashwell et al. 2004; Dy Phon 1970, 1982; Rollet 1972), most of these documented patterns were not available on a national scale. Therefore, general surface formations such as basalt-dominated deposits, non-basaltic volcanic deposits, alluvial pediments, and sandstone deposits (mapped by the Ministry of Industry, Mines and Energy, Department of Geography, and JICA (2001)) were used as the basis for further subdividing major forest formations where the literature indicated that this was a principal determinant of vegetation types and their distribution patterns[5].

A final subclassification was applied to the flora of sub-montane and lowland areas in recognition of two general elevation classes (below and above 650 masl) that capture widely documented patterns of floristic distinctiveness—likely due to extreme temperatures during the coldest months of the year in these areas (David Ashwell, pers. comm.).

Further details of specific mapping steps are as follows:

- Evergreen forests were each divided into four types on the basis of the bioclimatic considerations (humidity level and temperature of the coldest months) described in the literature. An elevation with 650 m was used as the boundary between lowland and sub-montane vegetation floras and the very humid forests (moist evergreen forests) of the coastal ranges and coastal hinterlands were distinguished from the less humid forests (dry evergreen forests) of inland areas.
- Semi-evergreen forests were divided into four types on the basis of the bioclimatic considerations in the same manner.
- Shrublands and grasslands were also divided into lowland and sub-montane types using an elevation with 650 m.
- Extensive lowland forest types (lowland moist evergreen, lowland dry evergreen, lowland semi-evergreen and deciduous forests) were divided on the basis of select categories of surface geology where the literature indicated these had a bearing upon the character of the vegetation.
- The bamboo forests of the mountains of the Cardamom Ranges and Virachey National Park were distinguished from those in inland areas except where the literature and aerial surveys indicated that they resulted from recent disturbance.

The resulting "terrestrial habitats" were informally ground-truthed through an extensive series of aerial surveys with a light aircraft (Cutter 2005). Where discrepancies were observed, a georeferenced database of images from the aerial surveys enabled minor corrections to the final habitat maps.

Finally, standard GIS methodologies were used to develop area statements for each vegetation type in terms of its vulnerability and current protection status.

Freshwater Habitats

Although numerous hydrological classification systems have been suggested for Cambodia and the region, consensus on a general framework still has yet to emerge.

[5] JICA's numerous geomorphologic mapping units were condensed into eleven geological substrates in accordance with JICA's hierarchical classification. Those substrates that were identified in the literature as determinants of vegetation patterns were then used in this national level environmental stratification. The use of the finer resolution geomorphologic mapping units may be appropriate for regional environmental analyses and action plans where they give greater detail upon soil conditions and land-use capability.

Additionally, while some wetland areas have received very detailed study, very little information is available on a country-wide scale. Within the limitations of available data, a freshwater classification system was developed that would contribute meaningfully to the current analysis and also provide hierarchical structure for more detailed future inventories and analyses.

Specifically, I used wetland vegetation types identified in the MLMUPC/JICA landcover mapping process, and open water features (e.g. lakes, ponds, streams, etc.) from the Department of Geography as the basis for defining freshwater habitat elements. I summarized representation and distribution geographically by using the area of vegetation types, the length of streams and other linear water features, and the perimeter of small ponds and pools. In some cases, existing data were modified based on features from 1:50,000 scale topographic basemaps and from photos acquired during aerial surveys of extensive areas of the country.

Marine/Coastal Habitats

Focal habitats in the marine ecosystem were delineated based on a fairly limited yet diverse set of spatial data related to Cambodia's marine and coastal areas. Cambodia's sovereign marine zone occurs completely within the Gulf of Thailand. Given the importance and distinctiveness of estuarine zones for supporting numerous communities and species, I included coastal estuarine areas as a feature by identifying all areas from coastal river mouths to an elevation of 2 meters above sea level. In addition, I included several benthic zones as defined by depth ranges, coral formations, and seagrass beds.

Analysis and Mapping of Focal Species

Gap analyses often use point records of target species to develop models of species distributions that are subsequently used for assessment and planning (Gap Analysis Program 1998). However, in cases where the coverage, evenness, or general number species occurrence records is limited, resulting distribution maps can lead to serious misapplication of conservation resources including unjustified interventions and unwarranted land acquisitions (Freitag et al. 1998; Freitag & Van Jaarsveld 1998).

To avoid these pitfalls, a more focused "evidence-based" approach was employed to construct polygons representing the ***minimum documented area of occurrence*** for focal mammals, reptiles and amphibians. It was envisioned that this focused approach to identifying fine-filter conservation areas would be followed in the future by a broader and more detailed evaluation of potential habitat.

Species occurrence areas for birds were derived directly from an independently conducted Important Bird Area (IBA) analysis (Hout et al. 2003). The IBA process identified areas necessary for the persistence of a subset of Cambodia bird species based on the same screening criteria used for other taxa in this analysis. Each IBA supports a number of species. I therefore used areas associated with each focal species for all subsequent spatial analysis with regard to birds. used in the Important Bird Area analysis included records and observations dating back to the early 1990's (Hout et al. 2003).

As the basis for this approach, I compiled an extensive database of point records based published and unpublished papers and reports and on records provided by research and conservation organisations and agencies operating in Cambodia. To minimise the risk of misrepresenting the current status of a species based on out of date information, only observation records collected since January 2000 were included in the analysis of mammals, reptiles, and amphibians. A single tabular database was established to manage all occurrence records.

I used the following set of rules and procedures based on species occurrences, habitats, and impact patterns to construct a ***minimum documented area of occurrence*** for each mammal, reptile and amphibian considered in the analysis (also see Figure 3-4):

1) Categorize all occurrence records as ***confirmed*** or ***provisional*** based on detailed information accompanying each record. Define **confirmed records** as *points where the species has been documented through one or more of the of the following:*

   - *Direct sightings (live or remains found in the wild)*
   - *Camera trap photos*
   - *In the case of animals that leave unambiguous distinctive sign (e.g. tigers, elephants, crocodiles, etc.), credible and well-documented sign records by trained field personnel*

   …and **provisional records** as *point locations based on credible reports of the species that do not meet the criteria above.*

2) Within an interactive GIS environment, assemble and display in the following background spatial data layers:

- Maps of human impact patterns (see detailed description of the 'human footprint' map below).
- Detailed maps of terrestrial, freshwater, and marine habitats.

3) For each species, in consultation with published references or experts, identify ***potential habitat*** as: areas of sufficient size, habitat suitability, and tolerable impact levels to sustain a breeding population (e.g. source habitat) *or* areas of sufficient size, habitat suitability, and tolerable impact levels to sustain non-breeding or dispersing individuals (e.g. sink habitat).

4) For each species, use a buffering operation to construct 5 km circular polygons[6] around all confirmed occurrence points and, separately, around all provisional points.

5) With buffered areas overlaid on habitat and impact data layers, use the following rules to identify and map minimum areas of occurrence:

- All areas within the **buffers of confirmed points** that intersect with **potential habitat**
- To these areas, add all contiguous areas of **potential habitat** as long as they fall within the **buffers of provisional points**

[6] A distance of 5 km was selected to represent 1) a distance that most species could disperse through suitable habitat, and 2) a conservative upper bound for extrapolating beyond documented species occurrences given relatively high levels of illegal collection and poaching throughout the country.

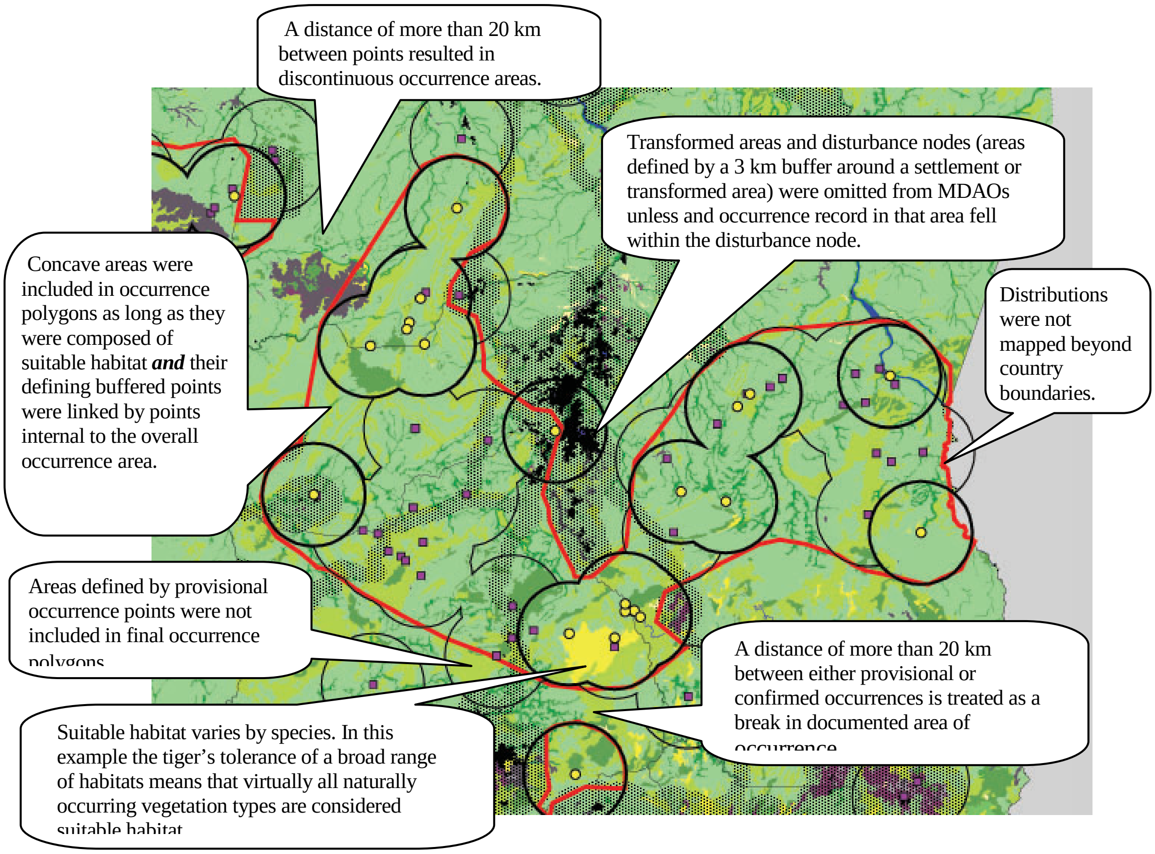


Figure 3-4. Illustration of conventions used in constructing "minimum documented areas of occurrence (MDAOs)" for focal species.

Mapping Human Impacts and Feature Vulnerability

Proximity to centers of human population density and associated land transformation is closely correlated with declines in biodiversity (Cincotta & Engelman 2000; Main et al. 1999). Road construction and the access it provides into otherwise little-disturbed areas can lead to fragmentation, disruption of ecological processes, reduction in population viability, and loss of ecosystem resilience (Belisle & St. Clair 2001; Forman & Alexander 1998; Forman & Godron 1986; Gaston et al. 2002). Maps of transformed areas, human population centers, roads, and other sources of impact on natural systems were used to develop a detailed model of current and potential human impacts on the environment (similar to the process used to develop a global level "human footprint" map (Sanderson et al. 2002a)). All areas of Cambodia's terrestrial, freshwater, and marine ecosystems were assigned to one of three categories based on relative amounts of current or anticipated human impact: transformed, impacted/vulnerable, and remote. While general, these categories offer planners a robust framework for assessing the general status of focal biodiversity elements and for applying conservation action. At one end of the spectrum, transformed areas consist of urbanized areas and those fundamentally transformed to a point where restoration of ecological functions would require enormous investment. At the other end of the spectrum, remote areas are those where natural ecological patterns and processes remain largely intact. In a third category are areas that have been partially disturbed or fragmented or where such impacts are anticipated in the near future. It is in areas assigned to this final category where conservation investment is likely to offer the most dramatic returns over the short term. In order to achieve long-term benefits, investment must be additionally directed to remote areas and, potentially, to transformed areas where intensive restoration is among the only options to achieve desired conservation outcomes.

Details on the definition and derivation of each impact category are provided in table Table 3-3.

Table 3-3. Categories used to assign levels of current and potential future human impacts in Cambodia's terrestrial, freshwater, and marine ecosystems.

Category	Practical Definition	Derivation and Data Sources
Transformed	All areas fundamentally transformed from their natural state	• All areas mapped as built up areas (villages, towns, and cities), areas under agricultural production (including croplands, orchards, and monoculture such as rubber plantations), and lowland shrublands
Impacted or Vulnerable	All recently disturbed areas (since approximately 1990) or areas considered vulnerable to disturbance in the short term (within 5 years)	• All areas within 3 km of village sites (village locations from the JICA data and Dept. of Geography) • All areas within 1 km of transport routes (routes from Department of Geography with additional data from various site inventories - not including remote cart tracks, seasonal dirt roads, or walking trails) • Impacted sites within protected areas (identified during an intensive protected area assessment workshop (Lacerda *et al.* 2005))
Remote	All areas considered natural or semi-natural	• All areas not contained in the above two categories

Results

Biodiversity Feature Screening

The results of the initial screening of candidate focal species were sobering. At the most fundamental level, most experts agreed that surveys with the objective of, or even incidental capacity for, recording plant or invertebrate species occurrences have been so infrequent, uneven, and spatially limited that country-wide data were simply not reliable for any member of these broad and important groups. After some preliminary mapping and data assessment, and in further consultation with fish taxonomic experts working in the country, a similar conclusion was reached with regard to fish. It was concluded that the conservation needs of these groups would best be served through coarse-filter representation approaches.

At the species level, the fine-filter element inclusion criteria resulted in a final list of focal species consisting of 26 mammals, 43 birds, 13 reptiles, and 6 amphibians. These species, details on listing criteria, and their vulnerability status are presented below.

Impacts and Vulnerability

The impact and vulnerability model resulted in the assignment of approximately 22% of Cambodia's land area to the "transformed" category and 41% to the "vulnerable" category. Remaining areas were classified as "remote".

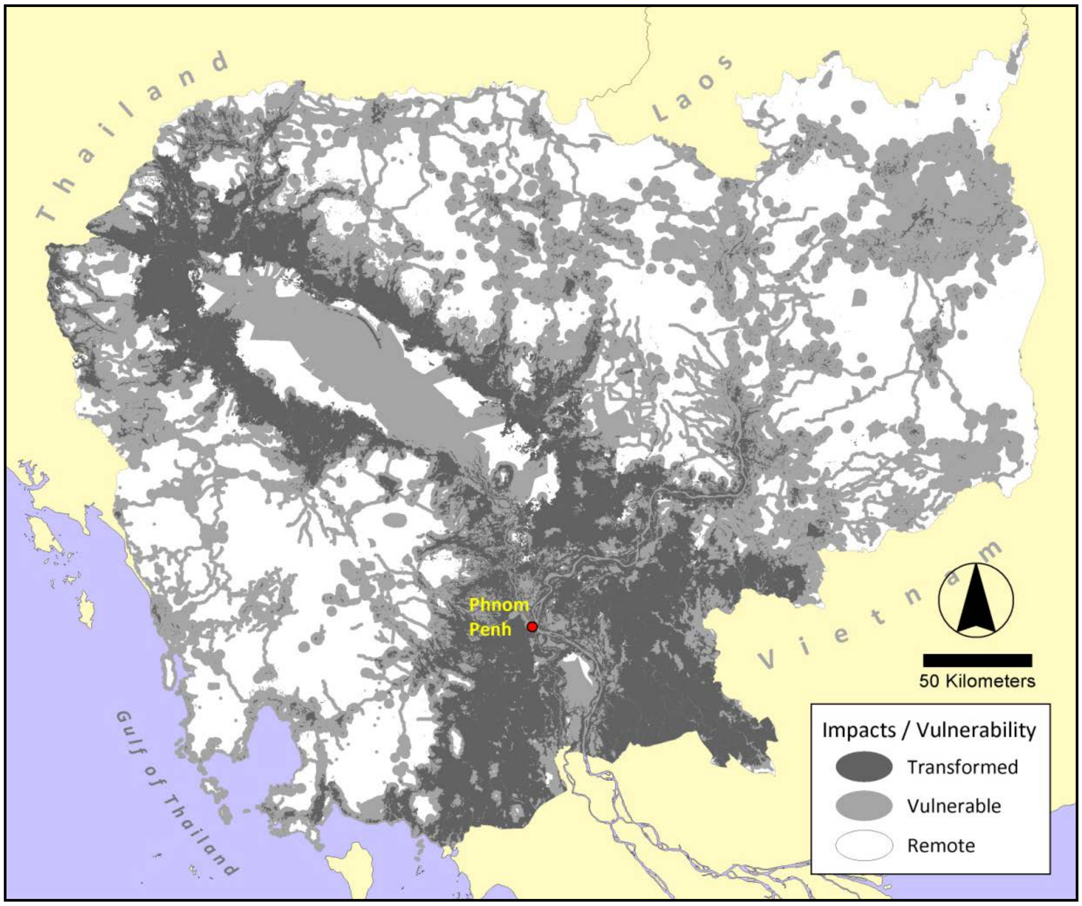


Figure 3-5. Map showing three relative categories of human impact and conservation area boundaries.

Focal Habitat Inventory, Distribution, and Status

Terrestrial Habitats

Procedures for defining terrestrial habitat diversity resulted in 38 distinctive natural and semi-natural terrestrial habitat types covering 63% of Cambodia's land area. Detailed descriptions of many of these types can be found in the Forest Ecology and Status section of the Cambodia Independent Forest Sector Review document prepared in 2004 (Ashwell et al. 2004). Table 3-4 summarizes the hierarchical organization, extent of occurrence, and vulnerability of these types.

Table 3-4. Focal dryland vegetation types: inventory, extent, and vulnerability. Particularly vulnerable habitats (e.g. portion of mapped extent considered vulnerable > 50%) are highlighted in gold.

General Ecological Setting	Habitat Type *(-habitat subtype)*	Extent (km^2)	% of Cambodia Land Area	% Vulnerable

Very Humid Sub-Montane	**Sub-montane moist evergreen forest**	**3,738.43**	**2.06**	**8**
	- on sandstones etc.	*3,131.90*	*1.73*	*8*
	- on intrusive volcanics	*606.54*	*0.33*	*8*
	Sub-montane shrubland	**57.92**	**0.03**	**17**
	Sub-montane grassland	**324.75**	**0.18**	**51**
Humid Sub-Montane	**Sub-montane dry evergreen forest**	**841.25**	**0.46**	**15**
	Sub-montane semi-evergreen forest	**213.13**	**0.12**	**37**
Very Humid Lowland	**Lowland moist evergreen forest**	**13,706.48**	**7.56**	**30**
	- on alluvial deposits	*1173.63*	*0.65*	*40*
	- on coastal deposits	*70.51*	*0.04*	*56*
	- on basalts	*305.38*	*0.17*	*65*
	- on non-basaltic volcanics	*1382.92*	*0.76*	*25*
	- on sandstones	*10772.07*	*5.94*	*28*
	- on limestones	*1.71*	*0.00*	*57*
Humid Lowland	**Lowland dry evergreen forest**	**19,564.37**	**10.78**	**40**
	- on older alluvial peneplains	*8576.779*	*4.73*	*38*
	- on older alluvial pediments	*3610.802*	*1.99*	*44*
	- on recent alluvial deposits	*23.364*	*0.01*	*86*
	- on sandstones	*2523.637*	*1.39*	*38*
	- on limestones	*74.269*	*0.04*	*29*
	- on basalts	*1662.242*	*0.92*	*62*
	- on other volcanic substrates	*3092.997*	*1.71*	*30*
	Lowland semi-evergreen forest	**13,398.10**	**7.39**	**45.7**
	- on alluvial pediments	*1145.70*	*0.63*	*46*
	- on alluvial peneplains	*4887.04*	*2.69*	*59*
	- on sandstones etc	*3,695.60*	*2.04*	*44*
	- on limestones	*135.62*	*0.07*	*48*
	- on basalts	*1,313.36*	*0.72*	*44*
	- on other volcanic substrates	*2220.76*	*1.22*	*34*
	Riparian forest	**3,823.58**	**2.11**	**46**
Sub-Humid Fire Disclimaxes	**Deciduous forest and woodland**	**40,240.35**	**22.19**	**49.4**
	- on alluvia	*21,620.71*	*11.92*	*56*
	- on sandstones	*12,744.08*	*7.03*	*39*
	- on limestones	*202.54*	*0.11*	*47*
	- on basalts	*1,928.96*	*1.06*	*48*
	- on other substrates	*3744.07*	*2.06*	*51*
	Coniferous forest	**86.45**	**0.05**	**83**
Grasslands and Bare Areas	**Lowland Grassland**	**1,472.06**	**0.81**	**62**
	Rock outcrop, sand, or barren land	**366.93**	**0.20**	**84**
Secondary formations derived from closed forests	**Lowland shrubland**	**4,299.41**	**2.37**	**80**
	Tree dominated secondary formation	**6,211.50**	**3.42**	**70**
	Bamboo forest mosaic	**2,362.18**	**1.30**	**50**
	Swidden / rotating agriculture	**3,494.59**	**1.93**	**100**
	Totals	**114,041.68**	**62.88**	

Of the 38 terrestrial habitats considered, almost half are at risk of significant alteration in the near future. Of particular concern are several types of lowland moist and dry evergreen forest occurring as small stands. Coniferous forests, already naturally limited in extent, are threatened with conversion as are rocky outcrops that may support distinctive species adapted to these specialized formations. While vulnerable to additional impacts, secondary formations such as shrubland, secondary forests, and rotating swidden systems likely retain enough natural character, soil structure, and seed bank value to represent viable areas for restoration in many areas.

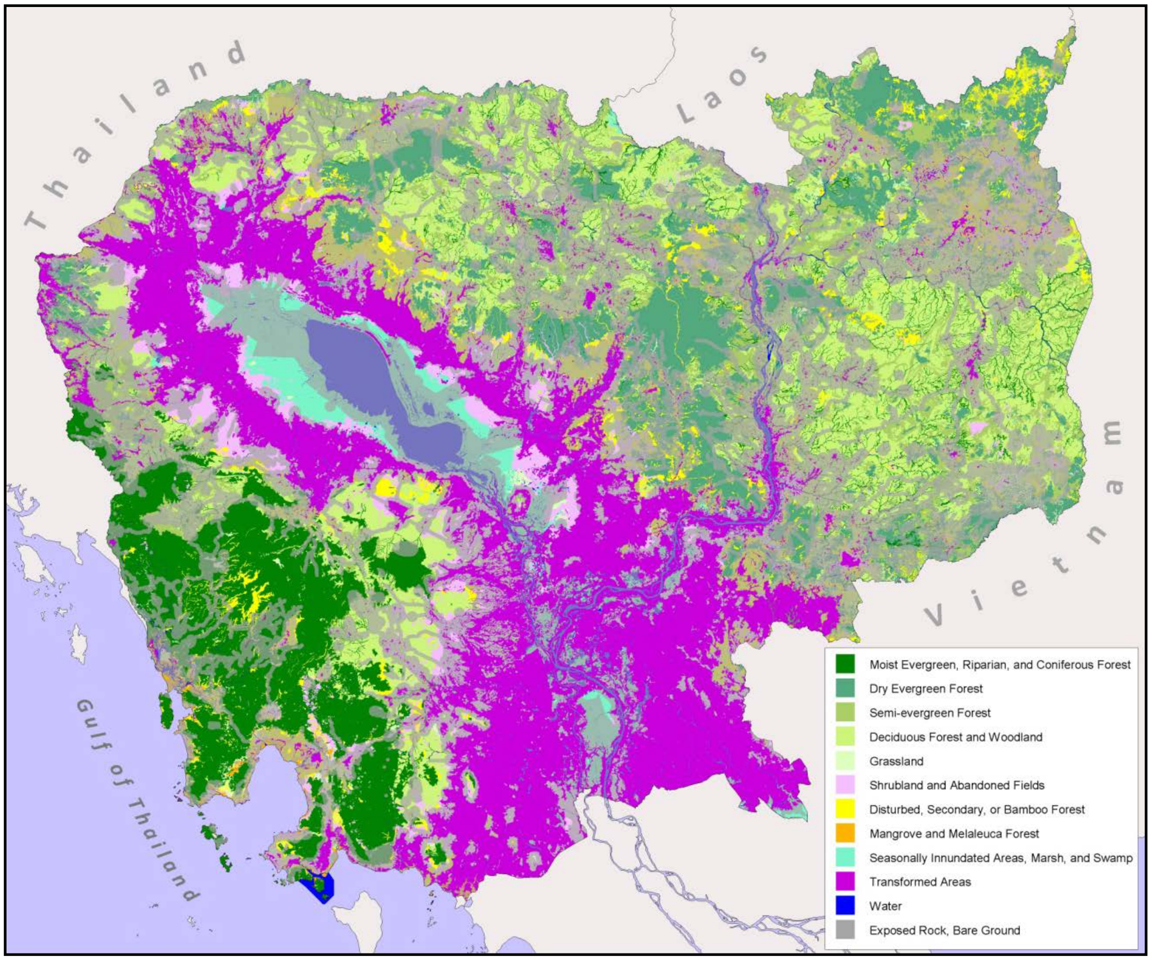


Figure 3-6. Map of major landcover categories in Cambodia used as the basis for identifying focal habitats in the terrestrial ecosystem. Purple areas have been drastically transformed from their natural state. Grey shading indicates areas vulnerable to significant transformation in the near future.

Freshwater Habitats

In general, the freshwater system is the most threatened of the three ecosystems considered with all but two mapped habitat types potentially subject to significant impacts or alteration in the near future (Table 3-5-20,). Of particular concern are limited but very diverse and distinctive flooded forests, shrublands, and grasslands around the Tonle Sap and marshes and swamps scattered throughout the country. These systems are subject to both direct threats such as overharvest of economically valuable species (including numerous fish, turtles, crocodile and watersnakes) as well as alterations related to changes in the hydrological regimes on which they rely.

Table 3-5. Focal wetland habitats: inventory and area statements. Particularly vulnerable habitats (e.g. portion of mapped extent considered vulnerable > 50%) are highlighted in gold.

Habitat	Extent (km^2)	% of Total Area	% Vulnerable
Flooded forests	206	2.72	90
Flooded grasslands	1,680	22.11	76
Flooded shrublands	5,313	69.92	74
Marsh and swamps	399	5.26	58
Totals	**7,599**	**100**	

Table 3-6. Focal inland water bodies: inventory and perimeter statements. Particularly vulnerable habitats (e.g. portion of mapped extent considered vulnerable > 50%) are highlighted in gold.

Habitat	Perimeter Length (km)	% of Total Water Body Perimeter	% Vulnerable
Permanent lakes, ponds, and pools	43,044	72.08	51
Seasonal lakes, ponds, and pools	16,673	27.92	45
Totals	**59,717**	**100**	

Table 3-7. Focal stream types: inventory and length statements. Particularly vulnerable habitats (e.g. portion of mapped extent considered vulnerable > 50%) are highlighted in gold.

Habitat	Length (km)	% of Total Stream Length	% Vulnerable
Permanent streams <18 m wide	46,964	44.44	22
Permanent streams >18 m wide	19,267	18.23	78
Seasonal streams	39,445	37.33	62
Totals	**105,676**	**100**	

Coastal and Marine Habitats

Table 3-8. Focal marine and coastal habitats: inventory, area statements, and vulnerability. Particularly vulnerable habitats (e.g. portion of mapped extent considered vulnerable > 50%) are highlighted in gold.

Sub-Ecosystem	Coastal/Marine Habitat	Total	% of Marine AoA	% Vulnerable
Coastal mainland	Estuarine habitat	218	**1.4%**	84%
	Mangrove forests	325	**2.1%**	89%
	Rear mangrove forests	316	**2.0%**	83%
Island	Island evergreen forest	238	**1.5%**	64%
	Island mangrove forests	9	**0.1%**	100%
	Island grasslands and secondary growth	306	**2.0%**	64%
Open ocean	Ocean 0-6 meter depth	3,907	**25.3%**	20%
	Ocean 6-10 meter depth	1,606	**10.4%**	3%
	Ocean 10-20 meter depth	6,608	**42.8%**	0%
	Ocean 20-40 meter depth	1,546	**10.0%**	0%
Underwater communities	Coral formations	28	**0.2%**	66%
	Seagrass beds	323	**2.1%**	24%
	Totals	**15,431**	**100**	

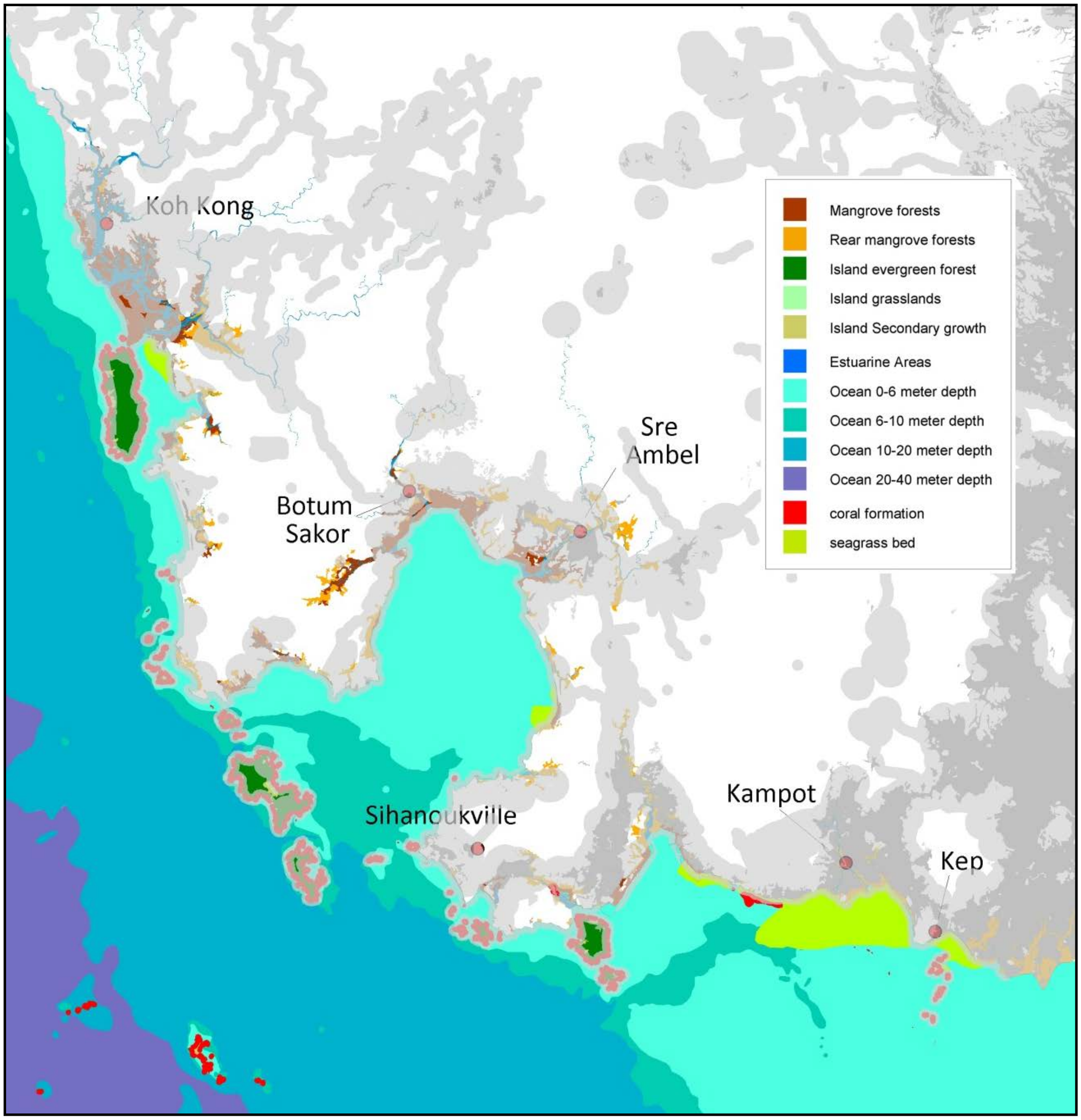


Figure 3-7. Focal conservation habitats in Cambodia's marine zone. Dark shading represents heavily transformed areas and light shading are areas vulnerable to significant impacts in the near future.

Focal Species Inventory, Distribution, and Status

Of 88 species meeting criteria for inclusion in the analysis, most were included based solely on their IUCN Redlist global threat rank. Many of these met other criteria for inclusion (Table 3-9). Minimum areas of occurrence were mapped for 80 of the 88 species listed with the remaining 8 species lacking dependable occurrence information on which to base explicit areas of occurrence. Occurrence richness patterns are shown in Figure 3-8. The combined minimum areas of occurrence for all mapped species amounts to 59,815 km^2 or approximately 1/3 of Cambodia's land area. Focal species occurrence areas were concentrated in 5 areas of the country: portions of the Annamite mountains mostly within Virachey National Park in the northeast, portions of the Annamite mountains and plateau in the east, forested areas near the northern intersection of Cambodia, Laos, and Thailand, areas around the Tonle Sap Lake, and major portions of the Cardamom mountains.

Table 3-9. Inventory, listing criteria, and vulnerability of focal species considered in the analysis. Particularly vulnerable species (e.g. portion of mapped extent considered vulnerable or transformed > 50%) are highlighted in gold.

Count by Feature Subclass	Focal Feature ID	Taxonomic Subcategory	Scientific Name	Common Name (English)	Global Threat Ranking	Vulnerable	Endemism	Restricted in Range	Congregatory	Global or Regional Priority Population	Map Basis	Mapped Focal Conservation Area Extent (km^2)	% Remote	% Impacted / Vulnerable	% Transformed
1	211101	M	*Otomops wroughtoni*	Wroughton's Free-tailed Bat	CR					G	OR	52	100	0	0
2	211201	M	*Pygathrix spp.*	Douc Langur	EN		M	**Y**		G	OR	4035	68	32	0
3	211202	M	*Bos javanicus*	Banteng	EN					G	OR	9634	82	18	0
4	211203	M	*Cuon alpinus*	Asian Wild Dog	EN						OR	9645	81	19	0
5	211204	M	*Elephas maximus*	Asian Elephant	EN						OR	24231	72	27	1
6	211206	M	*Bubalis bubalis*	Wild Water Buffalo	EN			**Y**		G	OR	247	100	0	0
7	211207	M	*Panthera tigris*	Tiger	EN						OR	11360	77	22	0
8	211301	M	*Cervus eldii*	Eld's Deer	VU					G	OR	3183	71	25	4
9	211302	M	*Dugong dugon*	Dugong	VU						OR	11862	75	25	0
10	211303	M	*Hylobates pileatus*	Pileated Gibbon	VU		M			G	OR	9053	71	28	0
11	211304	M	*Macaca arctoides*	Stump-tailed Macaque	VU						OR	12015	67	32	0
12	211305	M	*Macaca leonina*	Northern Pig-tailed Macaque	VU						OR	3489	79	21	0
13	211306	M	*Nomascus gabriellae*	Yellow-cheeked Crested Gibbon	VU		M	**Y**		G	OR	78	37	63	0
14	211307	M	*Nycticebus pygmaeus*	Pygmy Slow Loris	VU						OR	2525	85	15	0
15	211308	M	*Ursus thibetanus*	Asiatic Black Bear	VU						OR	12050	84	15	0
16	211311	M	*Bos gaurus*	Gaur	VU						OR	313	38	61	0
17	211312	M	*Lutrogale perspicillata*	Smooth-coated Otter	VU						OR	224	84	16	0
18	211314	M	*Naemorhedus sumatraensis*	Southern Serow	VU						OR	1327	77	23	0
19	211315	M	*Catopuma temminckii*	Asiatic Golden Cat	VU						OR	957	63	37	0
20	211316	M	*Neofelis nebulosa*	Clouded Leopard	VU						OR	370	76	24	0
21	211317	M	*Pardofelis marmorata*	Marbled Cat	VU						OR	156	62	36	2
22	211318	M	*Prionailurus viverrinus*	Fishing Cat	VU						OR	9377	69	30	0

Count by Feature Subclass	Focal Feature ID	Taxonomic Subcategory	Scientific Name	Common Name (English)	Global Threat Ranking	Vulnerable	Endemism	Restricted in Range	Congregatory	Global or Regional Priority Population	Map Basis	Mapped Focal Conservation Area Extent (km^2)	% Remote	% Impacted / Vulnerable	% Transformed
23	211319	M	*Hystrix brachyura*	Malayan Porcupine	VU						OR	52	100	0	0
24	211320	M	*Lutra sumatrana*	Hairy-nosed Otter	VU										
25	214601	M	*Murina harrisoni*	Kirirom Forest Bat	NA		F	**Y**		G					
26	217201	M	Orcaella brevirostris	Irrawaddy Dolphin, Mekong River subpopulation	EN SS*		M	**Y**	**Y**	G					
1	221101	B	*Gyps bengalensis*	Asian White-backed Vulture	CR					G	IBA	16973	63	35	2
2	221102	B	*Gyps tenuirostris*	Slender-billed Vulture	CR					G	IBA	14410	67	31	2
3	221103	B	*Pseudibis davisoni*	White-shouldered Ibis	CR					G	IBA	11637	63	33	4
4	221104	B	*Thaumatibis gigantea*	Giant Ibis	CR		M		**Y**		IBA	21270	63	35	2
5	221105	B	*Fregata andrewsi*	Christmas Island Frigatebird	CR						IBA				
6	221201	B	*Tringa guttifer*	Nordmann's Greenshank	EN				**Y**		IBA	273	10	87	3
7	221202	B	*Arborophila avidi*	Orange-necked Partridge	EN					G	IBA	2578	44	55	1
8	221203	B	*Cairina scutulata*	White-winged Duck	EN				**Y**		IBA	12150	69	29	1
9	221204	B	*Houbaropsis bengalensis*	Bengal Florican	EN					G	IBA	3853	34	39	27
10	221205	B	*Leptoptilos dubius*	Greater Adjutant	EN		M		**Y**		IBA	13367	54	42	5
11	221301	B	*Arborophila cambodiana*	Chestnut-headed Partridge	VU		M				IBA	7448	82	18	0
12	221302	B	*Grus antigone*	Sarus Crane	VU				**Y**	G	IBA	23758	61	35	4
13	221303	B	*Heliopais personata*	Masked Finfoot	VU					G	IBA	8934	65	33	2
14	221304	B	*Leptoptilos javanicus*	Lesser Adjutant	VU				**Y**	R	IBA	29659	56	40	5
15	221305	B	*Mycteria cinerea*	Milky Stork	VU				**Y**	G	IBA	1846	39	48	13
16	221306	B	*Pelecanus philippensis*	Spot-billed Pelican	VU				**Y**	G	IBA	4360	30	56	14
17	221307	B	*Pavo muticus*	Green Peafowl	VU						IBA	30771	66	33	1
18	221308	B	*Polyplectron germaini*	Germain's Peacock Pheasant	VU			**Y**			IBA	6903	68	32	0

Count by Feature Subclass	Focal Feature ID	Taxonomic Subcategory	Scientific Name	Common Name (English)	Global Threat Ranking	Vulnerable	Endemism	Restricted in Range	Congregatory	Global or Regional Priority Population	Map Basis	Mapped Focal Conservation Area Extent (km^2)	% Remote	% Impacted / Vulnerable	% Transformed
19	221309	B	*Columba punicea*	Pale-capped Pigeon	VU										
20	221310	B	*Rhynchops albic*	Indian Skimmer	VU										
21	221311	B	*Haliaeetus leucoryphus*	Pallas's Fish Eagle	VU										
22	221312	B	*Haliaeetus leucoryphus*	Greater Spotted Eagle	VU						IBA	11213	56	37	7
23	221313	B	*Aquila heliaca*	Imperial Eagle	VU						IBA	1220	51	33	17
24	221314	B	*Oriolus melianus*	Silver Oriole	VU										
25	221315	B	*Acrocephalus tangorum*	Manchurian Reed Warbler	VU						IBA	4125	64	28	9
26	222401	B	*Motacilla samveasnae*	Mekong Wagtail	NT		M	**Y**			IBA	4326	44	50	5
30	222701	B	*Garrulax vassali*	White-cheeked Laughingthrush	LC			**Y**			IBA	2578	44	55	1
31	222702	B	*Macronous kelleyi*	Grey-faced Tit-babbler	LC			**Y**			IBA	2578	44	55	1
32	222703	B	*Garrulax ferrarius*	Cambodian Laughingthrush	LC			**Y**			IBA	6432	81	19	0
27	223401	B	*Anhinga melanogaster*	Oriental Darter	NT				**Y**		IBA	13922	53	43	5
28	223402	B	*Threskiornis melanocephalus*	Black-headed Ibis	NT				**Y**		IBA	525	23	70	7
29	223403	B	*Mycteria leucocephala*	Painted Stork	NT				**Y**		IBA	1488	20	70	10
33	223701	B	*Dendrocygna javanicus*	Lesser Whistling Duck	LC				**Y**		IBA	127	52	21	27
34	223702	B	*Sarkidiornis melanotos*	Comb duck	LC				**Y**		IBA	127	52	21	27
35	223703	B	*Vanellus duvaucelii*	River Lapwing	LC				**Y**		IBA	205	11	78	11
36	223704	B	*Glareola lactea*	Small Pranticole	LC				**Y**		IBA	1121	8	77	15
37	223705	B	*Chlidonias hybridus*	Whiskered Tern	LC				**Y**		IBA	547	13	86	1
38	223706	B	*Phalacrocorax niger*	Little Cormorant	LC				**Y**		IBA	399	14	86	0

Count by Feature Subclass	Focal Feature ID	Taxonomic Subcategory	Scientific Name	Common Name (English)	Global Threat Ranking	Vulnerable	Endemism	Restricted in Range	Congregatory	Global or Regional Priority Population	Map Basis	Mapped Focal Conservation Area Extent (km^2)	% Remote	% Impacted / Vulnerable	% Transformed
39	223707	B	*Phalacrocorax fuscicollis*	Indian Cormorant	LC				**Y**		IBA	793	7	93	0
40	223708	B	*Casmerodius albus*	Great Egret	LC				**Y**		IBA	399	14	86	0
41	223709	B	*Mesophoyx intermedia*	Intermediate Egret	LC				**Y**		IBA	59	48	52	0
42	223710	B	*Anastomus oscitans*	Asian Openbill	LC				**Y**		IBA	1921	37	43	20
43	223711	B	*Ephippiorhyncus asiaticus*	Black-necked Stork	LC				**Y**		IBA	2957	64	35	2
1	231101	R	*Crocodylus siamensis*	Siamese Crocodile	CR	Y				**G**	OR	2473	53	44	3
2	231102	R	*Batagur baska*	Mangrove Terrapin	CR				**Y**	**R (G?)**	OR	452	40	55	6
3	231103	R	*Eretmochelys imbricata*	Hawksbill Turtle	CR										
4	231201	R	*Chelonia mydas*	Green Turtle	EN										
5	231202	R	*Hieremys annandalii*	Yellow-headed Temple Turtle	EN					**G**	OR	91	4	55	41
6	231203	R	*Indotestudo elongata*	Elongated Tortoise	EN						OR	3170	59	40	1
7	231204	R	*Pelochelys cantorii*	Cantor's Giant Turtle	EN					**R**					
8	231302	R	*Amyda cartilaginea*	Asiatic Softshell Turtle	VU						OR	224	18	79	3
9	231303	R	*Cuora amboinensis*	South Asian Box Turtle	VU					**R**	OR	126	9	57	34
10	231304	R	*Heosemys grandis*	Giant Asian Pond Turtle	VU						OR	95	2	98	0
11	231305	R	*Malayemys subtrijuga*	Snail-eating Turtle	VU										
12	231306	R	*Manouria impressa*	Impressed Tortoise	VU						OR	68	48	52	0
13	231307	R	*Siebenrockiella crassicollis*	Black Marsh Turtle	VU						OR	29	18	82	0
1	241301	A	*Paa fasciculispina*	Spiny Mountain Frog	VU		M	**Y**		**G**	OR	635	88	12	0
2	241302	A	*Limnonectes toumanoffi*	Toumanoff's Wart Frog	VU			**Y**							
3	241303	A	*Rhacophorus annamensis*	Annam Flying Frog	VU			**Y**							

Count by Feature Subclass	Focal Feature ID	Taxonomic Subcategory	Scientific Name	Common Name (English)	Global Threat Ranking	Vulnerable	Endemism	Restricted in Range	Congregatory	Global or Regional Priority Population	Map Basis	Mapped Focal Conservation Area Extent (km^2)	% Remote	% Impacted / Vulnerable	% Transformed
4	242601	A	*Philatus Cardamonus*		NA		F	**Y**		**G**					
5	242602	A	*Megophrys auralensis*		NA		F	**Y**		**G**	OR	311	96	4	0
6	242603	A	*Rana faber*		NA		F	**Y**		**G**	OR	1028	93	7	0

Explanatory Notes:

Taxonomic Subcategory:	**M = mammal; B = bird; R = reptile; A = amphibian**
Global Threat Rank (IUCN Redlist Category):	CE = Critically endangered; EN = Endangered (*ENSS = Endangered subspecies); VU = Vulnerable; NT = Near Threatened; LC = Least Concern; NA = Not assessed
Vulnerable:	Y = The viability of this species or subspecies is particularly vulnerable due to one or more natural history traits or due to being targeted for consumption or collection
Endemism:	F = Fully endemic to Cambodia; M = Majority of the species global distribution (either by area of occurrence or population) occurs in Cambodia
Restricted Range:	Y = The global extent of occurrence of this or species or subspecies is less than 50,000 km^2
Congregatory:	Y = This species occurs in Cambodia in congregations of more than 1% of the species global population for all or part of the year
Global or Regional Priority Population:	One or more of the occurrences of this species in Cambodia are among the 5 most viable occurrences either **G = globally** or **R = within the Indo-Burma region**
Map Basis:	OR = based on occurrence records and the methods outlined above; IBA = based on the subset of Important Bird Areas within which this species occurs; NM = Not mapped (see explanation in text)

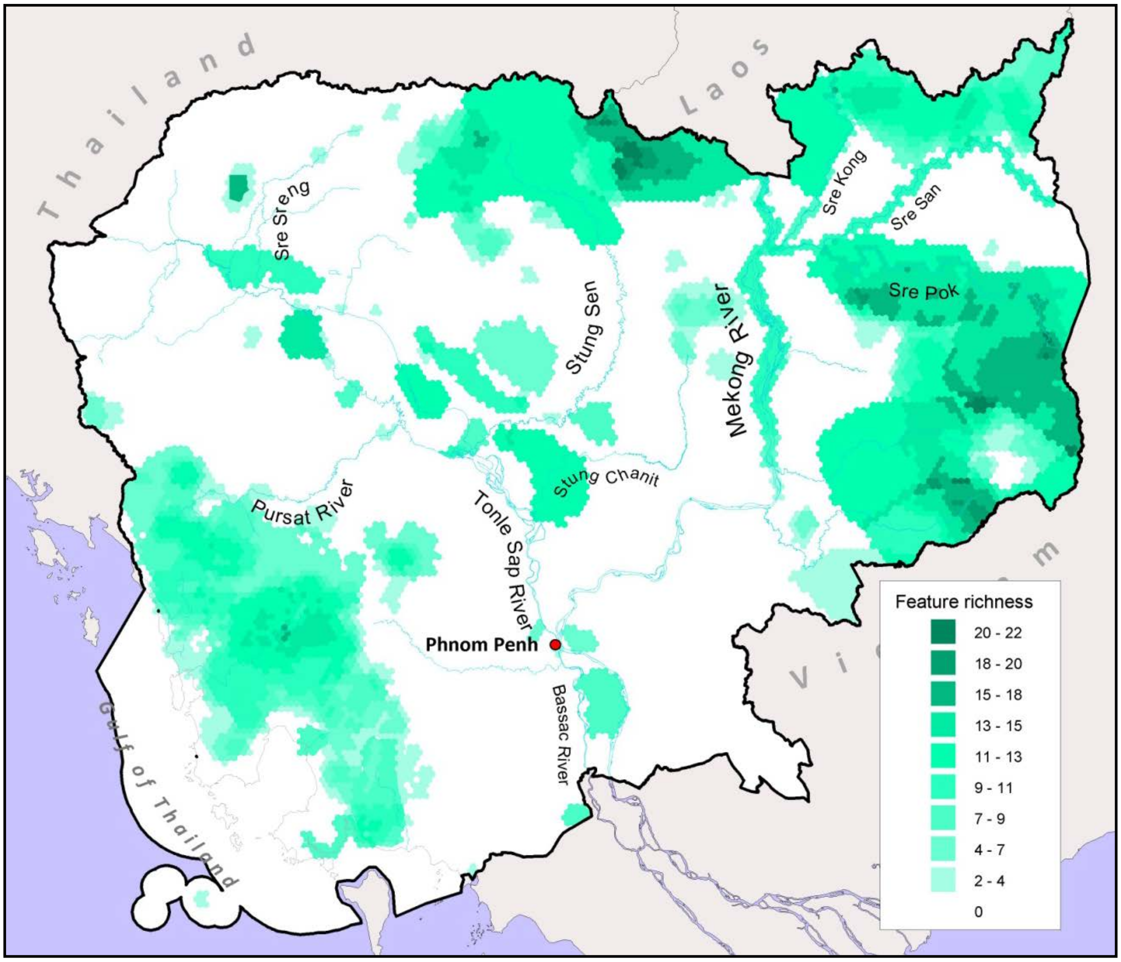


Figure 3-8. Map of focal species richness based on number of focal species occurring within 10 km^2 hexagonal planning units.

Of all species mapped, areas important for bird survival appear to most threatened by development or some form of significant habitat transformation. This reflects the reliance of many bird species on lowland wetland habitats that are among the most economically important areas in the country in terms of agriculture and fishing. Only one mammal species, the yellow-cheeked crested gibbon, was identified as being particularly vulnerable to large-scale habitat alteration. Almost all reptile species are vulnerable to extensive habitat alteration. This pattern is reflective of their reliance on very threatened estuarine areas and other wetland types. While apparently quite limited in range, the amphibian species considered occur in remote mountainous areas and therefore are not at immediate risk of extensive habitat alteration.

Discussion

This review of national biodiversity patterns provides an explicit basis for conducting gap analyses and other conservation planning activities. It is a transparent and modular approach that allows for systematic review and revision on a number of hierarchical levels.

This is the first time such a detailed and spatially explicit analysis has been conducted for the country of Cambodia as a whole. It builds on previous efforts and incorporates the best available data for mapping individual habitat and species distributions.

The analysis is limited to biodiversity elements and processes. While most conservation planning activities will not be limited to this subset of potential conservation features of interest, the methods used here could be extended to other conservation features such as cultural resources and ecosystem services.

It is widely agreed that using explicit, repeatable methods for selecting and quantifying biodiversity surrogates is a critical step in the larger effort to conduct systematic conservation planning including carrying out gap analyses (Bottrill et al. 2006; Johnson 1995; Pressey et al. 1993; Warman et al. 2004). When undertaken as part of an explicit, systematic, and iterative process, the selection and representation of biodiversity surrogates can increase the transparency and effectiveness of a range of on the ground conservation actions (Pressey & Cowling 2001; Rodrigues et al. 2000).

While grounded in theory and experience, procedures for selecting elements of biodiversity to represent biodiversity in general (e.g. “biodiversity surrogates”) are subject to some unavoidable amount of subjectivity and data availability (Margules & Pressey 2000; Pressey & Cowling 2001). In a way, generating indices of (or mapping patterns of) biodiversity in any area should be seen as a natural experiment with the final outcomes (e.g. success in surrogates adequately representing larger patterns of biodiversity) only fully available once a more detailed understanding of biodiversity the fates of its component parts are better understood. There is a growing body of studies that have assessed such outcomes (Reyers & van Jaarsveld 2000; Reyers et al. 2002; Rodrigues et al. 2004b) but they represent very short timeframes which are typically much shorter than the periods over which planning and management are intended to apply. With extensive areas of intact natural habitat yet relatively poorly understood patterns of biodiversity, Cambodia has the potential to represent a rich and instructive experiment in how effective a necessarily limited set of biodiversity surrogates may be as the basis for setting priorities with regard to land use and a wide range of other conservation-related decisions.

Procedures used here for mapping occurrences of mammals, reptiles, and amphibians (and the IBAs used for identifying focal bird conservation areas) are a response to the need to provide strong justification for any conservation investment or intervention. While this conservative approach will help ensure that limited resources are appropriately applied in the short term, future efforts should seek to better understand the full extent of habitat patterns as they relate to focal species and groups. Such analyses should include an evaluation of potential meta-population dynamics and in particular, the contributions of source and sink habitat to long-term population viability and persistence.

While all of the focal conservation elements and associated data considered here have undergone significant review by a range of experts and other stakeholders, such review should not be seen as a finite step to be fully concluded during any given evaluation. Rather, the processes of consultation and stakeholder engagement must be part of an iterative process whereby information products are regularly subjected to review and communication to a wide community of stakeholders. This ensures not only an ongoing mechanism for the improvement of information, but the transparency and stakeholder "buy-in" so important to achieving desired conservation outcomes (Davey 1998; Pressey & Cowling 2001).

The data products described here have been developed as an essential input into a gap analysis of Cambodia's biodiversity and protected areas to satisfy clear objectives set out under the Convention on Biological Diversity's program of work on protected areas. However, the products and explicit procedures used in developing them are potentially suited to a broad range of conservation planning-related applications. It is important for users to view these and similar efforts to express biodiversity patterns as dynamic processes that will likely produce somewhat different results as data availability, survey coverage, and other variables change. As with any such dynamic process, the experience of trained analysts is crucial.

CHAPTER 4. CONSERVATION AREAS IN CAMBODIA: HISTORY AND CURRENT CONTEXT

As in many countries, protected areas represent a cornerstone of conservation efforts in Cambodia. The country's conservation area system is vast and continues to evolve at a rapid rate. A concise understanding of the protected area system is a prerequisite for gap analyses and other conservation efforts that Cambodia has committed to as a signatory to the Convention on Biological Diversity. This evaluation provides an overview of Cambodia's diverse protected area system in terms of overall size, individual conservation area size and location, management objectives, legal "durability" and levels of current impacts and potential threats. Management objectives are used to assign each area to one of the widely accepted IUCN protected area management guidelines. Priorities for conservation area planning and management are discussed.

Introduction

Protected areas are accepted as perhaps the most effective and widely applied mechanism for achieving a wide range of biodiversity conservation and other conservation objectives and are seen as the cornerstone of broader conservation efforts (Margules & Pressey 2000). It is therefore appropriate that they receive special attention in conservation planning. In developing comprehensive national and regional conservation strategies, it is also important that conservation areas and conservation area systems be seen in the context of the broader range of approaches and spatial scales at which conservation takes place.

Major conservation themes that complement protected area mechanisms include other site-based approaches, species-based approaches, ecosystem approaches, community based conservation, policy advocacy and governance reform, education and public awareness, and efforts to manage trade in wildlife and other biological resources.

While the term ***protected area*** is often used in a broad sense to describe conservation areas, in Cambodia the term has come to be associated (exclusively in many cases) with the 23 areas designated in the 1993 Royal Decree. However, numerous other sites have been established to provide for the conservation or sustainable use of natural resources since that time.For this reason, the terms ***conservation area*** and ***conservation area system*** are used to refer to the broad range of sites that have been established for the purpose of conservation. In addition to the 23 protected areas established by the 1993 Royal Decree, these areas include seven “protection forests” (established by sub-decree) under the jurisdiction of the Forestry Administration, a Sarus Crane Sanctuary (designated by Royal Decree), three Ramsar sites (also administered by the MoE), a number of genetic conservation tree stands, numerous Community Conservation Areas, and a variety of other sites explicitly created for the purpose of biodiversity or natural resource conservation. Although not defined as a protected area *per se*, the landscape surrounding the Tonle Sap lake (together with the already protected lake at its core) was designated a Biosphere Reserve under UNESCO’s Man and Biosphere Programme in 1999. Finally, a number of areas have been set aside (under the jurisdiction of either the APSARA authority (Angkor Temple Complex) and/or the Ministry of Culture and Fine Arts) to protect sites of cultural significance and many of these arguably contribute to the conservation of biodiversity as well.

Definitions: *Conservation Area* and *Conservation Area System*

A ***conservation area*** (CA) is an area of land and/or sea specially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (adapted from IUCN & WCMC 1994).

A ***conservation area network*** (CAN) is a collection of protected areas managed with the aim of optimising various characteristics and interrelationships that cannot be addressed when considering areas on an individual basis. PA system characteristics include representativeness, connectivity, coherence and complementarity, consistency, ecological durability, cost effectiveness and equity. Interrelationships refer to those relationships between individual protected areas and between protected areas and the wider landscapes of which they are part.

As a signatory to the CBD, Cambodia has endorsed the development of a range of in situ measures for the conservation and sustainable use of its biological diversity and biological resources includeing the development of guidelines for the selection, establishment and management of protected areas where special measures need to be taken to conserve biological diversity (Secretariat of the Convention on Biological Diversity. 2005). These are to be addressed in the development of individual “protected areas” and integrated “protected area systems”.

As per the various “Programmes of Work” that arise from decisions of the parties to the Convention on Biological Diversity, Cambodia has agreed, among other things, to undertake the programme of work arising from decision VII/28 at the 2004 Kuala Lumpur Conference of the Parties (COP) (Secretariat of the Convention on Biological Diversity 2005). The first goal of the first programme element is “to establish and strengthen national and regional systems of protected areas integrated into a global network as a contribution to globally agreed goals”. To achieve this goal, the programme recommends that parties undertake gap analyses to:

- identify sites of global and national biodiversity significance,
- identify which sites and features are currently not adequately represented or adequately managed in protected area systems, and
- prioritize conservation actions to undertake at these sites.

Cambodia’s conservation area system continues to evolve at a rapid rate. This review and evaluation attempts to present a clear picture of the current status of the country’s conservation areas in 2009. This is as an important step in charting a responsible course action for the continued development of the country’s conservation area system in general and as a critical input to the explicit gap analysis called for by CBD obligations.

Cambodia’s Conservation Area Network: A Brief History

In 1925, Cambodia became the first county in modern Southeast Asia to establish a protected area when 10,800 hectares of forestland around the renowned Angkor temple complex were designated for protection. During the 40’s and 50’s, approximately one third of the country was classified into 173 forest reserves and six wildlife protection areas. The 173 forest reserves covered approximately 39,000 km^2 and were designated primarily for forest production. The six wildlife reserves (dedicated primarily to the management of large game) covered approximately 22,000 km^2. Although there was some intention to declare the wildlife reserves ***national parks*** in the 1960’s, conflicts during this period delayed efforts to further develop the protected area system.

From the mid-1960s through the fall of the Khmer rouge regime in 1979, reserves were virtually ignored as Cambodia and its neighbors struggled with widespread war and humanitarian emergencies. During the 1980s, the pro-Vietnamese government and subsequent lingering Vietnamese military forces pursued aggressive logging practices throughout the country. Although often justified as a security measure against Khmer

Rouge forces that occupied remote forested areas, in practice, the logging fueled a lucrative timber trade to primarily communist block countries.

Another widespread pattern throughout this extended period of conflict was the placement of landmines in many areas that had formerly been or would later become conservation areas. This legacy has hampered the development of the conservation area system in many ways and continues to present a challenge to Cambodia's conservation area system.

As the country moved into a phase of post-war rehabilitation in the early 1990s, the government was quick to integrate conservation into national planning activities. In 1993, a new constitution was promulgated with specific provisions for the conservation and sustainable use of biological diversity. Shortly afterwards, a system of 23 protected areas (covering a totoal of 3.3 million hectares, or just over 18% of the county's total land area) was established by royal decree with a view to ensuring the conservation of biological diversity and maintaining the productivity of the landscape. The selection of these newly designated protected areas was based on a review of protected areas designated or proposed prior to the 1960s. The review was guided by widely accepted principles of reserve design and selection and informed by previous reviews of the protected areas system (MacKinnon and MacKinnon 1986, Collins et al 1991 and Ashwell 1992) and relevant biodiversity information. With limited data available on species distribution and security issues preventing visits to much of the country, a primarily 'coarse filter' approach was used to represent major habitats, elevation gradients, and climate regime-driven variation in the country's vegetation patterns. The result is a system of protected areas that effectively represents the country's biodiversity by many measures. The complementary objectives of four categories of protected areas laid out in that decree continue to provide a framework for a ***national conservation area system*** rather than a collection of ad-hoc conservation areas.

In 1996, the State Secretariat for Environment was converted to the Ministry of Environment (MoE) and the Law on Environmental Protection and Natural Resource Management was issued with the following objectives:

- To ensure the rational and sustainable preservation, development, management and the use of the natural resources of the Kingdom of Cambodia.
- To encourage and provide opportunities for public participation in the protection of the environment and in the management of natural resources.

- To suppress activities which harm the environment.
- To make assessments on impacts to the environment before the issuance of a decision by the Royal Government on all proposed projects.
- To protect and upgrade the environment quality and public health by means of prevention, reduction and control of pollution.
- To enable the development of both national and regional environmental action plans.

This new ministry was also given the authority to manage the nascent 23 area conservation system and has kept this role through the present. However, management of publicly owned land beyond the boundaries of these areas (much of it rich with timber resources) has been the responsibility of the Forestry Administration (FA) under the Ministry of Agriculture which, as per its mandate, sold large forest concessions to both domestic and foreign interests during the 1990s.

As the decade came to a close, concern was mounting about the extent and oversight of these often massive areas. Concurrently, information on the distribution of biodiversity-rich habitats and rare species was also increasing and demonstrating that many key areas for biodiversity conservation fell well outside of the 1993 protected area system. In response to these and other considerations, between 2002 and 2004, the the FA took steps to designate a portion of the forest areas under its jurisdiction as “Protection Forests” (via sub-decrees) with management objectives including conserv[ing] biodiversity, genetic resources, and wildlife habitat” (Royal Government of Cambodia 2002). These areas now make up a significant proportion (more than 23%) of Cambodia’s overall conservation area system.

A vibrant non-governmental organization (NGO) sector has made significant contributions to conservation in Cambodia including undertaking substantial projects to inventory the country’s biodiverisity and to support the effective natural resource management both within and outside of the conservation area system. By calling on regional networks of expertise, NGOs have led the way in conducting large-scale assessments that provide critical context for understanding the role of Cambodia’s biodiversity and conservation efforts.

Although several reviews have attempted to address the status of Cambodia’s conservation area system as a whole, all are somewhat dated and most look at only a portion of the system. Ashwell’s Cambodia: A National Biodiversity Prospectus (1997) details the system as it stood in 1997. The extensive Protected Area and Development Review (ICEM 2003) provides a substantial update and challenges stakeholders to acknowledge values of conservation areas that are often taken for granted and are rarely figured into decisions about conservation investments. A 2005 assessment of the management effectiveness of the system applies widely used RAPPAM assessment tool (Rapid Assessment and Prioritization of Protected Area Management Methodology (Erwin 2003)) to detail the compare management efforts and challenges within conservation areas (Lacerda et al. 2005) but limits this assessment to MoE-managed areas.

Name	**Designation**	**Administrative Responsibility**	**Area (km^2)**
Kulen Promtep	Wildlife Sanctuary	Ministry of Environment	4,096
Lomphat			2,526
Boeng Per			2,497
Phnom Prich			2,242
Phnom Nam Lyr			549
Phnom Samkos			3,297
Phnom Aural			2,542
Snoul			753
Roniem Daun Sam			400
Peam Krasop			259
Virachey	National Park		3,342
Phnom Kulen			374
Kirirom			336
Bokor			1,499
Ream			184
Botum Sakor			1,834
Kep			28
Samlaut	Multiple Use Area		610
Dong Peng			286
Tonle Sap			3,314
Banteay Chhmar	Protected Landscape		848
Angkor			137
Preah Vihear			33
Stung Treng	Ramsar Site		149
Southern Cardamoms	Protected Forest	Ministry of Agriculture, Forestry, and Fisheries	1,451
Preah Vihear (FA)			1,900
Ang Trapeng Thmor			129
Mondulkiri			4,307
Central Cardamoms			4,007
Phnom Thmau			24
Kbal Chhay			64
Seima Biodiversity	Biodiversity		2,987

Conservation Area	Conservation Area		
Koh Ker Historical Site	Cultural/Historical Site	Ministry of Culture and Fine Arts	79
		Total	**47,083**

Conservation Area Objectives

While official objectives for various conservation areas in Cambodia are usually provided in the legislation creating the area, these objectives are usually grossly oversimplified. Furthermore, they often compete with well-established and often legally protected objetives and practices already in place in the areas covered by a particular area. Table 4-1 compares stated management objectives for all conservation areas recognized by national legislation.

Table 4-1. National conservation area types and management emphases.

Type of Conservation Area	Stated Management Objective
Protected Landscapes	Areas to be maintained as scenic views for pleasure and tourism.
Wildlife Preserves	Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance
National Parks	Areas reserved for nature and scenic views to be protected for scientific, educational and entertainment purposes.
Multi Use Protected Areas	Areas necessary for the stability of the water, forestry, wildlife, and fisheries resource, for pleasure, and for the conservation of nature with a view of assuring economic development.
Protected Forests	Conservation of biodiversity, genetic resources and wildlife habitat
Seed Source Areas	Maintenance of genetic resources
Fish Sanctuaries	Fish regeneration

These objectives often differ markedly from what stakeholders perceive to be or wish were the objectives for protected areas. Table 4-2 summarizes the diversity of potential protected area objectives identified by stakeholders at four regional workshops carried out by the Biodiversity and Protected Area Management Project in 2005.

Table 4-2. Summary of Values and Contributions of Cambodia's Protected Area System.

General Role	Specific Goals and/or Contributions
Biodiversity Conservation	• Conserve biodiversity that might be otherwise negatively impacted by certain activities. • Maintain areas that represent the natural diversity of Cambodia. • Contribute to the conservation of rare and threatened species • Provide protection for ecological systems.
Maintenance of Ecological Services and Environmental Security	• Provide for the sustainable use of resources so that they are available for future generations • Maintain local, regional, and global weather patterns and climate regimes. • Maintain ecological balance at multiple scales. • Maintain ecologically and economically valuable services such as: o nutrient cycling o soil formation o erosion control o pollination o disturbance regulation o climate regulation o adequate water supply o nutrient cycling o waste treatment o pollination • Buffer negative impacts of severe weather events such as heavy rains, wind, drought, etc.
Realization of National Development Goals	• Can contribute to the growth and sustainability of local economies, provide income for local residents, and help in the reduction of poverty (through providing ecotourism opportunities, etc.). • Can contribute to income generation through the leasing of concessions under some circumstances. • PAs can strengthen and be used to promote ecotourism. • Protected areas conserve and maintain resources that can be the focus of valuable ecotourism.
Realization/Fulfillment of International Commitments	• Contribute to the conservation of sites of world heritage significance. • Protected areas in Cambodia contribute to global environmental conservation, sustainable development, and poverty alleviation objectives as defined in the Millenium Development Goals[7] • PAs are recommended by the CBD and Cambodia is a signatory
Other	• Provide opportunities for spiritual revitalization and development. • Provide opportunities for education. • Provide opportunities for research. • Preservation of indigenous cultures and traditions

[7] United Nations. 2005. Millenium Development Goals Progress Chart: 2005. Page 3. United Nations, Washington, DC.

In contrast, while this evaluation focuses on a limited set of conservation area descriptors, it attempts to be as inclusive as possible in its inclusion of protected areas.

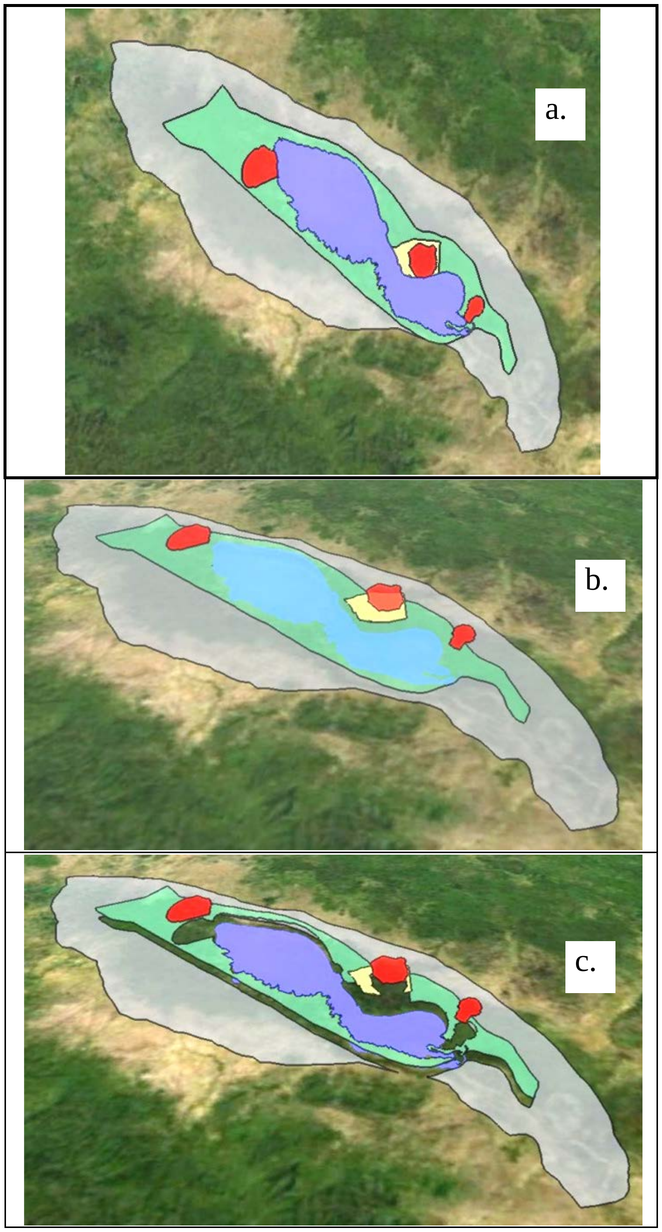


Figure 4-1. Data models for the conservation area database. Overlapping conservation areas with differing management objectives occur in and around Tonle Sap Lake (a). A ***conservation area*** *dataset (b) tracks the area and associated attributes for each conservation area (b). A* ***conservation unit*** *dataset (c) avoids any overlap to facilitate accurate area calculations in terms of the conservation area system as a whole.*

Methods

Data Compilation and Structure

Data for conservation areas and associated attributes were complied from the various legislative mechanisms that established them and expert workshops and correspondence with officials from the Cambodian Ministry of Environment, Forestry Administration, and Departement of Fisheries. The final set of conservation areas was reviewed by a broad range of experts from these agencies as well as protected area experts from local and international NGOs working in Cambodia.

To facilitate an explicit inventory and documentation of Cambodia's conservation area system, I designed two complementary spacially explicit datasets: one tracking each conservation area as discrete unit—regardless of overlap with other conservation areas (***conservation area dataset***) and one representing all conserved areas but with no overlap (***conservation unit dataset***). The latter facilitates accurate area calculations across the conservation area system as a whole Figure 4-1.

Attribute data for the conservation area dataset included the name of each conservation area, year established, establishment mechanism, and several criteria relevant to the assignment of IUCN conservation area category. Since polygons derived for the protection dataset were sometimes subunits of conservation areas but never supersets, all attributes of the conservation area dataset are retained in the attribute table of the summary protection dataset. A full list of attributes is shown in Table 4-3.

Table 4-3. Explanation of conservation attributes compiled for this review. The 'S' column indicates attributes that are stored with the spatial datasets.

Attribute	Explanation	Example(s)	CA	P
ID Code	Unique but meaningful abbreviation of conservation area. Facilitates linking attribute tables with spatial data files.	• TSMUA *(for Tonle Sap Multiple Use Area)*	●	●
English Name	Full name of protected area (English translation)	• Boeng Per Wildlife Sanctuary • Ang Trapeng Thmor Crane Sanctuary	●	●
Khmer Name	Full name of protected area in Khmer	•	●	●
Conservation Area Type	Type of conservation area	• Multiple Use Area • Protected Forest	●	●
Conservation Area Type Abbreviation	Abbreviation of type of conservation area	• MUA • PF	●	●
Administrative Responsibilty	Agency (or agencies) with administrative/ management responsibility for the area	• Ministry of Environment • Forestry Administration	●	●
Legal Mechanism	Legal machanism(s) by which protected area is established - if this mechanism is provincial in scope, this should be explicitly listed here	• Royal Decree • Sub-decree	●	●
Legislation Name	Formal name of the Decree, Sub-decree, Declaration (Prakas), or other mechanism establishing the site.	• **Anuk Kret (Subdecree) 75** on the Establishment of Protected Forest MondulKiri for Genetic Resources and Wildlife Conservation		
Establishment Date	Exact date of establishment by legitimate legal mechanism	• 30-Jul-2002	●	●
Establishment Year	Exact year of establishment by legitimate legal mechanism	• 2002	●	●
Management Objective (Full)	Original text of legal gazettement instrument or restated as part of a participatory process (e.g. Virachey National Park's 5-year management plan)	•		
Management Objective (Abbr)	Abbreviated version of above	•	●	●
IUCN	IUCN management objective category	• Ib • IV	●	●

Size (Km²)	ArcView GIS calculation based on best available boundary information	•	●	●
Provinces	List of intersected provinces	•	●	●
Terrestrial/Freshwater Area	The amount of area that the conservation area uniquely contributes to conservation in Cambodia's terrestrial and freshwater realms. If the area straddles marine and terrestrial/freshwater areas, only the portion of the area occurring in terrestrial/freshwater realms is recorded here.	•		●
Marine Area	The amount of the area occurring in Cambodia’s marine realm. If the area straddles marine and terrestrial areas, only the portion of the area occurring in the ocean realm is recorded here.	•		●
Unique Contribution to Cultural Resource Conservation System	The amount of area that the conservation area uniquely contributes to conservation in Cambodia's cultural conservation system.	•		●
Concise Boundary Descriptions	Is there a concise description of the boundaries of the area included with the orignal establishing legal mechanism or subsequently issued in accordance with accepted legal procedures.	•		
Field Demarcation	Have the boundaries of the area been established on the ground through the installation of boundary markers or other permanent features?	•		
Shapefile	Does the protected area review team have what is understood to be a genuinely accurate shapefile of the area in hand for display/area calculation purposes?	•		

Protected Area Legislative, Policy, and Administrative Frameworks

Cambodian protected area policy is nested within several hierarchical levels of government policy. The Social and Economic Development Plan II (2002b), the National Poverty Reduction Strategy (2002), and the Rectangular Development Strategy (2004) set the overall direction and priorities for planning and policy at the national level. At the sector level, the Ministry of Environment’s National Environmental Action Plan (1998)[8] and Ministry of Agriculture, Forestry and Fisheries’ National Forest Policy Statement outline the agendas of the two primary actors in the protected area sub-sector. Multiple other sector-level strategies are relevant to the protected area system. Policy documents relevant to protected area planning and development are summarised in table 9.

[8] Although past its intended period of relevance, it continues to serve as a central resource for policy and planning with the Ministry of Environment.

Management responsibility for protected areas in Cambodia falls primarily under the Ministry of Environment's Department of Nature Conservation and Protection (all National Parks, Wildlife Sanctuaries, Multiple Use Areas, Protected Landscapes, and Ramsar Sites)[9] with responsibility for Protected Forests, Biodiversity Conservation Areas, and Tree Genetic Conservation sites falling under the Ministry of Agriculture, Forestry, and Fisheries' Forestry Administration. For the MoE, the legal basis for protected area management authority is the 1993 Royal Decree on Protected Areas and the 1994 Prakas # 1033 elaborating the on the Ministry's role and powers.

Table 4-4. Policy documents relevant to protected area planning and development.

Name of Strategy/Plan/Document	Administrative Level/Initiating Agency
Social and Economic Development Plan II	Central Government
National Poverty Reduction Strategy	Central Government
Rectangular Development Strategy	Central Government
National Environmental Action Plan	Sector/Ministry of Environment
National Forest Policy Statement	Sector/Ministry of Agriculture, Forestry and Fisheries
Master Plan for Fisheries 2001-2011	Sector/ Ministry of Agriculture, Forestry and Fisheries/ Department of Fisheries

As detailed in the Forestry Law (2002a), the Forestry Administration may designate and is responsible for the management of Protection Forests. Although lacking the full force of a Royal Decree in their designation, the stated management objectives of these areas are similar to those of the MoE protected areas.

Management authority for the Angkor historical site and surrounding cultural landscape come under the management of the APSARA authority. Other cultural and historical sites come under the management of the Ministry of Culture and Fine Arts (Royal Government of Cambodia 1996).

A detailed new Protected Area Law which will supersede much of the 1993 Royal Decree has been approved by the council of ministers and now awaits parliamentary approval for

[9] The one exception to this is the Angkor Protected Landscape which is managed by the Apsara authority under the Ministry of Culture and Fine Arts.

final adoption. Under the new law, provisions for the MoE to propose changes to the protected area system are retained. Another major feature of the new law is the provision of a legal basis for a logical zoning structure within all areas under MoE management:

- **Core Zones**: Access restricted areas for strict conservation and research
- **Conservation Zones**: Managed-access areas where conservation is the primary objective but within which some use of natural resources deemed sustainable may be permitted.
- **Sustainable Use Zones**: Areas where a variety of sustainable activities (both commercial and non-commercial) deemed beneficial to local communities, the protected area, and/or society at large may be permitted.
- **Community Zones**: Zones within protected areas that are co-managed with communities for the socio-economic benefit of those communities.

Processes to facilitate the participatory development of zoning under this structure are already underway in a number of protected areas.

The Forestry Administration has also recently initiated an effort to establish management zoning within these areas.

Compiling information on the location, design, and status of current protected areas

In this analysis, the term protected area is used in a broad sense and includes both MoE-administered protected areas and Ramsar sites, MoA-administered protection forests, and larger cultural sites administered by the Ministry of Culture and the Apsara Authority. To provide the information necessary to evaluate these areas and their current and potential conservation contributions, a comprehensive database of protected area boundaries and other information was compiled. A review of the governance and impact status of these areas, as well as their conservation objectives is provided in Chapter 4 of this analysis.

Applying IUCN's global classification system

The International Conservation Union (IUCN) has developed a seven category system for characterizing protected areas based primarily on an explicit set of management criteria (Table . To accurately portray Cambodia's conservation area system, each conservation unit was assigned to one of the seven IUCN categories based on explicit guidelines provided by the IUCN (IUCN & WCMC 1994).

Table 4-5. IUCN Management categories definitions and associated management objective categories.

Management Category	Short Description	Full Definition	Importance of Management Objective: Scientific Research	Wilderness Protection	Preservation of species and genetic diversity	Maintenance of environmental Services	Protection of specific natural/cultural features	Tourism and recreation	Education	Sustainable use of resources from natural ecosystems	Maintenance of cultural / traditional attributes
Ia	Strict Nature Reserve: protected area managed mainly for science	Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.	1	2	1	2	-	-	-	-	-
Ib	Wilderness Area: protected area managed mainly for wilderness protection	Large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.	3	1	2	1	-	2	-	3	-
II	National Park: protected area managed mainly for ecosystem protection and recreation	Natural area of land and/or sea, designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.	2	2	1	1	2	1	2	3	-
III	Natural Monument: protected area managed mainly for conservation of specific natural features	Area containing one, or more, specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.	2	3	1	-	1	1	2	-	-
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention	Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats and/or to meet the requirements of specific species.	2	3	1	1	3	3	2	2	-
V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation	Area of land, with coast and sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.	2	-	2	2	1	1	2	2	1
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems	Area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.	3	2	1	1	3	3	3	1	2

Assessing the Legal Stability of Conservation Areas

The legislative mechanisms employed to create conservation areas in Cambodia range from those requiring formal passage at the highest government level (e.g. Royal Decree) to province-level declarations. Table 4-6 summarizes these mechanisms and which types of conservation areas they are typically applied to. Once a protected area and associated management mandate is established, new legislation of the same or higher hierarchical level is required to change the terms of the original legislation. Therefore, the level of legislation in force for existing protected areas provides some understanding of how ***legally durable*** that area is, in other words, how likely it is that the management mandate for a particular area might change to accommodate competing management interests in the future.

Table 4-6. Hierarchical structure of legislative mechanisms related to conservation areas in Cambodia.

Legislative Mechanism (in hierarchical order of legal standing)	…Used to Establish
Parliamentary Approval with Royal Approval	*Protected Area Law, Forestry Law*
Royal Decree (Preah Reach Kret)	*Wildlife Preserves, National Parks, Multi Use Areas, Protected Landscapes,*
Sub-decree (Anuk Kret)	*Protected Forests, Fish Sanctuaries, Ramsar Sites*
Inter-Ministry Declaration	*Management guidelines related to existing conservation areas*
Single Ministry Declaration (Prakas)	*Biodiversity Conservation Areas, Seed Source Areas,*
Decision	*Management guidelines related to existing conservation areas*
Circulars and Instructions	*Management guidelines related to existing conservation areas*
Provincial Declaration	*Integrated Farming and Biodiversity Areas*

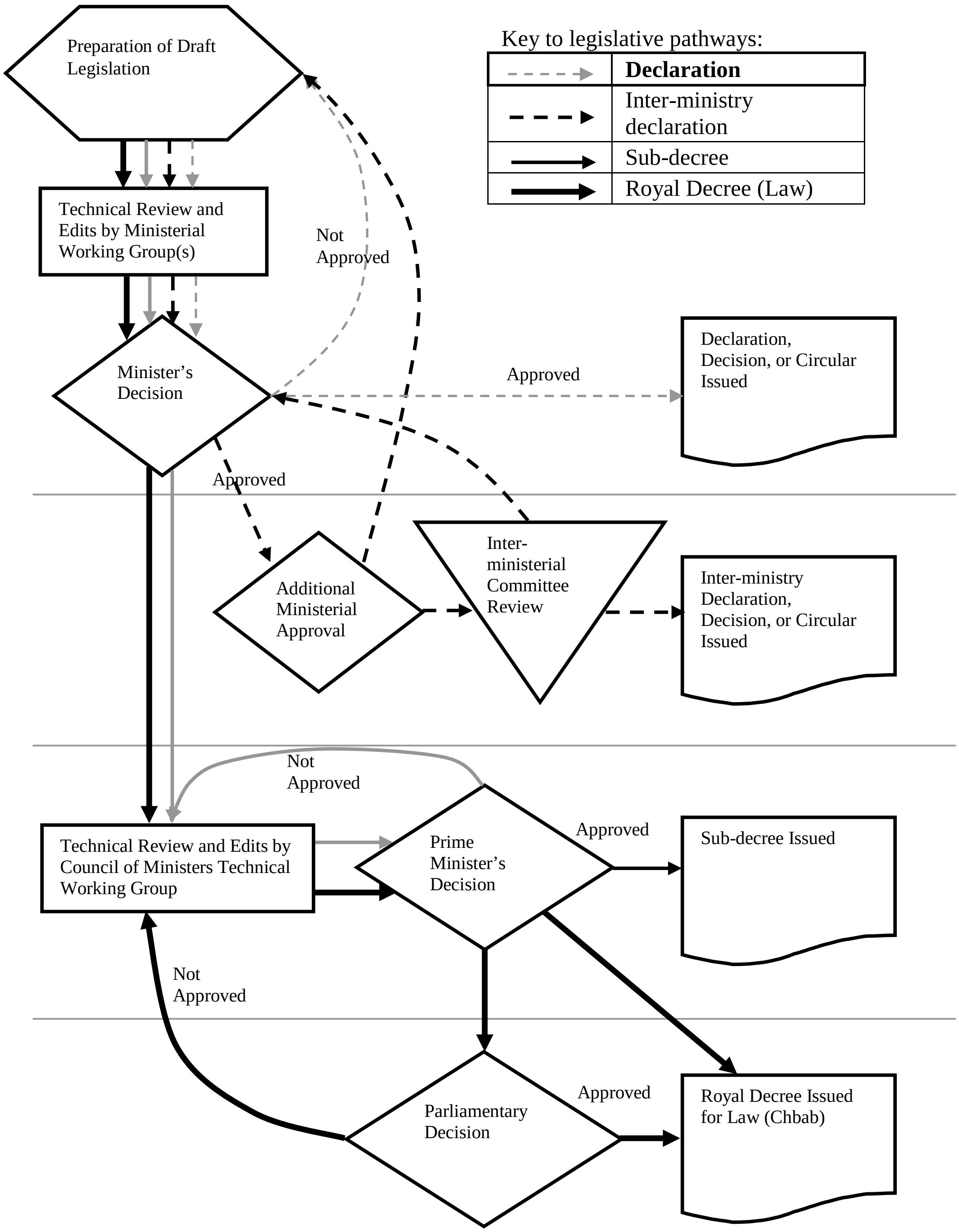


Figure 4-2. Legislative pathways for the establishment of conservation areas in Cambodia. Each successive level represents a more "durable" level of establishment.

Impacts and Threats to the Conservation Area System

To evaluate conservation areas in terms of current impact and threat levels, I overlaid the conservation area system with a map of relative human impact on the environment. This allowed for the explicit calculation of how much of the conservation area system falls into each of several impact/threat categories.

Results

Overview: Cambodia's Conservation Area System in 2009

Cambodia's conservation area system is growing in terms of both number and types of conservation areas. The current system represents approximately 26 percent of the country's land area (Lacerda et al. 2005). Currently only one conservation area (Ream National Park) provides direct protection in the marine ecosystem.

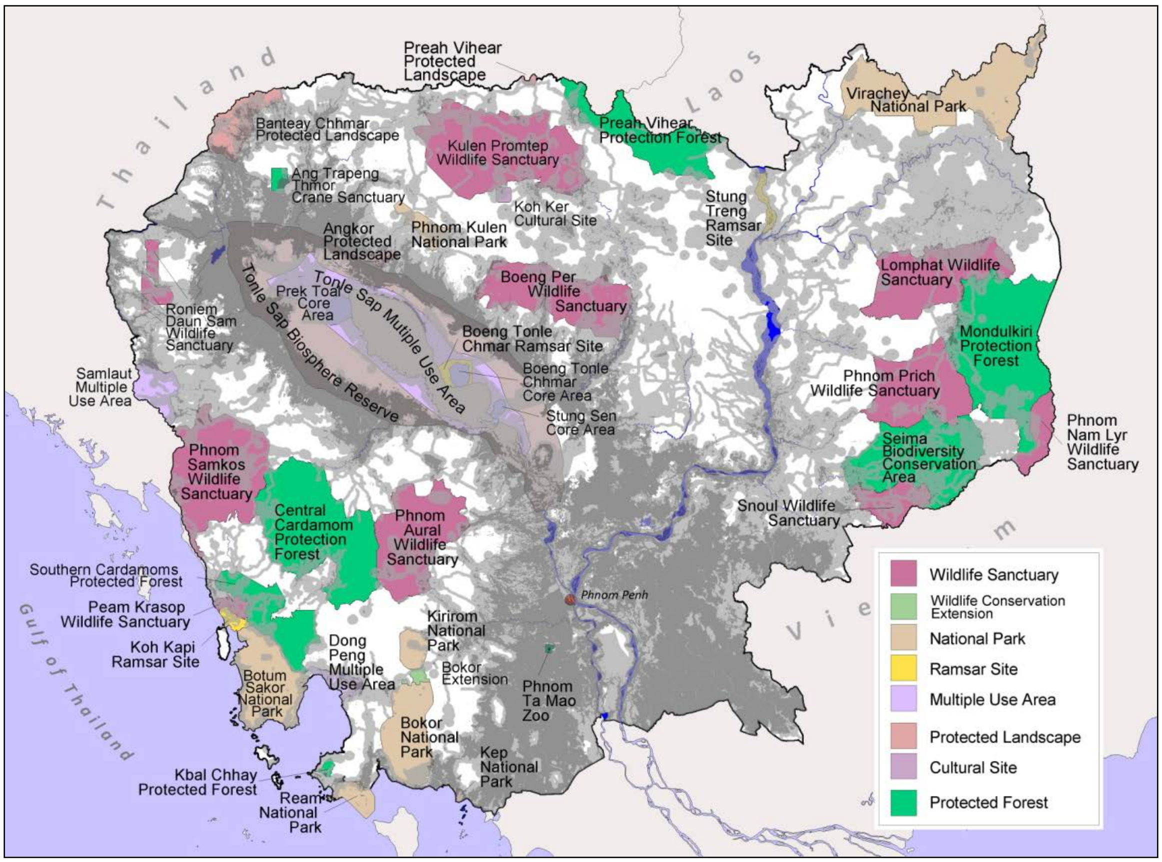


Figure 4-3. Cambodia's protected area system showing patterns of human impact. Dark shading represents heavily transformed areas and light shading are areas vulnerable to significant impacts in the near future.

As is the case in many countries, protected area status in Cambodia does not necessarily imply effective protection. The land and sea areas defined by protected area boundaries include a range of impacts and landuses that represent a wide range of conditions and effectiveness.

Virtually all of Cambodia's protected areas have human populations living within their boundaries and this was case even at the time of their establishment although some have been subjected to substantial in-migration in recent years. This has always been a challenging issue for managers, yet the acknowledgement of peoples' historical ties and legal claims to the land are important considerations in meeting various protected area objectives and in maintaining the support necessary to sustain the system.

In addition to this substantial human presence, there are vast areas of many protected areas that in effect are completely without any form of protection and, in fact, have been that way for years. This has led to marginal degradation in some areas and more severe impacts in others - especially where the establishment or improvement of roads and other infrastructure has facilitated unregulated access to formerly more remote areas.

Table 4-7 summarises the status of the protected area system with regard to 3 modeled impact categories. Map 2 (Annex 1) provides a graphic version of these data.

Table 4-7. Protected area status and impact levels.

Protection	Data	Remote	Vulnerable	Transformed	Row Totals
Protected Areas	km2	28,401	20,465	962	49,828
	% of all protected	57%	41%	2%	100%
Unprotected	km2	37,681	54,375	39,896	131,952
	% of all unprotected	29%	41%	30%	100%
	Category Totals	**66,082**	**74,840**	**40,858**	**181,780**
	Category % Totals	**36%**	**41%**	**22%**	**100%**

A full 41% of the area under protection either has undergone recent impacts or is vulnerable to impacts in the near future.

The current status of protected areas and their future is directly related to the formal and informal structures that derive from and frame the decisions and actions of key actors related to natural resource management in Cambodia. Prevailing power structures reinforce the marginalisation of many stakeholders. Many of the most influential players operate at the highest level of government – thus a meaningful discussion of the most relevant forces that will determine the future of the protected area system must necessarily involve consideration of the major policy and development structures and forces operating in contemporary Cambodia.

IUCN Conservation Area Categories

Table 4-8summarizes information relevant to the designation of conservation areas in terms of IUCN management objective categories. Categories from the current IUCN / WCMC database (WDPA Consortium 2004) are shown along with proposed categories as a result of this review.

Operational Gaps in Cambodia's Conservation Area Network

Gaps and Limitations in the Legal Framework

The largest single gap in the legal framework for protected areas is that the new Protected Area Law remains to be formally adopted. However, various elements of the law are already reflected in current policy and the law is expected to be adopted sometime in 2006.

Additional issues relating to the legal aspects of the protected area system include contradictions and overlaps in existing laws, and the absence of several key policy guidelines called for by current legislation.

Gaps and Limitations in Governance and Institutions

Legitimacy and Voice. Overall levels of confidence and trust in public institutions remain low in Cambodia (Hobley 2004a) as does the level of participation in protected area planning, establishment, and management. However, there are numerous signs of improvement that should be noted:

- Both the existing Sub-decree on Community Forestry Management (Royal Government of Cambodia 1999a) and the community co-management provisions in the draft Protected Areas Law represent positive steps in protecting the rights and traditions of local communities to manage natural resources as they have done for hundreds of years in many areas.
- Mechanisms for bringing diverse stakeholders together at a single table have improved through more frequent meetings and consultations representatives at the local level. National strategies of decentralization support this trend.

Remaining issues and challenges include:

- Fully implementing the new Protected Area Law provisions on community involvement in protected area planning and management;
- Strengthening mechanisms for responding to the concerns of local communities;
- Clarifying and harmonising the roles and responsibilities of groups living and/or operating within protected areas (e.g. military, rangers from MoE and/or MAFF, local residents, concession-holders, etc.) to reduce conflict.

- Improving mechanisms for resolving conflicts when they do occur.

Accountability. There is much progress to be made in this area as current policies and practices lack transparency and basic accountability mechanisms. As with many aspects of protected area governance, accountability issues are closely related to many of the more fundamental reform challenges facing the country as whole.

The slow development of a transparent and effective Environmental Impact Assessment process provides an example. Many projects requiring EIAs take place within protected areas but, despite the 1999 subdecree on EIAs (which emphasises the importance of public participation in the EIA process) (Royal Government of Cambodia 1999b) and continued calls by donors to increase the transparency of the process, there is currently little opportunity for such participation. Although there is some indication that more concerted efforts are being made to solicit the comments of relevant NGOs[10], these appear to be ad-hoc and not yet part of a sustained institutional commitment.

The new protected area law, with provisions for a greater degree of community participation in protected area management, will begin to address these issues but much remains to be achieved.

Other key issues in this area are:

- The absence of laws requiring public disclosure of assets and interests among public officials which often results in conflicts of interest (Hobley 2004b);
- lack of effective checks and balances in the institutions that administer protected areas (Hobley 2004b)
- Limited flow of relevant information (affecting oversight and limiting monitoring, accountability, and liability)

Performance. The overriding issue in this area is the overall limited capacity of relevant agencies to fulfill their protected area responsibilities and duties. This in turn is tied to a host of policy, institutional, and governance issues that tend to weaken the overall

[10] An example is the recent invitation from the MoE's EIA office to NGO Forum to review several EIAs for projects proposed in protected areas. Although the request represents a step in the right direction, the amount of time provided for review and input (approximately 2 weeks) was insufficient to provide for meaningful public participation.

"enabling environment" necessary for acceptable levels of performance. Key issues include:

- *Capacity of natural resource agencies and personnel*. Capacity to fulfill official duties is limited within most natural resource and protected area agencies. Related issues include limited opportunities for training in natural resource management and protection in Cambodia; lack of experience and knowledge of natural resource laws and penalties among provincial judges.
- *Personnel structures and policies*. Both formal and informal aspects of the personnel structure of protected area agencies serve to undermine the overall performance of these agencies. Key issues include:
    - extremely low salaries within protected area agencies (Hobley 2004c; Tordoff *et al.* 2005a);
    - an imbalance in staffing at the central and provincial levels;
    - lack of clarity in the duties and responsibilities of agency staff;
    - hiring and promotion practices that often pressure or require staff to make informal payments to secure a job or promotion;
    - informal tributary arrangements whereby staff are expected to pay a portion of monthly salary to superiors to retain good standing (and thus often supplant incentives for good performance); and
    - a "two-speed" personnel structure where one group of staff are well-paid (often through involvement with foreign-funded projects), and therefore motivated and more likely to put in a full day's work and another, poorly paid group who work part time at best and often pursue other employment on the side (Azima *et al.* 2000).
- *Information and communication issues*. A number of information-related issues work against performance within protected are agencies. These include:
    - the generally low availability and slow movement of information to, from, between, and within protected area agencies;
    - planning cycles that stagnate as they fail to respond to changing circumstances and new information;

- decisions that should be based on current and accurate information are instead based on outdated or non-applicable information;
- uncoordinated action with regard to the protected area system as agencies and indeed, departments and offices within agencies, fail to communicate and coordinate with each other.

Fairness. Cambodia faces great challenges in this area as wealthy and well-connected players (often military or other government officials and powerful businesspeople) continue to take part in lucrative illegal activities (Hobley 2004b) that often marginalise local people and deprive them of a fair share of the benefits of protected areas. Cases of judicial impropriety have been common in the natural resource sector in Cambodia and in some cases, powerful players have been able to prevent cases from even making it to court. Unofficial power structures at the provincial level also constitute a governance gap in the ability of stakeholders—including government agencies—to make appropriate use of existing laws. Although provincial subcommittees have been formed to improve dialogue and resolve conflicts, many abuses continue to go unreported or unresolved.

Direction and Leadership. Although there are gaps in protected area strategic and management planning, the broad objectives of protected areas are clearly (if very generally) set out in the 1993 Royal Decree and subsequent laws that have established other protected areas. It is hoped that this gap analysis, the National Protected Area Plan that it has informed, and the new protected area law will all serve to clarify both objectives and priorities for the protected area system.

However, many challenges remain in providing the direction and leadership required to increase the effectiveness of the protected area system including a **lack of clear and consistent leadership** due to behaviours driven by short-term incentives and an institutional structure that often rewards patronage before performance (Hobley 2004a).

Gaps and Limitations in Management Effectiveness

Many of the current gaps in protected area management effectiveness were identified during a 2004 national-level review of protected area management effectiveness (Lacerda et al. 2005). Although that review was limited to only the original MoE-administered conservation areas, most of the conclusions are relevant to the broad collection protected areas addressed in this analysis.

Primary gaps in management effectiveness within the protected area system include a lack of clear and consistent planning, limited opportunities for management capacity-building, a weak linkage between information and management decision-making, and the lack of a middle management structure in terms of both personnel and spatial management units.

Specifically, the planning cycle currently lacks the consistent preparation and update of appropriate management plans that, ideally, should indicate specific and measurable goals and objectives. Such documents, in turn, often provide the necessary structure for professional development as managers work through the challenges of achieving these objectives.

Information relevant to protected area management includes biodiversity data at multiple scales, socio-economic information, information about ecosystem linkages including watershed dynamics and soil processes, and information on ecological processes such as fire and draught. In all of these areas, monitoring data (e.g. data measuring the same phenomenon over time or between sites) are much more useful than data from a single survey. Building such datasets is a difficult task and one that requires planning, training, and commitment. Currently such data are difficult to find for much of the protected area system and what does exist is often maintained by organizations or institutions outside of the agencies responsible for protected area management.

The integration of such data can often be used to set management priorities that can in turn result in the more effective utilization of management resources.

Currently, management is primarily pursued at the level of individual protected areas with occasional system-level meetings or more informal correspondence between managers of neighbouring areas. A middle management level—one that coordinates and integrates management activities at the landscape level—is lacking. For such a level to operate effectively, management responsibility must be assigned for specific areas and individuals.

Table 4-8. Conservation area objectives, descriptors, and logical framework for assignement of IUCN protected area categories.

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	Current WCMC/ IUCN Categories	Proposed Category	Stated Management Objective(s)	Cambodia Category	National Legal Mechanism	Administrative Responsibilty	Size (Km^2)	% Wilderness	Large Undisturbed Blocks?	Supports Globally Rare Species?	Scientific research	Wilderness Protection	Preservation of species and genetic Diversity	Maintenance of environmental services	Protection of specific natural/cultural features	Tourism and recreation	Education	Sustainable use of resources from natural ecosystems	Maintenance of cultral/traditional attributes
Ang Trapeng Thmor Crane Reserve	**III**	**IV**	Conservation of biodiversity, genetic resources and wildlife habitat	Wildlife Reserve	Royal Decree	FA	129	**51**		**x**	**2**	**-**	**1**	**-**	**-**	**3**	**-**	**-**	**-**
Angkor Protected Landscape	**V**	**V**	**Protected scenic view areas:** Areas to be maintained as scenic views for pleasure and tourism.	Protected Landscape	Royal Decree	MoE	137	**-**			**-**	**-**	**-**	**-**	**-**	**1**	**3**	**-**	**1**
Banteay Chhmar Protected Landscape	**V**	**V**	**Protected scenic view areas:** Areas to be maintained as scenic views for pleasure and tourism.	Protected Landscape	Royal Decree	MoE	848	**26**			**-**	**-**	**-**	**3**	**-**	**2**	**-**	**3**	**1**
Boeng Per Wildlife Sanctuary	**VI**	**II**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	2,497	**53**	**x**	**?**	**2**	**2**	**1**	**2**	**-**	**3 [1]**	**-**	**3**	**-**
Bokor National Park	**II**	**II**	**National Parks:** Areas reserved for nature and scenic views to be protected for scientific, educational and entertainment purposes.	National Park	Royal Decree	MoE	1,499	**81**	**x**	**x**	**2**		**1**	**3**	**1**	**1**	**2**	**-**	**-**

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	**Current WCMC/ IUCN Categories**	**Proposed Category**	**Stated Management Objective(s)**	**Cambodia Category**	**National Legal Mechanism**	**Administrative Responsibilty**	**Size (Km²)**	**% Wilderness**	**Large Undisturbed Blocks?**	**Supports Globally Rare Species?**	**Scientific research**	**Wilderness Protection**	**Preservation of species and genetic Diversity**	**Maintenance of environmental services**	**Protection of specific natural/cultural features**	**Tourism and recreation**	**Education**	**Sustainable use of resources from natural ecosystems**	**Maintenance of cultral/traditional attributes**
Botum Sakor National Park	**II**	**II**	**National Parks:** Areas reserved for nature and scenic views to be protected for scientific, educational and entertainment purposes.	National Park	Royal Decree	MoE	1,834	**68**	**x**	**x**	**2**	**3**	**1**	**3**	**1**	**1**	**2**	**-**	**-**
Central Cardamoms Protected Forest	**IV**	**II**	Conservation of biodiversity, genetic resources and wildlife habitat	Protected Forest	Sub-decree	FA	4,009	**80**	**x**	**x**	**2**	**1**	**1**	**2**	**3**	**3**	**3**	**2**	**-**
Dong Peng Multiple Use Area	**VI**	**IV**	**Multi purposes areas:** Areas necessary for the stability of the water, forestry, wildlife, and fisheries resource, for pleasure, and for the conservation of nature with a view of assuring economic development.	Multiple Use Area	Royal Decree	MoE	286	**4**		**x**	**-**	**-**	**1**	**2**	**2**	**3**	**3**	**1**	**-**
Kbal Chhay Protected Forest	**-**	**VI**	Conservation of biodiversity, genetic resources and wildlife habitat	Protected Forest	Sub-decree	FA	64	**38**			**-**	**-**	**1 [3]**	**1**	**-**	**3**	**-**	**2**	**-**
Kep National Park	**II**	**V**	**National Parks:** Areas reserved for nature and scenic views to be protected for scientific, educational and entertainment purposes.	National Park	Royal Decree	MoE	28	**-**		**x**	**2**	**3**	**2 [3]**	**3**	**1**	**2**	**2**	**-**	**3**
Kirirom National Park	**II**	**II**	**National Parks:** Areas reserved for nature and scenic views to be protected for scientific,	National Park	Royal Decree	MoE	336	**71**	**x**	**x**	**2**	**2 [3]**	**1**	**3**	**1**	**1**	**1**	**-**	**3**

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	Current WCMC/ IUCN Categories	Proposed Category	Stated Management Objective(s)	Cambodia Category	National Legal Mechanism	Administrative Responsibilty	Size (Km^2)	% Wilderness	Large Undisturbed Blocks?	Supports Globally Rare Species?	Scientific research	Wilderness Protection	Preservation of species and genetic Diversity	Maintenance of environmental services	Protection of specific natural/cultural features	Tourism and recreation	Education	Sustainable use of resources from natural ecosystems	Maintenance of cultral/traditional attributes
			educational and entertainment purposes.																
Koh Ker Cultural Site	**-**	**V**	To preserve cultural heritage, archeology, genealogy, history, and upgrade the value of the site; To preserve the cutural, scenic view, and tourism development aspects of the site; To protect the natural environment of the site ["based on the obvious geography"]?	Cultural Site	Royal Decree	MCFA	79	**35**			**-**	**-**	**-**	**-**	**3**	**1**	**-**	**-**	**1**
Kulen Promtep Wildlife Sanctuary	**IV**	**IV**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	4,096	**56**	**x**	**x**	**2**	**2**	**1**	**2**	**-**	**2**	**3**	**3**	**-**
Lomphat Wildlife Sanctuary	**IV**	**II**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	2,526	**67**	**x**	**x**	**2**	**2**	**1**	**2**	**-**	**2 [1]**	**3**	**3**	**-**
Mondulkiri Protected Forest	**IV**	**II**	Conservation of biodiversity, genetic resources and wildlife habitat	Protected Forest	Sub-decree	FA	4,307	**76**	**x**	**x**	**2**	**2**	**1**	**3**	**2**	**2**	**3**	**2**	**-**

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	**Current WCMC/ IUCN Categories**	**Proposed Category**	**Stated Management Objective(s)**	**Cambodia Category**	**National Legal Mechanism**	**Administrative Responsibilty**	**Size (Km^2)**	**% Wilderness**	**Large Undisturbed Blocks?**	**Supports Globally Rare Species?**	**Scientific research**	**Wilderness Protection**	**Preservation of species and genetic Diversity**	**Maintenance of environmental services**	**Protection of specific natural/cultural features**	**Tourism and recreation**	**Education**	**Sustainable use of resources from natural ecosystems**	**Maintenance of cultral/traditional attributes**
Peam Krasop Wildlife Sanctuary	**IV**	**IV**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	259	**11**		**x**	**2**	**-**	**1**	**2**	**2**	**2**	**3**	**2**	**-**
Phnom Aural Wildlife Sanctuary	**IV**	**IV**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	2,542	**62**	**x**	**x**	**2**	**2**	**1**	**3**	**2**	**3**	**3**	**2**	**-**
Phnom Kulen National Park	**II**	**II**	**National Parks:** Areas reserved for nature and scenic views to be protected for scientific, educational and entertainment purposes.	National Park	Royal Decree	MoE	374	**41**			**3**	**3**	**2**	**-**	**1**	**2**	**3**	**3**	**-**
Phnom Nam Lyr Wildlife Sanctuary	**IV**	**Ib**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	549	**74**		**x**	**1**	**2**	**1**	**2**	**2**	**3**	**3**	**-**	**-**
Phnom Prich Wildlife Sanctuary	**IV**	**IV**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	2,242	**75**	**x**	**x**	**1**	**2**	**1**	**2**	**2**	**3**	**3**	**2**	**-**
Phnom Samkos Wildlfie	**IV**	**IV**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect	Wildlife Sanctuary	Royal Decree	MoE	3,299	**62**	**x**	**x**	**1**	**2**	**1**	**2**	**2**	**3**	**3**	**2**	**-**

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	**Current WCMC/ IUCN Categories**	**Proposed Category**	**Stated Management Objective(s)**	**Cambodia Category**	**National Legal Mechanism**	**Administrative Responsibility**	**Size (Km^2)**	**% Wilderness**	**Large Undisturbed Blocks?**	**Supports Globally Rare Species?**	**Scientific research**	**Wilderness Protection**	**Preservation of species and genetic Diversity**	**Maintenance of environmental services**	**Protection of specific natural/cultural features**	**Tourism and recreation**	**Education**	**Sustainable use of resources from natural ecosystems**	**Maintenance of cultral/traditional attributes**
Sanctuary			wildlife, vegetation and ecology balance																
Phnom Thmau Zoological Park		**V**	Conservation of biodiversity, genetic resources and wildlife habitat	Zoological Park	Sub-decree	FA	24	**-**			**2**	**-**	**-**	**-**	**2**	**1**	**1**	**3**	**1**
Preah Vihear Protected Forest	**IV**	**IV**	Conservation of biodiversity, genetic resources and wildlife habitat	Protected Forest	Royal Decree	MoE	1,900	**76**	**x**	**x**	**3**	**3**	**1**	**3**	**2**	**3**	**3**	**2**	
Preah Vihear Protected Landscape	**V**	**V**	**Protected scenic view areas:** Areas to be maintained as scenic views for pleasure and tourism.	Protected Landscape	Sub-decree	FA	33	**31**			**-**	**-**	**-**	**-**	**-**	**1**	**2**	**-**	**1**
Ream National Park	**II**	**II**	**National Parks:** Areas reserved for nature and scenic views to be protected for scientific, educational and entertainment purposes.	National Park	Royal Decree	MoE	338	**72**	**x**	**x**	**2**	**3**	**2**	**2**	**1**	**1**	**2**	**-**	**-**
Roniem Daun Sam Wildlife Sanctuary	**IV**	**VI**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	400	**38**			**2 [3]**	**2 [-]**	**1 [3]**	**2**	**2**	**2**	**2**	**- [2]**	**-**
Samlaut Multiple Use Area	**VI**	**VI**	**Multi purposes areas:** Areas necessary for the stability of the water, forestry, wildlife, and fisheries resource, for	Multiple Use Area	Royal Decree	MoE	610	**37**		**x**	**3 [2]**	**3**	**1**	**2**	**2**	**3**	**3**	**1 [3]**	**-**

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	**Current WCMC/ IUCN Categories**	**Proposed Category**	**Stated Management Objective(s)**	**Cambodia Category**	**National Legal Mechanism**	**Administrative Responsibility**	**Size (Km^2)**	**% Wilderness**	**Large Undisturbed Blocks?**	**Supports Globally Rare Species?**	**Scientific research**	**Wilderness Protection**	**Preservation of species and genetic Diversity**	**Maintenance of environmental services**	**Protection of specific natural/cultural features**	**Tourism and recreation**	**Education**	**Sustainable use of resources from natural ecosystems**	**Maintenance of cultral/traditional attributes**
			pleasure, and for the conservation of nature with a view of assuring economic development.																
Seima Biodiversity Special Management Zone	**-**	**IV**	Conservation of biodiversity, genetic resources and wildlife habitat	Special Management Zone	Sechkdey Prakas	FA	2,987	**38**		**x**			**1**		**2**	**3**	**3**	**2**	**-**
Snoul Wildlife Sanctuary	**IV**	**V**	**Wildlife Preserves**: Natural areas preserved at their natural conditions in order to protect wildlife, vegetation and ecology balance	Wildlife Sanctuary	Royal Decree	MoE	753	**36**		**x**	**2**	**2**	**1**	**3**	**2**	**3**	**3**	**2**	**-**
Southern Cardamoms Protected Forest	**-**	**VI**	Conservation of biodiversity, genetic resources and wildlife habitat	Protected Forest	Sub-decree	FA	1,451	**57**	**x**	**x**	**3**	**3**	**1**	**3**	**2**	**3**	**3**	**2**	**-**
Stung Treng Ramsar Site	**-**	**IV**		Ramsar Site	None	MoE / DoF	149	**-**		**x**	**2**	**3**	**1**	**2**	**1**	**3**		**2**	
Tonle Sap Multiple Use Area	**VI**	**VI**	**Multi purposes areas:** Areas necessary for the stability of the water, forestry, wildlife, and fisheries resource, for pleasure, and for the conservation of nature with a view of assuring economic development.	Multiple Use Area	Royal Decree	MoE	3,314	**67**	**x**	**x**	**3 [2]**	**3**	**1**	**2**	**2**	**3**	**3**	**1 [3]**	

			Management Objective (s) and Cambodia Protected Area Type Assignment		Other Basic Information			Indicators of potential to fulfill original management objectives			Categories of Management Objectives (after IUCN 1994)and Prominence in Stated or Demonstrated Management Objectives								
PA Name	Current WCMC/ IUCN Categories	Proposed Category	Stated Management Objective(s)	Cambodia Category	National Legal Mechanism	Administrative Responsibilty	Size (Km²)	% Wilderness	Large Undisturbed Blocks?	Supports Globally Rare Species?	Scientific research	Wilderness Protection	Preservation of species and genetic Diversity	Maintenance of environmental services	Protection of specific natural/cultural features	Tourism and recreation	Education	Sustainable use of resources from natural ecosystems	Maintenance of cultral/traditional attributes
Virachey National Park	II	II	**Virachey National Park Mission Statement:** To conserve and sustainably manage the natural and cultural resources of the park in partnership with local communities and other stakeholders for the benefit of the people from local communities and Cambodia as a nation.	National Park	Royal Decree	MoE	3,342	88	x	x	3	3	2	3	1	3	2	2	3

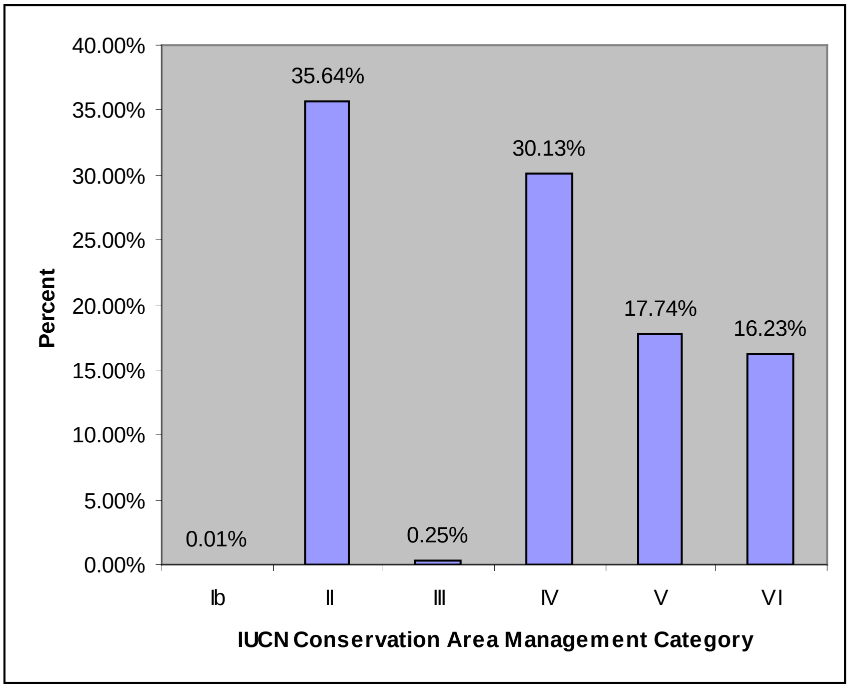


Figure 4-4. IUCN management objective categories by proportion of total conservation area in Cambodia.

Assessing the Legal Stability of Conservation Areas

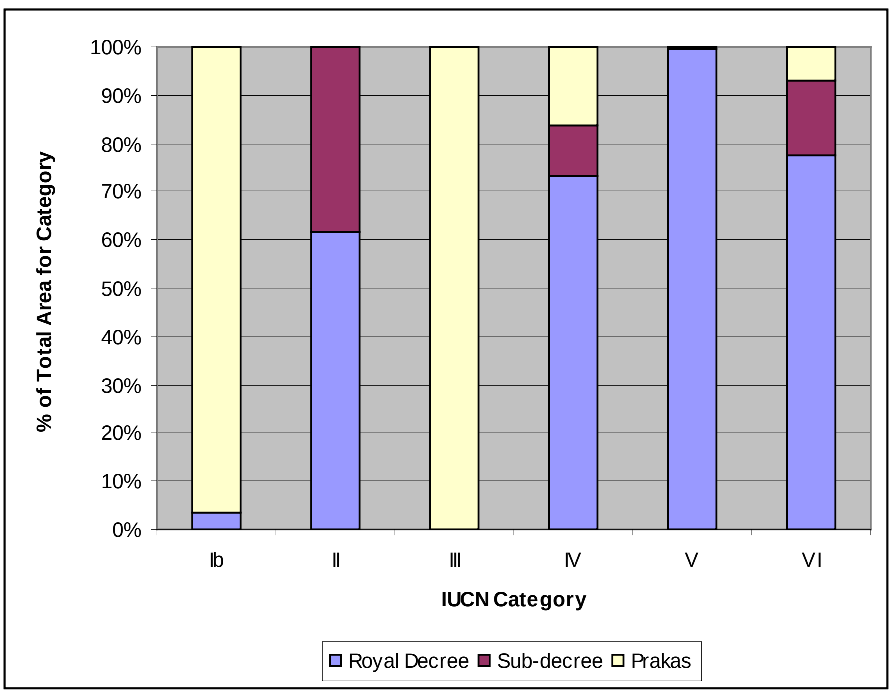
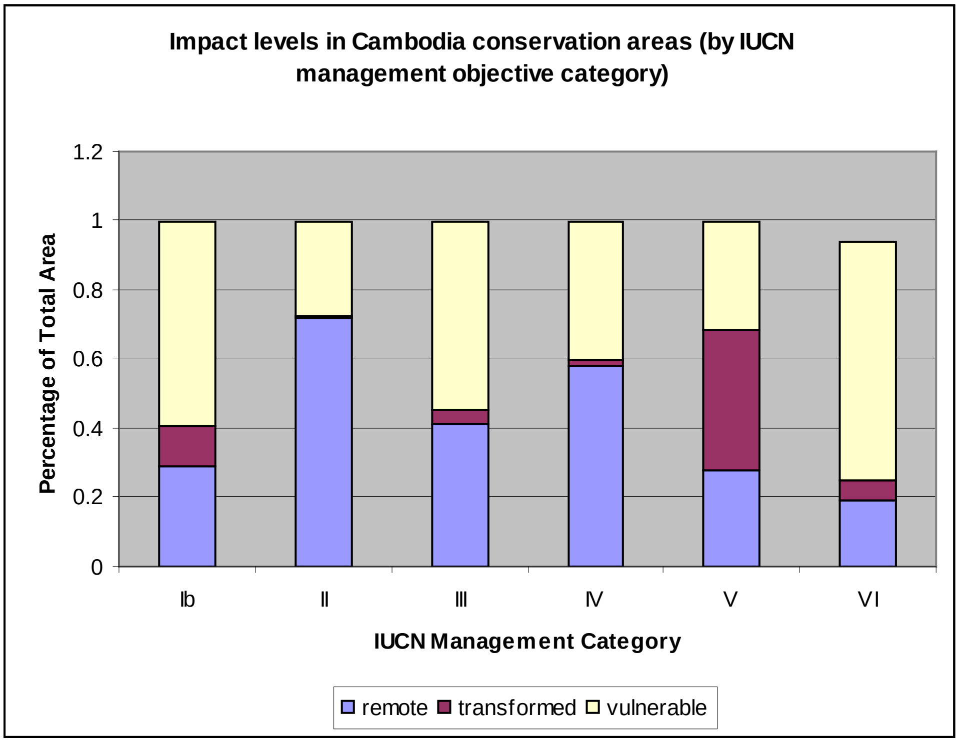


Figure 4-5. Proportion of each management category established by one of three legal mechanisms: Royal Decree, Sub-decree, and Prakas (Declaration).

Impacts and Threats to the Conservation Area System

All conservation area categories show at least some of each impact category considered.



4-6. Impact levels in each of 6 categories of conservation areas in Cambodia.

Discussion

As with all conservation area networks, the success of Cambodia's protected area system is closely tied to the policies and institutions that underpin the system are ineffective (Davey 1998). Of general importance are the institutional structures, laws, policies and traditions that form the backdrop of the protected area system as well as on-the-ground issues such as management structures, professional capacity, infrastructure and equipment. Also relevant to the operation of the conservation area network are cross-cutting issues such as governance, information management, and communication. Key issues relating to all of these areas are discussed below. Design and biodiversity representation aspects of the network are addressed in Chapter 5.

Revisiting the Roles and Goals of Protected Areas

In the relatively short time since the core system of 23 protected areas was created in Cambodia, global perspectives about the role of conservation areas has changed dramatically. In general terms, this shift can be summarized as a move from ***exclusion*** to *integration*. Table 4-9 summarizes this shift with respect to diverse aspects of conservation areas and conservation area systems.

Table 4-9. Changing Perspectives in the Establishment and Management of Conservation Areas (Adapted from Phillips, A. 2003. Turning ideas on their head: the new paradigm for protected areas. The George Wright Forum 20:8-32.)

CA – related Issue	Historical Perspective	Emerging Perspective
Objectives	• Set aside for conservation • Established to preserve wildlife or other natural spectacles or for sport hunting • Managed for visitors and tourists • Focused on protection	• Established for a broad range of reasons including cultural, economic, and scientific purposes • Local communities and other landscape linkages an integral part of management • Encompass restoration and rehabilitation goals.
Magnitude and Range of Values	• Narrower range of values considered • Ecosystem values rarely quantified	• Wider range of both primary and secondary values considered • Total economic valuation of protected areas has revealed a higher value than previously acknowledged
Distribution of Benefits	• Intangible • Benefiting a few • As a trade-off with other national goals	• Specific • Benefiting all sectors of society • Directly serving national goals
Governance	• Top-down decision-making • Run by a central authority	• Consultative decision-making and consensus-building • Often run by 2 or more partners including different tiers of government, local communities, NGOs, private sector, and others
Local People	• Management objectives conflicting with local needs and traditions • Limited or no scope for local perspectives	• Managed to accommodate or achieve local needs and traditions • Managed by or in partnership with local people
Perceived Responsibility	• Viewed as a national concern	• Viewed as an international concern
Landscape Context	• Developed separately • Managed as "islands"	• Conceived of and managed as parts of regional, national, and international systems • Managed as networks with dynamic connections to other protected areas and other elements of the landscape

CA – related Issue	Historical Perspective	Emerging Perspective
Land Use Issues	• Viewed as exclusive property of the state • Use dictated by the state	• Use determined by multiple stakeholders • Managed to accommodate human use in a sustainable fashion
Information Considerations	• Narrow range of information inputs • Focused on western science • Natural resource-based	• Broad range of information considered • Drawing on local knowledge • Inclusive of social, political, historical context
Management Techniques	• Managed as static entities • Reactive management • Short-term management horizon	• Managed as highly dynamic systems • Proactive, adaptive management • Long-term management horizon
Funding and Sustainability	• Paid for by central government budgets • Costs met by sources external to the PA	• Paid for by many sources • Costs met in part through charges for PA goods and services

While the establishing legislation, site-specific management plans, and other factors often provide a clear official statement of management objectives for conservation areas in Cambodia, these objectives are often insufficient for planning due to the fact that they are too general, are outdated, or do not represent the real objectives of relevant stakeholders. While a more detailed review of objectives was beyond the scope of this review, future work must confront these limitations to ensure that objectives have meaning beyond general documentation. This process should start with a conversation with a broad range of stakeholders about how people use conservation areas and what value they ascribe to various management actions.

It is often the case that some stakeholders may find it difficult to appreciate conservation area values that accrue at larger spatial and temporal scales. However, it is critical that planners and managers understand small-scale motivations and incentives to be able to chart realistic and effective management paths.

Governance and Institutional Issues

While the design and representativeness status of the protected area system is the focus of this gap analysis, an understanding of related policy, legislative, and institutional structures is critical to charting the future of Cambodia's protected area system. Good governance and effective institutions can be seen as creating the "enabling environment" for the protected area system to operate effectively.

The current viability of protected areas and their future is directly related to the formal and informal structures that derive from and frame natural resource management in Cambodia. Currently, prevailing power structures at the highest level of government organization and policy reinforce the marginalisation of many stakeholders. Therefore, a meaningful discussion of governance issues must necessarily involve consideration of the major policy and development structures and forces operating in contemporary Cambodia.

It has been suggested that a general challenge in understanding the 'natural resource sector' is that the issues surrounding natural resources, forestry, and other associated 'sub-sectors' lack the policy coherency and coordinated goals of more "simple" sectors such as health and transportation (Hobley 2004a). The conservation area network and all related actors, structures, and forces should be considered a sub-sector of a broader natural resources sector which includes the 'forestry sub-sector', 'water resources sub-sector', and other natural resource related areas. It is important to recognise that all of these are deeply interrelated and in many respects overlapping. It follows that many of the issues and challenges relevant to the natural resource sector and forest sub-sector are highly relevant to those of the protected area system.

In addition to formal structures created by the various laws, policies, and institutional structures, there are a variety of informal structures and practices that often have as much or more influence on the effective operation of the system. For a detailed discussion of many of most of the relevant issues and drivers, the reader is referred to Chapters 9 through 12 of the "Current Context" section of the recent Independent Forest Sector Review (Shields *et al.* 2004).

It has been suggested that protected areas provide the government with an opportunity to demonstrate good governance (ICEM 2003a), yet there are a number of areas where significant improvement is needed for the protected area system to succeed. Most are part of a more general need for governance transformation at all levels of government.

The following useful framework maps protected area institutional and governance issues to the United Nation's *Five Principles of Good Governance* (Scanlon & Burhenne-Guilmin 2004).

Table 4-10. Governance issues in the establishment of and management of protected areas (Scanlon & Burhenne-Guilmin 2004).

Five Principles of Good Governance and the UN principles upon which they are based	Related PA governance responsibilities

Legitimacy and Voice ***Participation***: All men and women should have a voice in decision-making, either directly or through legitimate intermediate institutions that represent their intention. Such broad participation is built on freedom of association and speech, as well as capacities to participate constructively. ***Consensus orientation***: Good governance mediates differing interests to reach a broad consensus on what is in the best interest of the group and, where possible, on policies and procedures.	• Promoting the **free expression** of views, with no discrimination related to gender, ethnicity, social class, etc. • Fostering **dialogue** and **consensus** • Fostering relations of **trust** among stakeholders • Making sure that rules are respected because they are “owned” by people and not solely because of fear of repression
Accountability ***Accountability***: Decision-makers are accountable to the public, as well as to institutional stakeholders. This accountability differs depending on the organisations and whether the decision is internal or external. ***Transparency***: Transparency is built on the free flow of information. Processes, institutions and information are directly accessible to those concerned with them. Enough information is provided to understand and monitor institutions and their decision-making processes.	• Making sure that stakeholders possess an adequate **knowledge,** and **quality of knowledge,** regarding what is at stake in decision-making, who is responsible for what, and how responsibilities can be made accountable • Making sure that the avenues to demand accountability are **accessible** to all • Making sure that accountability is not limited to verbal exchanges but linked to concrete and appropriate **rewards and sanctions**
Performance ***Responsiveness***: Institutions and processes try to serve all stakeholders. ***Effectiveness and efficiency***: Processes and institutions produce results that meet needs while making the best use of resources.	• Ensuring a **competent** administration. • Making certain there is sufficient institutional and human **capacity** to carry out the required roles and assume the relevant responsibilities • Being **robust** and **resilient**, i.e. able to overcome a variety of threats/ obstacles and come out strengthened from the experiences
Fairness ***Equity***: All men and women have opportunities to improve or maintain their well being. ***Rule of Law***: Legal frameworks are fair and enforced impartially, particularly the laws on human rights.	• Making sure that conservation is undertaken with **decency**: without humiliation or harm to people • Ensuring that the governing mechanisms (e.g. laws, policies conflict resolution forums, funding opportunities, etc.) **distribute equitably the costs and benefits deriving from conservation** • Making certain that public service promotions are merit-based • Being **consistent** through time in applying laws and regulations • Providing fair avenues for **conflict management** and, eventually, non-discriminatory recourse to **justice**

Direction	
Strategic vision: Leaders and the public have a broad and long-term perspective on good governance and human development, along with a sense of what is needed for such development. There is also an understanding of the historical, cultural and social complexities in which that perspective is grounded.	• Providing effective leadership, generating and supporting innovative ideas and processes. • Providing a model of good conduct, being consistent in what it is said and done

To date, involvement of relevant stakeholders in protected area planning and management activities in Cambodia has been relatively limited. However, recent pilot projects in several areas (Biodiversity and Protected Area Management Project 2003; Grieg-Gran 2008) provide a model for a structured approach to this critical endeavour.

Management at the System Level

The recent Rapid Assessment and Prioritisation of Protected Area Management (RAPPAM) of MoE-administered protected areas in Cambodia (Lacerda et al. 2005) revealed clear strengths and weaknesses in management at both the system and site level and many of the same issues are reflected in areas managed by other agencies. Among the system's strengths is its overall design (which was found to be conducive to effective management) and increasing levels of dialogue with and involvement of local stakeholders in all aspects of management. Among the system's weaknesses are the lack of appropriate information on which to base management decisions and perennial financial and staffing shortfalls that limit management effectiveness in numerous ways. Reporting and communication mechanisms are also inconsistent making it difficult to appreciate and act on opportunities and threats that relate to the system as a whole.

The RAPPAM Assessment was a systematic and repeatable process that should be adopted as an ongoing monitoring tool for conservation area management effectiveness. Future exercises would benefit greatly by including the full variety of Cambodia protected areas including protection forests and cultural sites.

One approach to addressing many of these network-wide issues is to adopt a "cluster" strategy to that would group individual conservation areas into landscape-scale clusters with regional and perhaps thematic affinities. Such a system has been applied in Thailand with much success (Prayurasiddhi et al. 1999). Such a structure would facilitate improved planning throughout both conservation areas and the matrix between areas. In addition, it would provide a more logical basis for integrated conservation and development planning.

Given that coordination has historically been limited between the two agencies with primary responsibility for the conservation area system, the use of IUCN categories for characterizing conservation units over the entire country may be an important means of facilitating systematic, objective, and transparent evaluation of the system.

Creation of New Conservation Areas

Almost a full 1/3 of Cambodia's protected area system has been established within the last 7 years. Several proposals for additional areas are pending and new policies related to the protected area system—such as ministerial level declarations mandated by higher-level legislation—are issued frequently. For this reason, the conservation area system is still a highly dynamic entity. Planning and monitoring activities are thus of particular importance at this time and at least for the next decade.

Management at the Site Level

Management Planning

At the site level, the lack of up-to-date management plans means that management action often lacks coherency and focus. The BPAMP project has published a user friendly guide to developing and formally adopting management plans called "*Participatory Development of Management Plans for Protected Areas in Cambodia"* (BPAMP 2005). Using this guide and other resources, the formulation, adoption, and maintenance of 5-year management plans should be a priority for all conservation area managers.

Boundary Demarcation

The process of establishing clear, legal boundaries for all protected areas has multiple values. Boundary demarcation can be a time-consuming process—especially in areas where current patterns of land ownership are poorly documented. However, establishing clear boundaries – often in partnership with local communities—will ultimately reduce conflict and improve the overall effectiveness of the protected area system. For this reason, legal boundary demarcation of conservation areas—accompanied by appropriate negotiation and arbitration mechanisms—should be a management priority throughout the conservation area network.

Within-Area Zoning

Zoning can be thought of as the application of the IUCN categories discussed above to sub-units of conservation areas. A new zoning system—outlined in the newly adopted Protected Area Law (Royal Government of Cambodia 2005)—now provides for four explicit categories of management within protected areas and the Forestry Administration, in its management of protected forests and biodiversity conservation areas is also promoting a zoning approach. The four categories, core zones, conservation zones, sustainable development zones, and community zones roughly reflect IUCN categories as applied to entire conservation areas and provide a logical framework for realigning priorities and resources within the current network. Within-area zoning is more flexible than the application of protected area categories in that formal adoption of zones can take place at the ministerial level without approval of the full legislature.

Within-area zoning has both positive and negative aspects. On the positive side, it may allow for a more efficient allocation of conservation resources without formally changing the boundaries of existing areas. On the negative side, zoning procedures are subject to abuse and there are few safeguards against zoning being used to facilitate resource extraction and other harmful activities in areas with critical biodiversity conservation value. One logical safeguard would be to set limits on the amount of each

Sustainability of the Conservation Area Network

The overall size of the current CAN (approximately 27% of the country's total land area) has always been a controversial issue and there are numerous indications that current resources and political will are strained to justify this large size. However, several related points should serve to mitigate concerns over the total size of the network:

- Of the land area of the country under some form of protection, approximately 37% is under either multiple use or protection forest categories, both of which explicitly allow for a relatively wide range of commercial, infrastructure, or development activities.
- All areas are soon to be subject to site zoning procedures that will further provided for sustainable activities under certain circumstances.
- A full 43% of the current system is within 3 km of a village or within 1 km of larger roads. Many of these areas are critical to sustain the livelihoods of local communities through the provision of food (fish, plants, etc.) and renewable resources such as bamboo and grasses.
- Several of Cambodia's protected areas cover some of the most commercially productive areas of the country including the Tonle Sap Lake and Angkor Protected Landscape.
- While it is important to appreciate the contributions of the existing system, it is also critical that conservation targets at the site level and for particular conservation features be seen in the context of national-level constraints.

Relatively few protected area systems are truly self-sustaining. In most western countries, domestic government budgets and various fiscal instruments provide a nationally self-sustaining source of funding while in developing countries such as Cambodia, the ability of domestic budgets to cover the costs of conservation is limited at best. Although other investors and have helped bridge the funding gap in recent years, these sources are relatively insecure in that they are subject to outside economic forces and simple donor fatigue.

As a result of this, much recent attention has been given to raising awareness of the actual financial value of protected areas and to developing strategies for translating this value into much needed revenues for their management (ICEM 2003b). Several studies specific to Cambodia clearly support the general conclusion that the sustainable management of natural resources through protected areas and other mechanisms can provide long-term financial and other benefits with relatively small investments in the medium to long-term.

What are the actual costs involved? In a recent review of protected area funding and sustainability, Brunner & Ashwell (2005) estimate that the current protected area system could be effectively managed at a rate of approximately $0.60 per hectare per year[11] or a total of approximately $2,970,780 exclusive of costs at the central administrative level (e.g. costs of staffing and running DNCP and FA). The same review estimates that currently, the government's contribution to the MoE's overall expenditure is approximately 25% with the remainder coming from contributors such as the Global Environment Facility (GEF) and various NGOs. Given that current spending from all sources is already only a fraction of what is needed to effectively manage the PA system, the sustainable financing of the protected area system constitute one of the system's biggest strategic challenges.

The draft Protected Area Law lists the following as sources of revenue to be developed for protected area operation:

- Entrance and other service fees
- Fines
- Environmental endowment fund
- Donations
- Assistance from national and international organisations and friendly countries
- Assistance from international environment funds

Of these, service fees, fines, and growth in the Environmental Endowment Fund12 represent significant, and as yet, very much untapped potential sources of revenue. In particular, service fees for commercial concessions within protected areas - if levied and

[11] A range of per hectare costs is presented in the review. This figure represents the low end of the range.
[12] Provisions for which are outlined in the Law on Environmental Protection and Natural Resource Management promulgated in 1996.

managed properly - have tremendous potential for defraying much of the cost of protected area management. There is clearly an interest among investors in developing commercial activities as exemplified by several large-scale commercial projects are now under review by the MoE in Ream National Park, Aural Wildlife Sanctuary, Samlaut Multiple Use Area, and other sites. The main challenges for relevant ministries are therefore:

- establishing a clear set of guidelines for collecting service fees based on a detailed assessment of the value of services accruing to private interests under each approved project, and
- ensuring that, to the extent possible, revenues collected from such fees be directed to the maintenance and/or improvement of the protected area system.

Meeting these challenges should be a priority for protected area management agencies and will require both formulation of appropriate legislation and policy as well as significant capacity development.

Efforts to conserve biodiversity and maintain ecosystems and the services they provide Cambodian society must take place at the level of entire landscapes rather than individual sites. Yet, conservation planning in Cambodia has focused disproportionately on efforts at the site level. Although some initiatives have attempted to encourage planning and action at the landscape, national, and regional level, efforts have been envisioned national and regional level, current institutional structures sometimes work against efforts at these levels by enabling direct competition for planning and management resources and allowing for redundancy and contradiction even at the official policy level.

The ecological and socio-economic settings of Cambodia's protected areas are diverse and the management of each area should proceed from a uniquely prepared plan. The recent publication of *"Participatory Development of Management Plans for Protected Areas in Cambodia"*, produced by the Biodiversity and Protected Area Management Project (2005) is an indispensable tool for undertaking this process.

CHAPTER 5. A BIODIVERSITY GAP ANALYSIS OF CAMBODIA'S PROTECTED AREA SYSTEM

Many elements of Cambodia's biodiversity are globally or regionally distinctive and have significant economic and other values. As in many countries, Cambodia's vast conservation area system is the cornerstone of biodiversity protection measures. This gap analysis was conducted In order to better understand the effectiveness of the conservation area system in representing and sustaining Cambodia's biodiversity. With the exception of the marine ecosystem—in which a significant reserve has yet to be formally established—Cambodia's protected area system is relatively well designed in terms of representing and protecting general biodiversity patterns but could be greatly enhanced with some strategic adjustments aimed primarily at representing broad habitat types that are poorly protected in either Cambodia, the region, or both. A simulated annealing approach is used to identify priority sites where conservation action would most effectively and efficiently lead to better representation of these habitats and many of the species they support. Gap analysis and the larger systematic conservation planning process of which it is a part are highly dynamic processes that must respond to changing circumstances and opportunities. Therefore, a dedicated system and sufficient capacity to carry out frequent reassessments is a critical need as Cambodia seeks to achieve both complementary and sometimes conflicting conservation and development objectives.

Introduction

Cambodia is fortunate to have a rich and diverse range of biodiversity. A number of highly distinctive ecological systems occur in the country including the largest remaining block of lowland humid (e.g. evergreen or semi-evergreen) forest in mainland Southeast Asia (Ashwell et al. 2004), the Tonle Sap Lake, and extensive intact mangrove forests.

With more than 500 documented and likely more than 600 total species of birds (Poole 2001), Cambodia has a particularly high rate of avian diversity. The country's unique hydrology provides critical breeding and feeding habitat for many species. Although only one endemic bird is known from the country (Chestnut-headed Partridge), Cambodia hosts the most viable populations globally for many species (including Giant Ibis, Bengal Florican, Slender-billed Vulture, White-rumped Vulture, and Spot-billed Pelican) and the most viable populations regionally for many others (including Greater Adjutant, Sarus Crane, and Manchurian Reed Warbler) (Hout et al. 2003).

Compared with its neighbors, Cambodia has the highest occurrence rate of globally threatened species (per unit area) in the region for mammals, birds and fish (Tordoff et al. 2005a). The occurrence of relatively extensive, intact tracts of habitat means that the country has a potentially pivotal role in global conservation efforts targeting these species.

However, as Cambodia strives to provide for the expanding needs and aspirations of its people, development pressures pose a mounting challenge to the size and viability of its vast conservation area system (CAS). At 27 % of the nation's land area, is among the largest such systems in the world (UNEP-WCMC 2004).

Working at a time when Cambodia was just emerging from a long period of regional war and civil unrest, the designers of Cambodia's original conservation areas had available only general biodiversity information and little reliable information about the condition of the landscapes that formed the basis of the system (Ashwell 1997). While the boundaries of the original system have changed little since that time, the ecological condition of the system and the impacts it faces have changed dramatically (See previous chapter). Yet, in the absence of explicit and transparent evaluation, it is unclear how effective the current system is at representing the country's biodiversity. To accomplish such an evaluation, the Biodiversity and Protected Area Management Project (a project of the Ministry of Environment with substantial support from the World Bank and Global Environment Facility) initiated this biodiversity and conservation area gap analysis in late 2004.

Since patterns of biodiversity are "rooted in place" (Sarkar & Margules 2002), the task of conserving biodiversity thus has an essential spatial component. Biodiversity gap analyses identify gaps in the representativeness and/or effectiveness of a conservation area system to conserve biodiversity (Scott et al. 1996). This is achieved by comparing the distribution and structure of mapped biodiversity elements to the extent and configuration of conservation area systems (Jennings 2000). Once gaps have been identified, explicit measures to address the gaps can then be identified and prioritized (Burley 1988; Dudley & Parrish 2006; Jennings 2000; Sarkar & Margules 2002).

Gap analyses are often prompted by the acknowledgement that the selection and establishment of many protected areas has not been based on biodiversity conservation objectives, or, where biodiversity conservation has been the goal, that the ad-hoc nature of creating reserves has resulted in significant bias and inefficiency (Margules & Sarkar 2007; Pressey 1994). To address these issues, gap analyses have been conducted at a variety of scales ranging from regional (Strittholt & Boerner 1995) to global (Rodrigues et al. 2004a) and now frequently as an important component of the Convention on Biological Diversity's 'Program of Work' on Protected Areas (Secretariat of the Convention on Biological Diversity 2005). In the last 25 years, gap analysis methods have received much focused attention and development—particularly in the United States and Australia (Jennings 2000; Kiester et al. 1996). The range of tools and approaches to conduct gap analyses has grown exponentially in recent years along with a substantial associated literature (Margules & Pressey 2000; Margules & Sarkar 2007; Sarkar et al. 2006).

Gap Analysis as a Component of Systematic Conservation Planning

In a broad sense, gap analyses identify gaps in the ability of a process, organisation, or strategy to achieve a given objective or set of objectives. In the conservation field, gap analyses identify gaps in protected area systems' representativeness and effectiveness in conserving biodiversity. Gap analysis can be seen as an important subset of what has come to be known as ***systematic conservation planning***, (Margules & Pressey 2000), a diverse set of tools and approaches to "identify areas that should have priority for the allocation of scarce biodiversity-management resources and to separate those areas from factors that threaten their persistence" (Margules & Sarkar 2007)***.*** Systematic conservation planning encompasses such diverse considerations as the socio-economic tradeoffs and political feasibility of potential conservation actions and the formulation of detailed implementation plans. In contrast, gap analyses usually focus on the technical and analytical aspects of mapping biodiversity patterns and assessing gaps in their representation. (Figure 5-1).

While the domain of this analysis is mostly the gap analysis elements of systematic conservation planning, steps are taken to identify potential means for filling the gaps identified.

Conservation planning is a dynamic process whereby decisions made at one stage will impact future options and frequently alter the trajectories of future action (Christensen 2004; Margules & Pressey 2000; Meir et al. 2004; Possingham et al. 2000). It is therefore best viewed as an iterative process where available information is frequently weighed against changing conditions and opportunities (Sarkar & Margules 2002). As multiple, spatially explicit considerations must constantly be re-evaluated in the gap analysis process, planning is best carried out with the support of a geographic information system or, at minimum, through the use of maps showing the spatial patterns of the various data used and that can be updated to reflect changing circumstances and priorities.

Conservation area system performance has both ***design*** and ***operational*** aspects--each with distinctive sets of potential gaps. ***Design aspects*** of CASs include the system's representativeness (e.g. what species, habitats, ecological functions, etc. are represented within its borders), the location, shape, and size of individual protected areas, and system-level attributes such as connectivity, evenness, and complementarity (Davey 1998; Forman & Collinge 1996; Forman & Godron 1981; Pressey et al. 1993). Operational aspects include management effectiveness, governance, and legal durability. Operational issues relating to Cambodia's conservation area system are addressed in the preceding chapter.

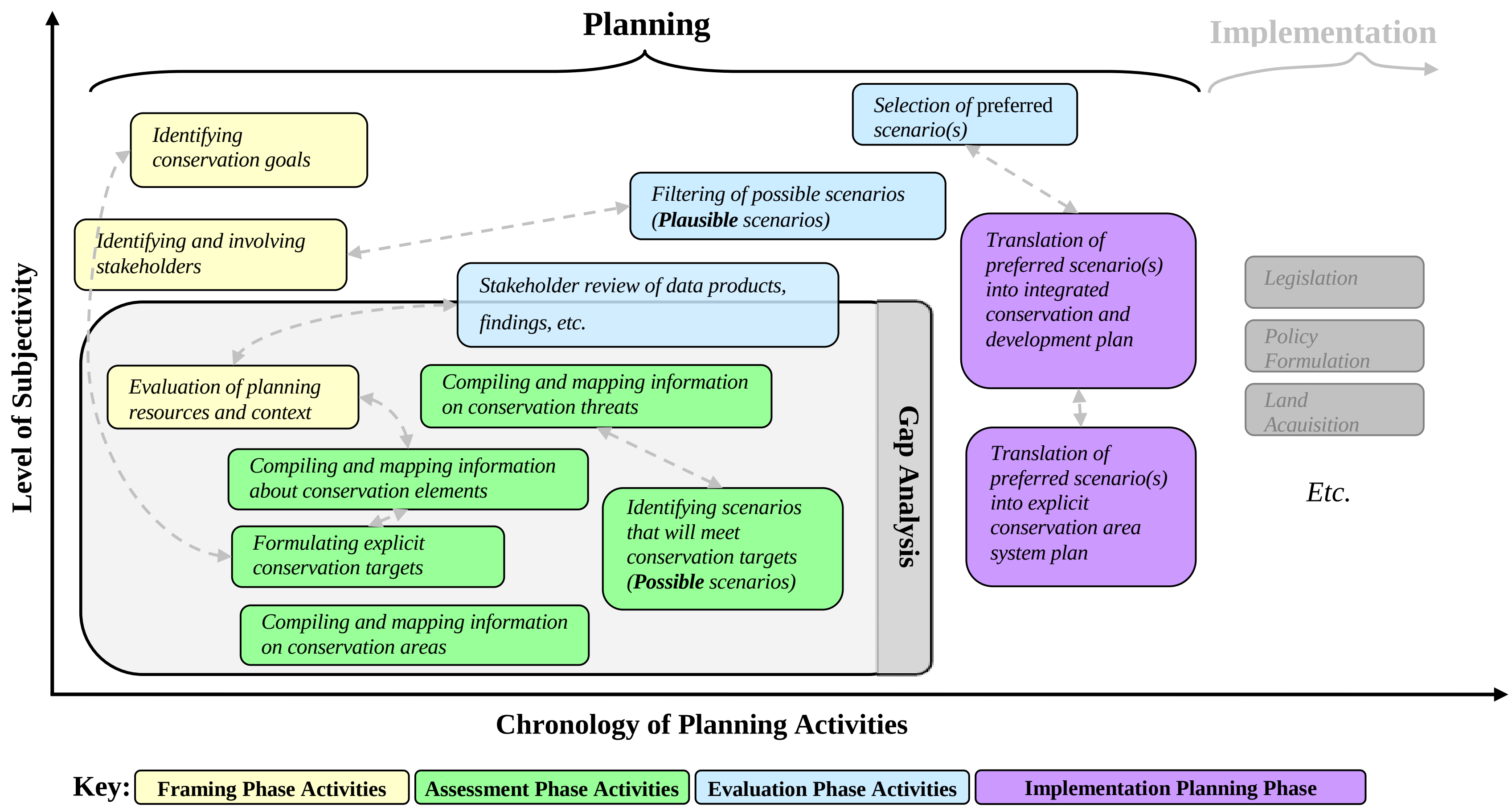


Figure 5-1. Conceptual diagram of activities commonly associated with gap analyses and systematic conservation planning efforts. General phases of systematic conservation planning are color coded. The shaded box indicates activities that are usually the domain of gap analyses. The horizontal axis represents a rough chronology of activities whereas the vertical axis denotes the relative level of subjectivity or deliberative process involved in that activity. Activities with strong feedback components are linked with a dashed line.

The process of identifying and prioritising design gaps in Cambodia's protected area system was inspired by the critical need for national-level strategic action in three key areas:

- the need to set priorities for **adjusting the boundaries of the protected area system** to address deficiencies in meeting the minimum protection needs of various conservation features,
- the need to identify priority sites ***within existing protected areas*** to inform more responsive and effective management at the site level (through zoning and other strategies), and
- the need to identify priority areas within which ***research and monitoring activities*** might fill critical gaps in information necessary to carry out effective planning and management.

Furthermore, a number of national and international level policies and recommendations strengthen the mandate for this activity. Cambodia: A National Biodiversity Prospectus (Ashwell 1997) details the need for and benefits of gap analysis as the basis for a comprehensive national conservation area system plan. The National Biodiversity Strategy and Action Plan (Cambodia Ministry of Environment & National Biodiversity Steering Committee 2002) reinforces this recommendation with specific action steps including reviewing the effectiveness of the existing system to secure key biodiversity sites. The recent Independent Forest Sector Review (Shields et al. 2004) recommends a "rationalization" of all forests under protection and call for systematic evaluation so as to better provide for an "evidence-based" understanding of the sector.

These goals are also reflected in Convention on Biological Diversity's (CBD) Programme of Work on Protected Areas which calls for all signatory countries to undertake gap analyses of their conservation area systems and to integrate these in similar regional efforts (Secretariat of the Convention on Biological Diversity 2005). This gap analysis, based on a compilation and assessment of current information, contributes directly to these goals.

Participation, Deliberation, and Review

Systematic conservation planning does not lead to a single solution to conservation challenges. The challenges themselves are often defined subjectively and the solutions often have as much or more to do with personal and societal values as they do with our ability to quantify and analyze the variables involved. For this and other reasons, planning can not be undertaken in a vacuum but instead must, from the outset, meaningfully engage the broad range of stakeholders who interact with the biodiversity and landscapes that are the reason for and the basis of the process. While gap analysis represents the more technical aspects of conservation planning, there are many points at which stakeholders—whether they be local residents, government representatives, or field biologists—must be participants in the procedures and decisions that make up the process.

My analysis represents an early stage of conservation planning in Cambodia and is therefore subject to additional review and evaluation by a wide range of stakeholders. However, it provides an important framework for evaluation and results that will likely prove to be robust as the process continues. Importantly, it provides decision-makers with explicit information on which to base urgent decisions about where to apply critically limited conservation resources.

Objectives

this gap analysis was conducted with the following objectives:

- Set explicit targets for the representation, configuration, and relationship of biodiversity features to allow for their indefinite persistence;
- Identify gaps in the effectiveness of Cambodia's protected area system to adequately represent and conserve these targets;
- Where such gaps occur, identify and prioritize potential areas where the application of effective conservation measures would allow for conservation objectives to be achieved;
- Demonstrate a systematic approach to identifying and prioritizing conservation action that can be used iteratively in an ongoing process of adaptive management and planning.

Study Area and Scope

This gap analysis was carried out over the entire extent of Cambodia's terrestrial boundaries and within a coastal and marine zone extending approximately 40 km from the country's coastline into the Gulf of Thailand (Figure 5-3).

In general, the analysis is a comparison of biodiversity patterns with Cambodia's conservation area system to assess the extent to which these patterns are adequately represented within that system. The term conservation area is used here in contrast to ***protected area*** due to the latter term's unique connotation in Cambodia. This special meaning stems from the distinction between 23 "protected areas" established together as a system in 1993, and other distinctive conservation areas (e.g. protected forests and biodiversity reserves) that have subsequently been established. The term ***conservation area*** is used in the broad sense to refer to any area being managed at least in part to preserve the biota that occur within their boundaries (Margules & Sarkar 2007). Furthermore, the analysis recognizes that only by considering the conservation area system (CAS) as a whole (together with the country's unprotected landscapes and all of the various uses and tenures associated with these areas), can Cambodia develop a truly effective and sustainable system for safeguarding its biological diversity and valuable ecosystem services.

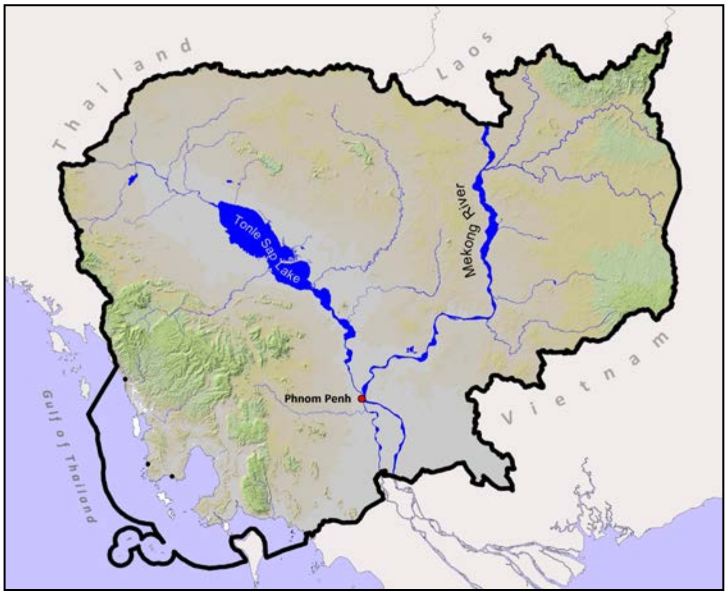


Figure 5-2. Areas of analysis: Cambodia mainland, offshore islands, and marine zone.

The goals of Cambodia's protected area system extend well beyond biodiversity conservation. The preservation of cultural and historical sites, the maintenance of local livelihoods, the provision of recreational activities and the maintenance of ecosystem functions and services are all important contributions and should be considered as part of overall system-level planning. However, given the primacy of biodiversity conservation in Cambodia's protected area system objectives, the time-bound mandates of the CBD Program of Work, limitations in the availability of non-biodiversity-related data, and the available timeframe, this analysis was limited to the biodiversity conservation functions of the conservation area system.

In terms of spatial scale, it is helpful to characterize conservation activities as taking place at (at least) the site, landscape, national, ecoregional, and global levels. ***Sites*** (such as blocks of similar habitat or entire protected areas) are often roughly homogenous in terms of ecological composition, have tightly interrelated natural systems, and are often under a single ownership or jurisdiction. These characteristics make sites uniquely robust from a planning and management standpoint.

In contrast, landscapes are large areas that often share a similar ecological setting but are usually composed of multiple sites with divergent ownership, landuse and administrative or management regimes. The size, shape, and spatial configuration of patches within a given landscape are important to understanding its properties and potential (Forman & Godron 1981).

Although rarely aligned with ecological patterns, national boundaries are the most fundamental de-facto global administrative unit for large-scale planning and policy. Many current efforts seek to minimize the impacts of divergent national policies and practices on landscapes and conservation efforts that span international boundaries.

Ecoregions (sometimes called bioregions) are:

> "large areas of land or water that contain a geographically distinct assemblage of natural communities that share a) a large majority of their species and ecological dynamics; b) share similar environmental conditions, and c) interact ecologically in ways that are critical for their long-term persistence" (Olson et al. 2001; Wright 1998).

These areas are linked in a functional way such that sufficient changes in one area can lead to substantial changes over the entire area.

Finally, conservation planning and implementation is increasingly being carried out at the global level. Understanding the contribution that sites, landscapes, and ecoregions make to global conservation objectives is useful for accurately assigning priorities to best achieve appropriate representation, complementarity, and redundancy in conservation efforts.

Within Cambodia, conservation planning and implementation in takes place within multiple sectors, at multiple spatial scales, and at many administrative levels (Figure 5-3). To maximize the benefits and value of a gap analysis, these relationships should be acknowledged and integrated into the planning process. Such integration will greatly improve overall stakeholder participation, avoid costly redundancy, and help establishment strategic linkages between a diverse yet interrelated set of activities.

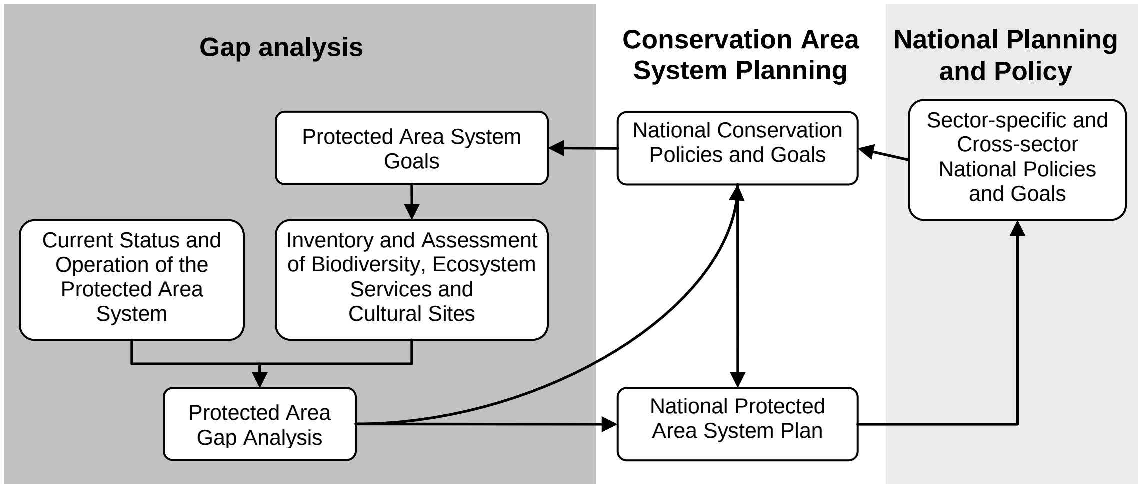


Figure 5-3. The relationship of this gap analysis to elements of national planning in Cambodia.

In summary, a national-level gap analysis is relevant and timely in several ways:

- It fulfils specific, time-bound activities of the CBD's Programme of Work on protected areas.
- It provides the basis for a National Protected Area System Plan by addressing biodiversity patterns and conservation needs at the country level – the level at which Cambodian laws and policies apply and at which the major agencies responsible for conservation planning and natural resource management operate.
- It synthesizes current knowledge of a broad range of conservation objectives and threats – including conservation of major habitats and globally threatened species in terrestrial, freshwater, and marine ecosystems - and uses objective criteria to translate that knowledge into explicit recommendations for conservation action.
- It serves as a focal point for the development of the capacity and information resources necessary to facilitate an ongoing process of conservation area system planning within the agencies directly responsible for that planning.
- It acknowledges practical constraints on the protected area system such as the overall size of the system and political and financial sustainability.
- It provides an objective basis for dialogue between relevant conservation area stakeholders at the country level and with others in the region.

Patterns of Biodiversity in Cambodia

Cambodia's total land area is approximately 181,373 km^2 and it shares its 2,438 km border with Thailand, Laos and Vietnam. Mountainous areas include the Cardamom and Elephant mountains in the southwest and portions of the Southern Annamites in the northeast – all of which have been identified as centers of relatively high plant endemism

(Schmidt 1989). Major hydrologic features include significant portions of the lower Mekong River, the renowned Tonle Sap Lake and surrounding floodplains. The diverse coastline stretches over 900 km (including island shorelines) and includes some of the most extensive mangrove forests in the region.

The seasonal flood cycle of the Mekong and Tonle Sap Lake has long provided Cambodians with a productive landscape and abundant natural resources. This unique ecological heritage serves as a key mechanism in driving and regulating water and nutrient cycles, maintaining soil resources and supporting of a wide range of natural products.

Efforts to survey and document Cambodia's biodiversity have intensified in recent years. Government agencies have been created to coordinate survey activities and manage resulting data and international non-governmental conservation organizations have developed dedicated country programs to initiate and support extensive survey and capacity-building activities.

Chapter 3 details a recent effort to explicitly map patterns of biodiversity in Cambodia. Using best practices in the field of conservation planning and extensive data from virtually every agency and organization conducting field surveys in Cambodia, explicit range maps are developed for 54 "Broad Habitat Units" (Cowling & Heijnis 2001), and 81 vertebrate species. This complementary set of "focal conservation features" is used as the basis for this gap analysis.

Threats to Biodiversity

Human activities have had a dramatic effect on patterns of biodiversity in Cambodia for thousands of years. For example, it is likely that much country's dry forest habitats are the result of human- initiated fire regimes that have taken place over centuries (Ashwell 1997; Wharton 1968)

Another dominant force in transforming Cambodia's landscape has been the development of extensive agricultural systems on the floodplains of the Tonle Sap Great Lake, the main course of the Mekong River, and Cambodian portions of the Mekong delta. Agricultural practices in these areas have long been heavily dependent on the annual flooding of the Mekong and Tonle Sap alluvial plains. Natural vegetation has been largely removed and replaced by flooded rice, rainfed rice and sugar palms. Fruit orchards continue to expand in upland areas and along the river verges.

While most people in Cambodia live more than ten kilometres from natural or semi-natural habitats, many people have maintained a dependence on forest products, particularly in the north and north-east. Wharton (1968) details aspects of the hunting and foraging practices of people in the forests of the northern plains. In addition to hunting for animals, more than 900 species of plants are used for food, animal feeds, medicines, veterinary medicines, construction, fibre, rituals, magic, ornamentation, charcoal, resins and other uses (Ashw(Smith 2001)ell 1997).

Levels of human impact and disturbance on natural systems vary widely both inside and outside of protected areas. To reflect this impact, a model was developed to classify all areas in the country as transformed, vulnerable, or remote based on the area's degree of naturalness and/or vulnerability to modification from a natural state. This model is briefly summarized here and described in detail in Chapter 3.

Three categories representing existing levels of impact or potential threat were used throughout the analysis to provide insight into the status of the focal conservation features and current and potential conservation areas. Table 5-1 summarizes the functional and technical definitions used to assign all areas of the country to one of these categories. Figure 5-4 is a graphic representation of the distribution and patterns that resulted from this part of the analysis.

Table 5-1. Classification of areas based on degree of human impact and/or vulnerability to degradation or transformation.

Category	Functional Definition	Expression in Model
Transformed	All areas fundamentally transformed from their natural state	• All areas mapped as built up areas (villages, towns and cities), areas under agricultural production, and lowland shrublands[13]
Vulnerable	All recently disturbed areas (since approximately 1990) or areas considered vulnerable to disturbance in the short term (within 5 years)	• All areas within 3 kilometers of village sites (village locations from JICA data and Dept. of Geography) • All areas within 1 kilometer of transport routes (routes from Department of Geography with additional data from various site inventories - not including remote cart tracks, seasonal dirt roads, or walking trails) • Impacted sites within protected areas (identified in the recent RAPPAM workshop (Lacerda *et al.* 2005))
Remote	All areas considered natural or semi-natural	• All areas not contained in the two categories above

[13] Based on the primary landcover map used in the analysis (see section 2.2.1).

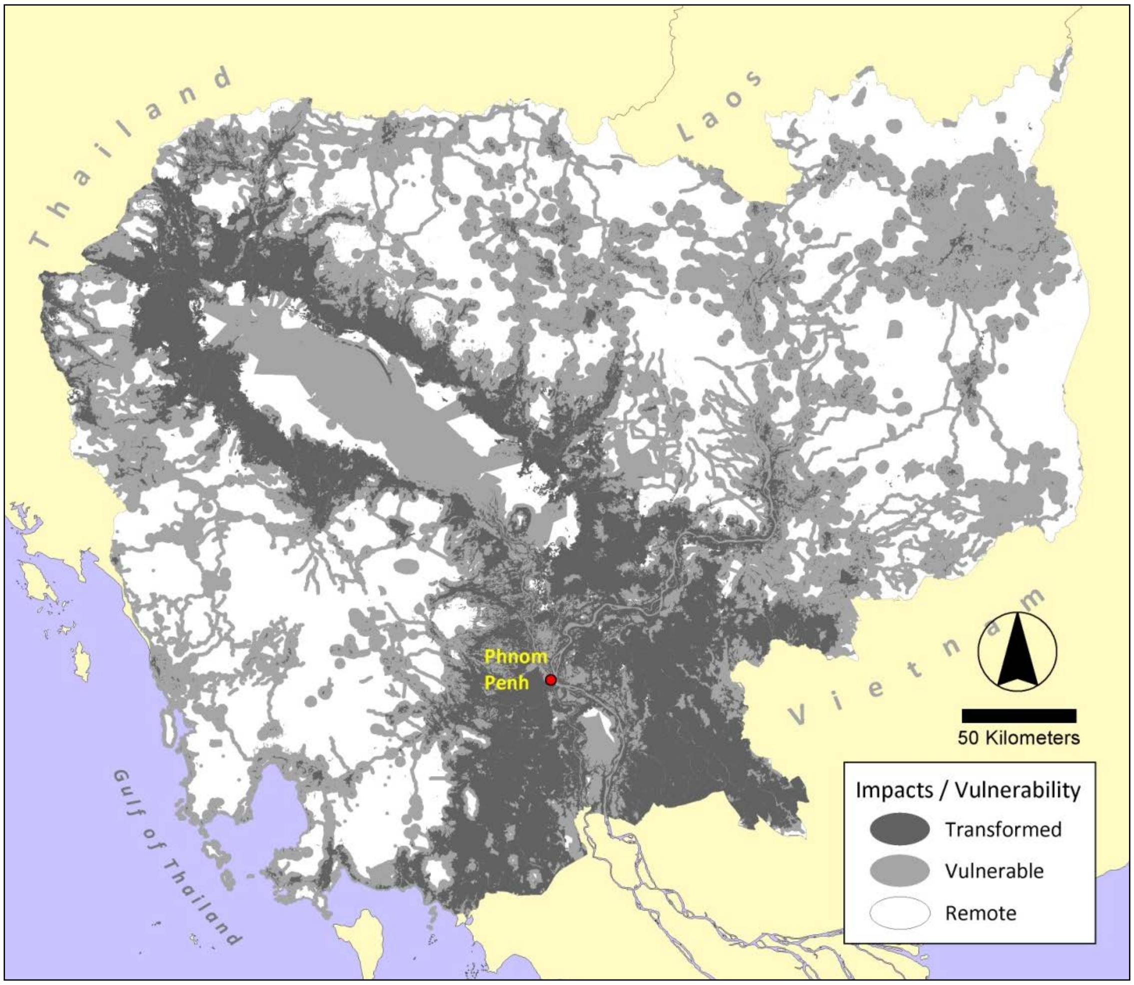


Figure 5-4. Map of modeled human impact patterns in Cambodia. See text for definitions of impact categories used.

Cambodia's Protected Area System

The composition and status of Cambodia's conservation area system are described in detail in the preceding chapter. The current protected area system covers over 47,083 km^2, or just under 27% of Cambodia's land area (Lacerda et al. 2005). The most significant changes to the protected area system in recent years have been the addition of several new protected forests. Table 5-2 provides a summary of the current conservation area system in terms of conservation area types, extent, and condition.

Table 5-2. Summary statistics for Cambodia's protected area system.

Name	Designation	Administrative	Area

		Responsibility	(km^2)
Kulen Promtep	Wildlife Sanctuary	Ministry of Environment	4,096
Lomphat			2,526
Boeng Per			2,497
Phnom Prich			2,242
Phnom Nam Lyr			549
Phnom Samkos			3,297
Phnom Aural			2,542
Snoul			753
Roniem Daun Sam			400
Peam Krasop			259
Virachey	National Park		3,342
Phnom Kulen			374
Kirirom			336
Bokor			1,499
Ream			184
Botum Sakor			1,834
Kep			28
Samlaut	Multiple Use Area		610
Dong Peng			286
Tonle Sap			3,314
Banteay Chhmar	Protected Landscape		848
Angkor			137
Preah Vihear			33
Stung Treng	Ramsar Site		149
Southern Cardamoms	Protected Forest	Ministry of Agriculture, Forestry, and Fisheries	1,451
Preah Vihear (FA)			1,900
Ang Trapeng Thmor			129
Mondulkiri			4,307
Central Cardamoms			4,007
Phnom Thmau			24
Kbal Chhay			64
Seima Biodiversity Conservation Area	Biodiversity Conservation Area		2,987
Koh Ker Historical Site	Cultural/Historical Site	Ministry of Culture and Fine Arts	79
		Total	**47,083**

While conservation and/or sustainable use of natural or cultural resources is a common objective of all conservation areas, the legal status and objectives of the various protected areas differs. Whereas those designated by Royal Decree may be considered “permanent” reserves, those designated as protected forests under the Forestry Law (largely by sub-decrees and *Prakas*) have less legal security as their official status can be altered through a decision of the Council of Ministers (see Chapter 4).

Methods

General Working Arrangements, Participatory Process, and Information Management

A public call for participation of government and non-governmental conservation stakeholders was undertaken as the first step of the gap analysis. Cooperative agreements with the Ministries of Agriculture, Forestry and Fisheries (MAFF), Meteorology and Water Resources (MoWRAM), and Land Management Urban Planning and Construction (MLMUPC) were established and these agencies provided essential information such as biodiversity occurrence records, digital maps, satellite images, and expert advice. These relationships also facilitated frequent dialogue and review of information products throughout the gap analysis process.

In Cambodia and the surrounding region, much work has already taken place to compile and synthesise biodiversity and threat information on the landscape, ecoregional, and national levels. Government agencies and their NGO partners provided a wealth of information ranging from locations of rare species occurrence to site reports and other expertise. Consultations and interviews with individual experts in various natural resource and development fields ensured that existing knowledge and experience directly informed the work. Four major workshops in different regions of the country provided information on impact patterns, conservation feature occurrence, and other information. Several technical roundtable discussions brought together stakeholders and specialists to conduct and/or review conservation feature selections and targets, to assist with mapping conservation features, and to provide expert advice with regard to various conservation features.

As much of the analysis relied on geographically explicit information, an extensive Geographic Information System (GIS) database was created and used frequently in the course of the project. Metadata for information sources used are summarized in Appendix 7.

Biodiversity Surrogates and Coarse and Fine Filter Approaches

Although the general objective of gap analyses is to identify gaps in biodiversity representation as comprehensively as possible, the complexity of biological systems and our limited understanding of much of that complexity dictates that we must focus on "surrogates" that can be mapped or otherwise explicitly quantified and which, if adequately represented, will presumably lead to the successful conservation of biodiversity more generally. A longstanding challenge has been to identify surrogates that perform well at representing broader patterns of biodiversity and there is a growing body of research dedicated to identifying effective surrogates (Landres et al. 1988). Much of the early work to address this challenge focused on species, traditionally called "indicator species" A biodiversity surrogate is thus an identifiable unit of biological organisation used to represent an element or elements of biodiversity that can not be readily measured or expressed individually due to limitations in knowledge or survey effort. For example, the extent and distribution of estuarine habitat may be used to describe the potential distribution of a number of species that can only survive in estuarine conditions.

Biodiversity is a hierarchical phenomena in terms of its components, structure, and functional aspects (Noss 1990). A growing appreciation of this has led to a simple but practical paradigm for conservation planners: that of coarse filter and fine filter approaches in selecting surrogates and conservation targets (Maddock & Plessis 1999; Stoms et al. 2005). Whereas coarse filter approaches focus on identifying and conserving biological units near the top of the hierarchy, ***fine-filter*** approaches focus on individual species, populations, or groups of ecologically similar taxa. Coarse filter approaches reflect the precautionary principle in that they focus on representing both rare and common elements and those both threatened and not. It has been estimated that that 85-90% of species can be protected through the use of coarse filter methods (USGS Gap Analysis Program 2005). In contrast, fine filter approaches—most appropriately applied subsequent to a coarse filter, are usually designed to meet the specific conservation requirements of individual species (Eken et al. 2004) whose conservation needs are not likely to be met through coarse filter approaches alone. A number of studies have demonstrated the complimentarity of these two approaches and using both is widely recommended as best practice when the goal is to represent biodiversity in a general sense (Dudley & Parrish 2006; Maddock & Plessis 1999).

Both coarse and fine filter approaches were used to establish a discrete set of biodiversity features to serve as the basis for this analysis. To achieve a set of features representing the coarse filter, procedures mirrored those of Cowling and Heijnis (2001) who used a combination of mapped vegetation cover, geological substrate, climate patterns, and expert advice and review to identify 102 “Broad Habitat Units” (BHUs) for the Cape Floristic Region of southern Africa.

To identify a similar set of BHUs for Cambodia, I used parallel procedures for the country’s terrestrial, freshwater, and marine ecosystems. To derive terrestrial BHUs, I combined information from three relevant maps: a recent national land cover classification, a map of physiographic/climate zones resulting from a detailed study of the country’s chief floristic zones, and a detailed map of the country’s surface geology. Expert review of the resulting categories narrowed a large list of types to a final set of 35 terrestrial BHUs. In the freshwater and marine ecosystems, the selection of BHUs was more constrained by the availability of relevant data that have been mapped consistently throughout these ecosystems. However, within this constraint, 10 distinctive freshwater and 9 distinctive coastal/marine BHUs were identified. In all cases, the classification process attempted to maximize the following:

- Ecological distinctiveness at a resolution appropriate for reflecting major patterns in biodiversity at a national level
- Consistency with published literature
- Consistency between the habitats defined and available mapped data
- Consistency with existing classification systems

Criteria for including species as focal conservation features included global rarity and endangerment, endemism, and the proportion of globally and regionally significant populations occur within Cambodia.

A more detailed treatment of feature selection and definition procedures and a complete set of features used in the analysis together with explicit conservation targets is presented in the results section below.

Setting Conservation Targets

A ***conservation target*** is a clear statement of a *desired* status, outcome, amount, or functional effectiveness of a species, habitat or other conservation feature against which its *current* status can be compared. Objectives can be quantitative or qualitative but should be as explicit as possible (Margules & Pressey 2000) to facilitate specific conservation action. In the context of protected area gap analyses, targets are usually expressed as a desired fraction of the total mapped extent of each conservation feature in the surrogate set (Dudley & Parrish 2006; Margules & Sarkar 2007).

Although conservation areas are usually a central component of a broader biodiversity conservation strategy, other conservation mechanisms can play important roles. Whereas formal conservation areas should represent the primary means of meeting the conservation needs of some features, those of other features' needs may be more appropriately met through a combination of other mechanisms such as the modification of agricultural practices or through the captive rearing of otherwise vulnerable young. In practice, most features' conservation needs are best addressed through a combination of protected areas and other conservation measures.

Pressey et al. (2003) suggest a strategy whereby representation targets for focal features vary according to each feature's "biophysical heterogeneity, rarity, reliance on the region for persistence, and threats from agriculture, urbanization, and invasion of alien plants." Using similar considerations, conservation targets for this analysis were developed based on each feature's spatial rarity (e.g. few or very focused occurrences vs. extensive and/or numerous occurrences), the primacy that inclusion in a formal conservation area has for that particular feature, and Cambodia's share of the feature's regional distribution. For example, whereas conservation measures are certainly critical for the protection of black-necked storks, it has been shown that effective conservation of this species can be achieved in part by bringing some areas under formal conservation and implementing appropriate land use policies on other seasonally flooded agricultural lands (Sundar 2004). Such a strategy has recently been pursued in meeting the conservation needs of both sarus cranes and Bengal floricans (International 2006) over significant portions of their Cambodian ranges.

Table 5 summarizes the minimum target representation for 6 general categories of conservation features based on the principles outlined above. Targets are expressed as a desired percentage of the documented area of occurrence of a feature that should fall within a formal conservation area network.

Table 5-3. Summary of minimum protection objectives for four categories of conservation features. Numbers represent targets for the amount of documented area of occurrence that should be protected through conservation area mechanisms.

Spatial Distribution or Conservation Significance	Ecological Classes	Species / Subspecies	Examples

Spatially concentrated Features and/or those of of critical Global or Regional Significance	**≥ 50 %**	**≥ 70 %**	• Congregatory waterbirds • Estuarine-dependent species • Submontane dry evergreen forests • Submontane grasslands • Evergreen forests on basalt-derived soils • Mangrove areas • Seagrass beds • Features once wide-ranging but now greatly reduced • flooded forests • Banteng • Green Peafowl • Irrawaddy dolphin (Mekong subpopulation)
Spatially Extensive Features with Clear Conservation Area Needs and/or those of of critical Global or Regional Significance	**≥ 25 %**	**≥ 40 %**	Species commonly identified as "Landscape species" (sensu Sanderson et al (2002b)). A realistically-sized conservation area system is likely to be too small to encompass all of the area or other conservation needs of these species *Extensively occurring features:* • Chestnut-headed Partridge • elephant • sun bear • tiger *Dispersed distribution features* • Vultures • Crocodiles • Lowland Dry Evergreen Forests on Sandstones
Spatially Extensive Features Whose Conservation Requirements Can be Substantially Met Through Other Conservation Mechanisms	**≥ 10 %**	**≥ 20 %**	• Semi-evergreen and deciduous forest mosaic with riparian (or gallery) forest strips • Lowland moist evergreen forests on sandstone secondary forest formations • Asian White-backed Vulture

Identifying Gaps

The distribution of conservation features (e.g. species and broad habitat units) and their coincidence with Cambodia's current conservation area system provided the fundamental basis for this analysis. I used the ArcView GIS software package to perform geospatial operations relating to the fundamental gap analysis procedure—the comparison of mapped conservation features to the boundaries of Cambodia's protected area system. This was achieved by performing a spatial "union" operation of protected area boundaries and each mapped feature. To further inform the conservation status of each feature, I used previously processed data representing levels of impact within the extent of each feature (see Chapter 3). These steps facilitated the calculation of 6 distinct categories of protection and impact with regard to each feature (see Figure 5-5). Resulting data were then tabulated to facilitate additional summary and reporting.

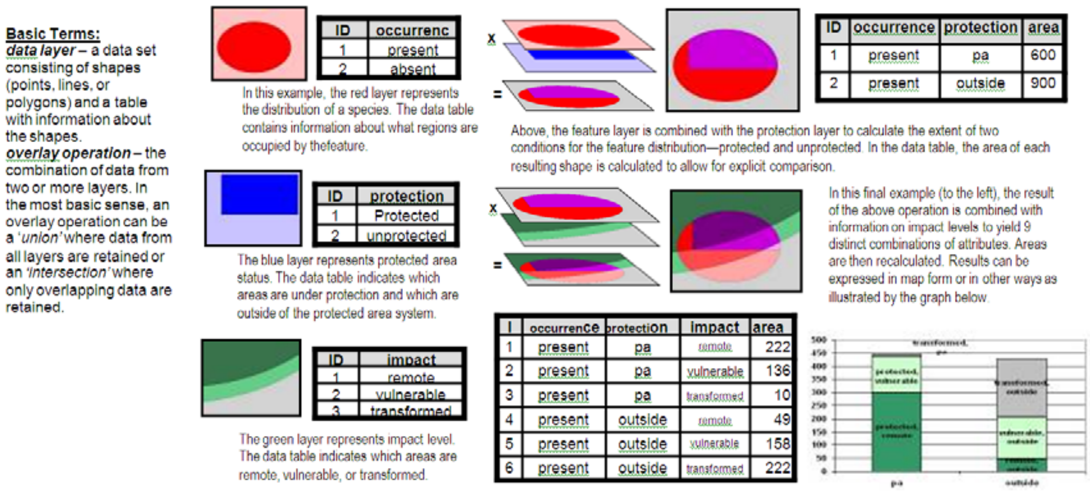


Figure 5-5. Summary of geospatial procedures used to characterize the status of 135 focal conservation features.

Based on these quantitative data and expert review, each feature was assigned to one of five qualitative categories (Table 5-4) for reporting purposes.

Table 5-4. Characterization of focal conservation features in terms of representation in the current protected area system.

Code	Protected Area Conservation Status of Conservation Feature	Explanation
1	**No viable** representation	The PA system contains no viable example of this feature.
2	**Inadequate** representation	Current representation of this feature in the protected area system is likely insufficient to provide for long-term viability.
3	Adequate but significantly **Compromised** representation	The feature is adequately represented but its occurrence is compromised to an extent where urgent conservation action is required to increase the effectiveness of protection in areas where it occurs.
4	**Adequate** representation	The PA system adequately represents and protects this feature.

5	**Surplus** representation	Based on the condition, vulnerability, overall extent, and protection status of this feature, the current amount of representation within the protected area system is not justified in some areas where this is the only focal conservation feature represented.

Additionally, tables include a graphic representation of the feature showing relative proportions of the feature within and outside of the current protected area system and levels of impact and vulnerability within these first two categories (Figure 5-6).

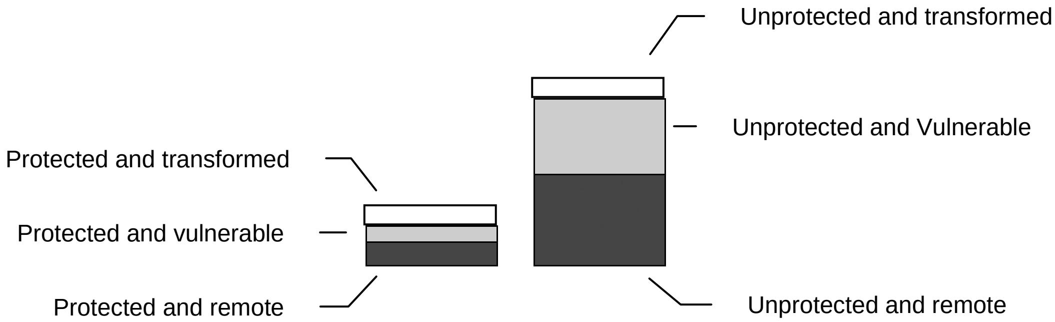


Figure 5-6. Key to the graphic summaries of conservation feature status.

The left division of the graphic represents the relative proportion of the entire extent of the feature falling within conservation area boundaries, and the right division the relative proportion in unprotected areas. Within these categories, the vertical layers represent relative proportions of remote (bottom-dark), vulnerable (middle-lighter), and transformed (top-white) disturbance/vulnerability categories.

Data on protection and condition were also summarized by ecosystems and major taxa of focal species.

Identifying Options for Filling Gaps

I used the Marxan software package (Ball & Possingham 2000) in combination with the CLUZ interface (Smith 2000) for ArcView GIS 3.3 (ESRI 2002) to carry out a simulated annealing solution-finding algorithm to identify priority areas where conservation action would most effectively contribute to satisfying multiple specified conservation targets. Marxan is one of several widely-used programs used to address this challenge (Sarkar et al. 2006). The CLUZ interface provides a convenient map interface for users of Marxan so that settings can be easily adjusted and results rapidly loaded and viewed. Using a set of discrete planning units with associated cost and feature occurrence data, Marxan's simulated annealing procedure uses a series of consecutive steps (usually tens of thousands) within which subsets of candidate units are evaluated in terms of their contribution to an objective function that seeks to satisfy conservation targets in a cost-efficient (or area-efficient) way. Through many iterations, the algorithm finds near-optimal solutions to the objective function. Specifically, Marxan is designed to minimize the following quantity:

$$\underbrace{\sum_{PUs} Cost}_{\text{Planning Unit Cost}} + \underbrace{BLM \sum_{PUs} BL}_{\text{Boundary Cost}} + \underbrace{\sum_{ConsValue} CFRF \times CFPenalty}_{\text{Conservation Feature Representation Penalty}} + \underbrace{CostThresholdPenalty(t)}_{\text{Cost Threshold Penalty}}$$

Where:

Cost = Cost assigned to each planning unit

BLM = Boundary length multiplier

Boundary = boundary length of any "external" boundaries

CFRF = Conservation Feature Representation Factor (a feature-specific multiplier set so that targets of features of higher significance are more likely to be met than those of lower significance)

CFPenalty = the base penalty to be adjusted by the CFRF on a feature by feature basis. This quantity is roughly equivalent to the cost of the group of planning units necessary

CostThresholdPenalty = A penalty applied

t = Proportion of overall algorithm completed

The **Cost** term is simply the sum of the cost assigned to each planning unit. The **Boundary Cost** term works to penalize networks that are fragmented and therefore expensive to manage. The **Conservation Feature Representation Penalty** term allows for features to be "preferred" by the objective function so that targets of features considered relatively more essential will have a higher likelihood of being selected when other constraints limit the achievement of all targets. Finally, the **Cost Threshold Penalty** term provides for the search for efficient solutions in situations commonly known as the "maximal coverage problem" where either the cost or size of the network is constrained.

The objective function-minimizing algorithm in Marxan provides a systematic means to achieve multiple goals in the identification of conservation networks. Chief among these goals are representation and complementarity. Whereas representation seeks to ensure that every conservation feature is represented in a network of conservation areas, complementarity seeks to identify areas that are as diverse in conservation feature representation as possible. In the case where a system is limited in terms of available area or resources, the objective function will prioritize the selection of rare and/or threatened features such that conservation action can be scheduled in a systematic and defensible way. Conditions of individual features (such as the need to conserve a contiguous block of habitat of a minimum size or to have occurrences of feature be separated by a minimum distance) can also be assigned to reflect biological requirements or feature-specific conservation goals. Due to time and data limitations, these constraints were not implemented in this analysis.

I used standard procedures (Game & Grantham 2008) to construct a set of planning units with the appropriate resolution for planning at the national level, I first constructed a hexagonal grid covering the entire country as well as a marine area of analysis described earlier. Hex units were approximately 10 km^2 in size. I then used a union operation with the boundaries of Cambodia's current conservation area network so that conservation area legal boundaries could be explicitly acknowledged in planning. Once the planning unit network was established, I used procedures available in the CLUZ interface to calculate the area represented in each planning unit by each of 135 previously mapped focal conservation features.

The cost of conserving areas usually depends on a combination of factors—many of which defy straightforward quantification. Since the objective is usually to identify priorities however, relative cost schedules are sufficient for most site selection algorithms. Methods of assigning costs to planning units include simply setting costs equal to area (Game & Grantham 2008), using land lease or acquisition costs (Knight & Cowling 2007; Polasky et al. 2001), estimating opportunity cost (e.g. the cost of lost opportunity to pursue other land uses) (Naidoo & Adamowicz 2006; Nelson et al. 2009), estimating relative willingness to undertake conservation action (Game & Grantham 2008; Winter et al. 2005), and estimating the costs associated with mitigating threats to desired conservation features (Davis et al. 2003; Game & Grantham 2008). In identifying priority areas in the Sierra bioregion, Davis et al. (2003) used ecological condition and proximity to potential threats as a surrogate for costs associated with mitigation.

I assumed that in Cambodia, costs of conservation will be closely related to the present condition of an area (current level of impact) and the proximity of an area to sources of human impact such as roads and towns (future vulnerability). However, I also recognized that land values vary dramatically from one part of the country to another. Combining these two ideas, I derived a cost structure that combined estimated land values with the human impact model (see above) to arrive at a composite cost for each planning unit.

I calculated land values (at the resolution of individual communes) based on the following estimated relationship between national patterns of human density and approximate 2007 per meter land prices in a number of representative locations (Sun Hean, pers. comm.):

Population Density of Commune (people / km^2)	**Land Cost (Millions of US$ /Km^2)**
0-9.9 (and all marine areas)	0.5
10-49.9	1
50-99.9	2.5
100-199.9	5
>200	10

Relative restoration and management costs were calculated using proportions of transformed and vulnerable area from the impact model. This quantity was calculated as follows:

Restoration and Management Cost/Km^2 = (*Proportion of Area Transformed + (0.5 * Proportion of Area Vulnerable)) * 10*

These quantities were then combined using the following equation:

Relative conservation cost = *Area (Km^2) * (Land Cost (Millions of US$/Km^2) + (Restoration and Management Cost/Km^2)*

…to produce a cost surface with values ranging from near 0 (e.g. very small remote units created at the margins of the coverage and around protected area boundaries) to ~200 million dollars (e.g. completely transformed areas of very high land value).

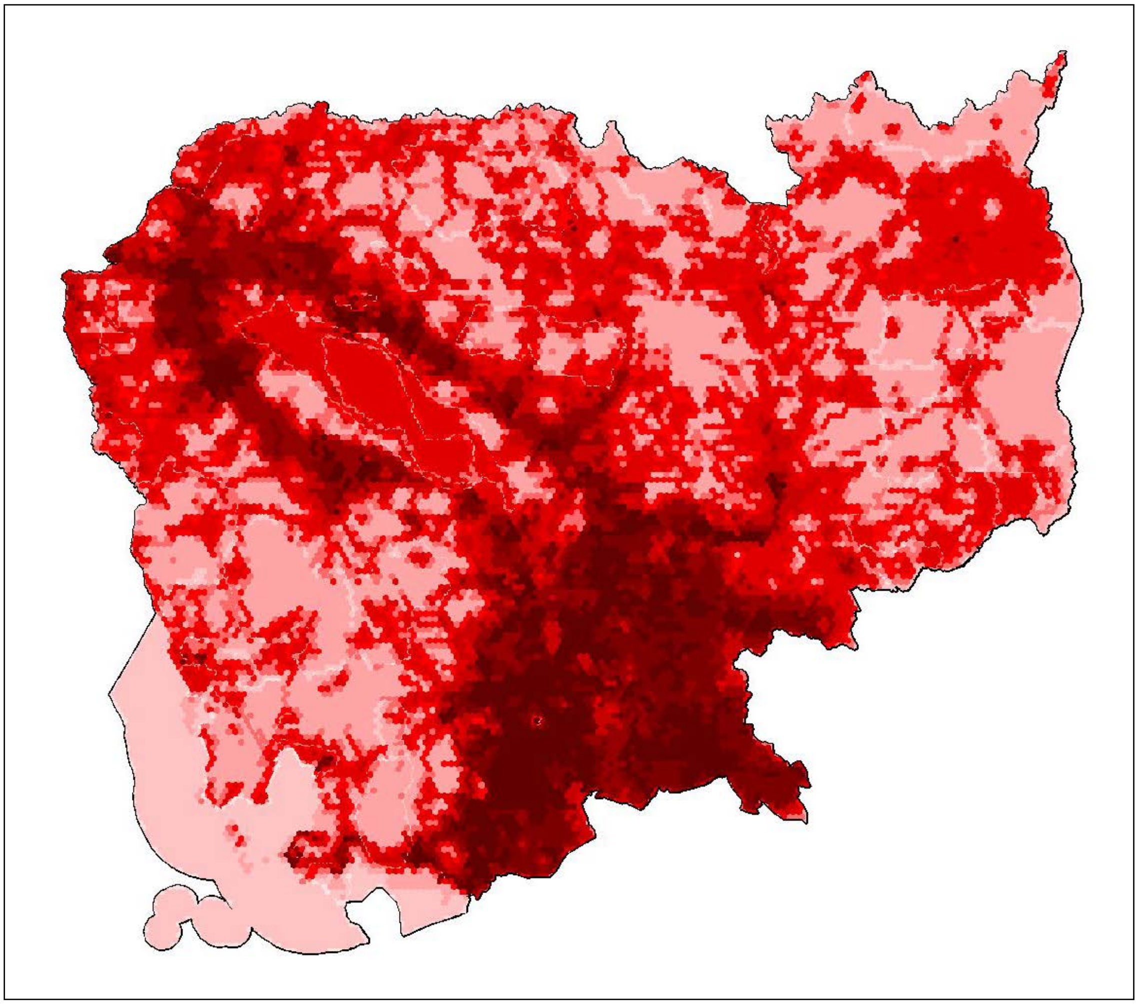


Figure 5-7. Estimated relative cost of conserving planning units in Cambodia. Cells range in value from approximately 5 Million dollars (lowest) to 200 million dollars (highest).

I used the boundary length penalty factor setting in Marxan to force the algorithm to find solutions with larger and more interconnected networks so that solution sets would be composed of a realistic set of larger sites made up of multiple planning units. The following table summarizes the logical basis and actual values for other settings required by the Marxan algorithm.

Table 5-5. Technical basis and operation details for variables used to carry out a simulated annealing algorithm in Marxan.

Marxan Variable	Strategy and Precedent	Final value / Range of Values
Planning Unit Size and Configuration	Balancing of specificity (for planning purposes) with what the resolution of data could support.	~10 km2 hex grids

Cost	Combined land value and impact index (see above)	Based on suggestions in -PP highest value may be as much as $500/m2 but these are estimates of average cost throughout the communes
Boundary Length Modifier	Set by identifying the “break point” of a of graph of BLM against reserve size and visual inspection (Stewart & Possingham 2005)	0.005
Non-Representation Penalty factor	Set using protocol in Game and Grantham 2008, others	3 for focused, threatened, underrepresented features 2 for other threatened features 1 for everything else
Annealing Settings	Comparison of	1,000,000 iterations 10,000 temperature decreases
Target success tracking	Set below 1 to accommodate issues with planning unit geometry	Counted as conserved if within 95% of target

Identifying Priority Conservation Sites

Irreplaceability has been defined as the percentage of possible conservation networks in a set in which a particular planning unit occurs (Pressey et al. 1994). As the number of sites that can potentially contribute to meeting a given conservation target decreases, the irreplaceability of such sites increases. One useful output of the Marxan algorithm is a measure of each planning unit’s ‘selection frequency’ (e.g. the number of times each unit was selected in the optimized solution of each iteration) which can be interpreted as representing the irreplaceability of individual units (Game & Grantham 2008). It is important to note that Irreplaceability is an “ephemeral” measure that changes when any element of system-wide conditions change (e.g. when one or more sites are conserved, when the condition or distribution of one or more features changes, or when knowledge of one or more features changes). This dynamic nature of conservation planning necessitates that gap analyses and the priorities they identify be seen as iterative steps in a continuing process rather than one-off products (Margules & Sarkar 2007).

I used “selection frequency” values calculated in the Marxan algorithm as the basis for identifying a discrete set of priority conservation action sites. To increase the robustness of the priority site identification procedure, I summed irreplaceability scores from two optimized scenarios (one representing an “unconstrained” optimum network ignoring current protectin and one built from the existing system) to define an irreplaceability surface where cells frequently selected by both of the two scenarios had the highest values. I then used a color-coded map representation of 10 levels of these scores to identify areas where at least 3 contiguous cells of the highest level occurred in areas outside of the curren conservation network (Figure 5-8). At each site I followed the approximate contour containing the highest three levels to hand digitize priority areas.

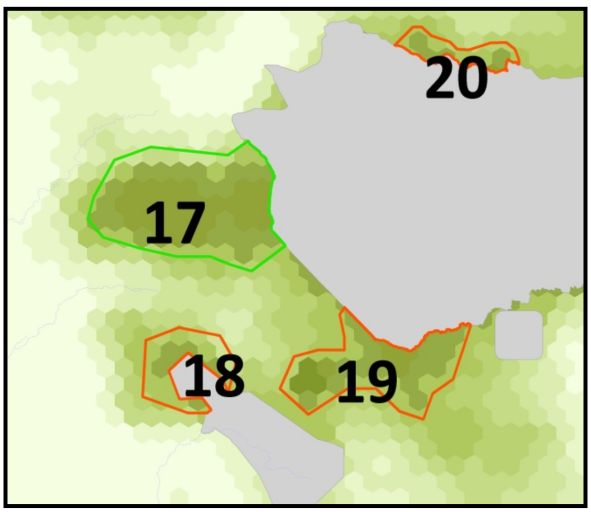


Figure 5-8. Example of procedure used to delineate priority conservation sites outside of the current protected area system. Selection frequency for each cell is identified through multiple runs of Marxan's simulated annealing algorithm. Dark green hexagons were selected in almost all solutions and therefore represent areas where relatively few other options could make the same contribution to the conservation area network. Lighter hexagons are planning units selected less frequently due to the fact that there are more numerous possible units that might make similar or greater contributions to any number of potential conservation networks.

Scheduling Conservation Action

I used measures of both irreplaceability and ***vulnerability*** to assign relative conservation action urgency to each priority conservation site identified. Vulnerability refers to the likelihood that the condition of a site or feature will decline or become completely unviable. Vulnerability has at least three distinct aspects. ***Inherent vulnerability*** arises from characteristics or site itself or the features that occur there. For example, the economic value of tree species or the relative susceptibility of a fish species to disease in polluted waterways. ***Geographic vulnerability*** can be used to describe the susceptibility sites or features due to their proximity to threats (e.g. streams that pass through urban areas are particularly vulnerable due to their proximity to industry and intensive anthropomorphic activities). Finally, ***political vulnerability*** may be used to describe susceptibility to transformation due to land tenure and land use policies and patterns. The procedures used to set the cost of planning units reflects all three of these types of vulnerability. As the relative vulnerability of a conservation feature or site increases, so does the urgency for conservation action.

Measures of ***irreplaceability*** and ***vulnerability*** are commonly used for assigning relative urgency of conservation action (Margules & Pressey 2000). Sites representing the only place (or one of a very few places) where one or more features occurs are considered highly irreplaceable. When these areas are also highly vulnerable, they represent a clear priority for conservation action because there will be no option for achieving at least one goal as soon as they become unsuitable for supporting the features of interest. Sites with relatively less irreplaceable features but that are still highly vulnerable should recieve attention as a matter of secondary urgency. Sites that are highly irreplaceable but not threatened (e.g. remote mountain areas) should get receive tertiary conservation attention. All other sites ranking low in terms of both irreplaceability and vulnerability should receive conservation attention as a matter of last priority. Figure 5-9 provides a graphic illustration of how four levels of priority can thus be assigned.

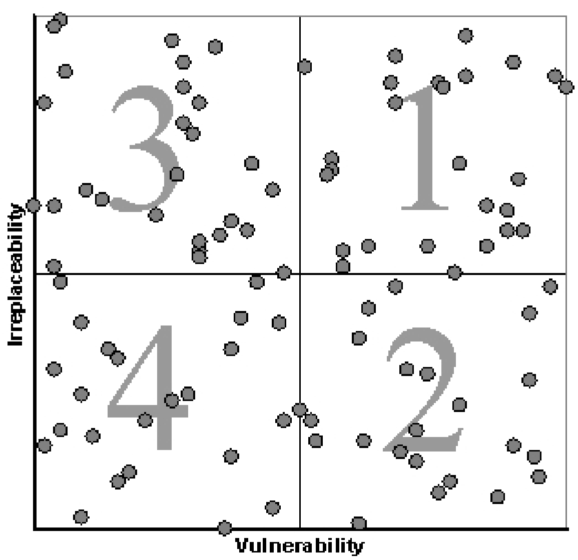


Figure 5-9. Using irreplaceability and vulnerability as the basis for assigning conservation priority to a set of sites. Dots represent discrete sites. Numbers indicate the order in which limited conservation resources should be applied. Note that irreplaceability and vulnerability values of all sites are subject to change when any one site either comes under protection or loses conservation value (e.g. due to degradation or other reasons).

I used these concepts and a simple irreplaceability and vulnerability scoring system to assign conservation urgency to the set of priority conservation sites identified in the previous step.

Score	Irreplaceability	Vulnerability

1	Sites with features unrepresented elsewhere or represented in only one or tow other areas	Sites near areas of rapid environment transformation
2	All other sites	All other sites

In addition to assigning urgency, I further classified sites into five categories based on their configuration or the role that they could potentially play in meeting the broad design objectives of the conservation area network. In this way, I characterized each site as an extensive contiguous block of high irreplaceability, an important corridor area, an important marine zone, or a smaller site representing an extension from an existing conservation area or smaller isolated site.

Contrasting Network Performance

I used Marxan to identify a number of hypothetical network scenarios and conditions in an effort to demonstrate the “efficiency frontiers” (Polasky et al. 2005) of networks with different constraints and to compare these with the existing network. I used several measures of network performance including the number of targets successfully met (grouped into BHU and species target categories), cost, area, and an impact index (derived from the human impact model) to contrast potential conservation networks resulting from a range of assumptions and conditions.

The starting point for this part of the analysis was characterizing the current conservation area network in terms of each descriptor. I then used Marxan to find the most efficient way to build off of the existing network until all targets were satisfied. Next I explored the performance of networks arrived at if Marxan was constraining by the cost of the existing network and then by its area. I then removed allconstraints to identify a network representing all targets in as efficient way as possible. To assess the performance of subsets of features to serve as effective surrogates for other other elements of biodiversity, I used Marxan to find near-optimal conservation networks based only on species targets and then only on broad habitat unit representation. I calculated descriptors for two explicit sets of conservation priority areas that have been proposed in recent years: a set of Important Bird Areas (IBAs) resulting from a mapping and deliberative process carried out in 2003, and a more recent set of Key Biodiversity Areas specified as part of an ecoregional assessment carried out between 2004 and 2005. For comparative purposes, I also calculated the performance of networks that combined these proposed priority sites with the existing conservation area network. Table 5-6 summarizes the definitions of these alternative networks.

Table 5-6. A comparative set of existing, proposed, and modelled conservation networks.

Actual or Conditional Conservation Landscape	Insights Sought (Key Questions)	References
Current CAN	Baseline for comparison with other strategies to meet conservation objectives	See Chapter 4
Building on current CAN cost-efficiently until all targets satisfied	Areas identified represent perhaps the most relevant sites for immediate conservation action	
Most target-efficent network constrained by the <u>cost</u> of the current CAN	Provides additional perspective assessment of the current network's effectiveness meeting biodiversity objectives (How much more efficient could the network be if the current cost were redistributed?)	
Most cost and target-efficent network constrained by the <u>area</u> of the current CAN	Provides additional perspective in the assessment of the current network's –cost-effectiveness (How much more efficient could the network be if redistributed over a similar area?)	
Most cost and target-efficent network for achieving all conservation targets (unconstrained)	Provides additional perspective in the assessment of the current network's overall performance (How much more effective could the network be on multiple criteria if the objective was only to reach all conservation targets?)	
Most cost-efficent network for achieving BHU conservation targets	Provides perspective on the performance of the broad habitat units to act as surrogates for vertebrate species diversity (Could we use habitat units alone to achieve biodiversity conservation objectives?)	
Most cost-efficent network for achieving species conservation targets	Provides perspective on the performance of species targets to act as surrogates for representing the diversity of broad habitat types (Could we use species targets alone to achieve general biodiversity conservation objectives?)	
IBAs (2003)	Allows for objective assessment of a process lacking in modularity and transparency	(Hout et al. 2003)
IBAs+ Current CAN	Allows for objective assessment of a process lacking in modularity and transparency	
KBAs (2005)	Allows for objective assessment of a process lacking in modularity and transparency	(Tordoff et al. 2005a)
KBAs + Current CAN	Allows for objective assessment of a process lacking in modularity and transparency	

Results

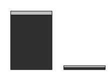
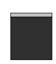
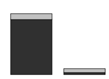
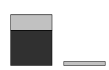
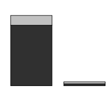
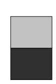
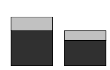
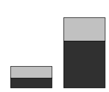
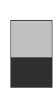
Focal Feature Gap Summary

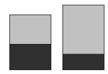
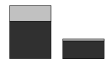
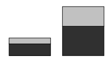
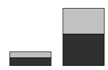
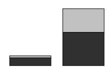
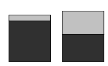
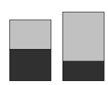
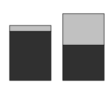
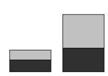
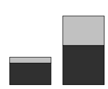
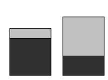
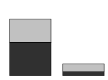
This section presents all 135 focal conservation features considered in the analysis in terms of each feature's overall distribution and extent, the representation target that was assigned to that feature, the features current status with regard to that target and overall impact patterns, and notes on which areas are particularly important areas for the conservation of that feature. Reporting is by general ecological realm (e.g. terrestrial, freshwater, and marine).

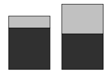
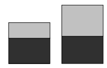
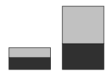
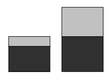
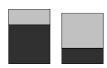
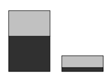
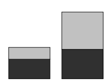
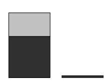
<u>Terrestrial BHUs</u>

Overall representation of terrestrial habitats within the protected area system is quite good. Additionally, large areas of relatively intact habitat outside of protected areas provide opportunity to link protected areas with landscape corridors that are sustainably managed. However, there are a number of terrestrial vegetation types for which additional protection is needed including a number of lowland forest formations.

Table 5-7. Distribution patterns, representation targets, status, and options for addressing representation gaps for focal terrestrial ecological classes.

Feature	Spatial Pattern	Representation Target	Current Protection Status	Options for Addressing Gaps
Sub-montane moist evergreen forests on sandstone	Extensive	25	 ***Adequate.*** Well represented in MoE protected areas. Protection forests provide additional and comprehensive protection.	Inclusion of remaining areas could contribute to corridor development between Central Cardamoms and Kirirom.
Sub-montane moist evergreen forests on volcanics		50	 ***Adequate.*** Principal locations are the focus of two protected areas where they have generally low vulnerability to recurrent disturbance.	Not required.
Sub-montane dry evergreen forests	Highly Localised	50	 ***Adequate.*** Principal locations are the focus of two protected areas where they have generally low vulnerability to recurrent disturbance.	Not required.
Sub-montane semi-evergreen forests		50	 ***Adequate.*** Principal locations are the focus of two protected areas. Generally low vulnerability to recurrent disturbance.	Not required.
Sub-montane shrublands		0	 ***Adequate.*** Almost entirely within protected areas. Generally low vulnerability to recurrent disturbance.	Not required.
Sub-montane grasslands	Localised	50	 ***Adequate.*** Areas in south-west almost entirely within protected areas with those in north-east adequately represented.	Not required.
Lowland moist evergreen forests on sandstone	Extensive	25	 ***Compromised.*** Well represented in MoE protected areas except in rain shadow areas. Entire community subject to logging over recent years with some areas vulnerable to recurrent disturbance and infrastructure development. Some areas need rehabilitation.	Options for maintenance of full diversity associated with elevation gradient need clarification. Condition of vegetation needs to be maintained and/or enhanced if target is to be maintained as road and hydropower infrastructure is developed.
Lowland moist evergreen forests on old alluvial pediments	Highly Localised	50	 ***Inadequate.*** Protected areas not considered viable due to high degree of degradation and fragmentation.	Areas east of Bokor national park and the northern reaches of the Kampong Saom river.
Lowland moist evergreen forests on limestone		100	 ***No viable representation.*** Site isolated and outside protected areas	Singular site is small and isolated. Provincial reservation be the more viable form of protection.

Lowland moist evergreen forests on basalt		50		***Compromised.*** Well represented in MoE protected areas with additional protection in protection forests. Generally vulnerable and of economic interest.	Sites around Choam Sla and Areng suitable for corridor development between Central and Southern Cardamoms protection forests.
Lowland moist evergreen forests on other volcanics		50		***Adequate.*** Well protected in MoE protected areas with additional protection in protection forests.	Not required.
Lowland dry evergreen forests on old alluvial peneplains	Extensive	50		***No viable representation.*** Currently reserved areas are subject to heavy logging and land clearance with some areas within protection forests being considered for commercial production.	Primary forest in Prey Long are the only remaining viable site for this forest type.
Lowland dry evergreen forests on old alluvial pediments	Extensive but fragmente d	50		***Inadequate.*** Represented within protected areas but generally vulnerable. Major site occurred in the now degazetted and heavily degraded portion of Roniem Daun Sam.	Small area near Spean Kbal and contiguous with Phnom Kulen national park.
Lowland dry evergreen forests on sandstones	Extensive	25		***Compromised.*** Largely unrepresented within protected areas except on the plains where vulnerable to fire.	Phnom Tbeng and Dangrek Range for mountain communities. Areas around Phnom Colapuok for forests on plains
Lowland dry evergreen forests on limestones	Highly localised	50		***Compromised.*** Karst formations poorly represented in protected areas and generally vulnerable. Areas frequently with high economic significance.	Options unclear and subject to a national survey. Botanical values of karst areas could be considered alongside anthropological and cultural values, e.g. Phnom Laong in Battambang. Reconsideration of some of the areas degazetted from Roniem Daunsam should not be ruled out.
Lowland dry evergreen forests on basalts		50		***Compromised.*** Well represented within protected areas but generally vulnerable to both fire and recurrent disturbance.	Continue strengthening of protection in Seima and Nam Lyr. Possible addition of small area near Voensai.
Lowland dry evergreen forests on other volcanics		50		***Adequate.*** Well represented in Virachey national park where it is of low vulnerability	Protection of areas west and south of Virachey would improve trans-frontier linkages with Xe Piane and ensure comprehensive protection. Areas near Phnom Colapouk would be of lower priority.
Lowland semi-evergreen forests on old alluvia	Localised	50		***Adequate.*** Well represented within protected areas but often vulnerable. Requires effective protection from fire and land clearing.	Protection of area between Prey Long and the Mekong River contingent upon protection of Prey Long.
Lowland semi-evergreen forests on sandstones		50		***Compromised.*** Adequately represented within protected areas but generally compromised by recurrent disturbance and fire.	Marginal value in protection of plains near Phnom Colapouk.
Lowland semi-evergreen forests on limestones	Highly localised	50		***Compromised.*** Karst formations poorly represented in protected areas and generally vulnerable. Areas frequently with high economic significance.	Options unclear and subject to a national survey. Botanical values of karst areas could be considered alongside anthropological and cultural values, e.g. Phnom Laong in Battambang. Reconsideration of some of the areas degazetted from Roniem Daunsam should not be ruled out.
Lowland semi-evergreen forests on basalt	Localised	50		***Adequate.*** Well represented within protected areas but generally vulnerable when associated with slopes of the Bokeo and Chhlong Plateaus.	Continue strengthening of protection in Seima and Nam Lyr.

Lowland semi-evergreen forests on other volcanics		50		***Adequate.*** Well represented in protected areas from the south-west to the north-east, especially in Virachey national park Protected sites not generally vulnerable to recurrent disturbance.	Protection of areas west and south of Virachey would improve trans-frontier linkages with Xe Piane and ensure comprehensive protection.
Riparian forests		25		***Adequate.*** Well represented within protected areas across its range. Some sub-types poorly represented or highly vulnerable even within protected areas	Not required, though condition of sub-types unclear and subject to a national survey.
Deciduous forests on old alluvia	Extensive	25		***Adequate.*** Well represented within protected areas and less vulnerable than similar communities on alluvia. Remote areas of south-western Cambodia generally outside protected areas.	Minor areas contiguous to Phnom Aural and Roniem Daunsam wildlife sanctuariea.
Deciduous forests on sandstone		25		***Surplus representation.*** Well represented within MOE protected areas and in the north-east and less vulnerable than similar communities on alluvia. Protection forests provide additional protection. Essentially unrepresented within the wetter south-west.	Protection of areas in the south-west contiguous with southern boundaries of Phnom Aural wildlife sanctuary and Central Cardamoms protection forest, and the hill area north-east of Phnom Tumpor.
Deciduous forests on limestone	Highly Localised	50		***Compromised.*** Karst formations poorly represented in protected areas and generally vulnerable. Areas frequently with high economic significance.	Options unclear and subject to a national survey. Botanical values of karst areas could be considered alongside anthropological and cultural values.
Deciduous forests on basalt		50		***Adequate.*** Well represented within protected areas but generally vulnerable when associated with slopes of the Bokeo and Chhlong Plateaus.	Continue strengthening of protection in Seima and Nam Lyr.
Deciduous forests on other volcanics	Highly Localised	50		***Adequate.*** Well represented within protected areas but generally vulnerable when associated with slopes of the Bokeo and Chhlong Plateaus.	Continue strengthening of protection in Seima and Nam Lyr.
Coniferous forests		70		***Adequate.*** All more extensive stands under protection.	Strengthen protection in Kirirom.

Freshwater BHUs

In general the freshwater ecosystem is the most threatened of the 3 ecosystems treated in this analysis. Human settlement and agricultural patterns focus on areas near water so it is no surprise that this has resulted in a high degree of transformation of the country's freshwater habitats. Whereas a significant portion of the country's streams, ponds, and other wetlands remain protected by virtue of their remoteness, the seasonal flooding patterns of the Tonle Sap facilitate easy access to these tremendously rich areas and it is these areas that are most threatened.

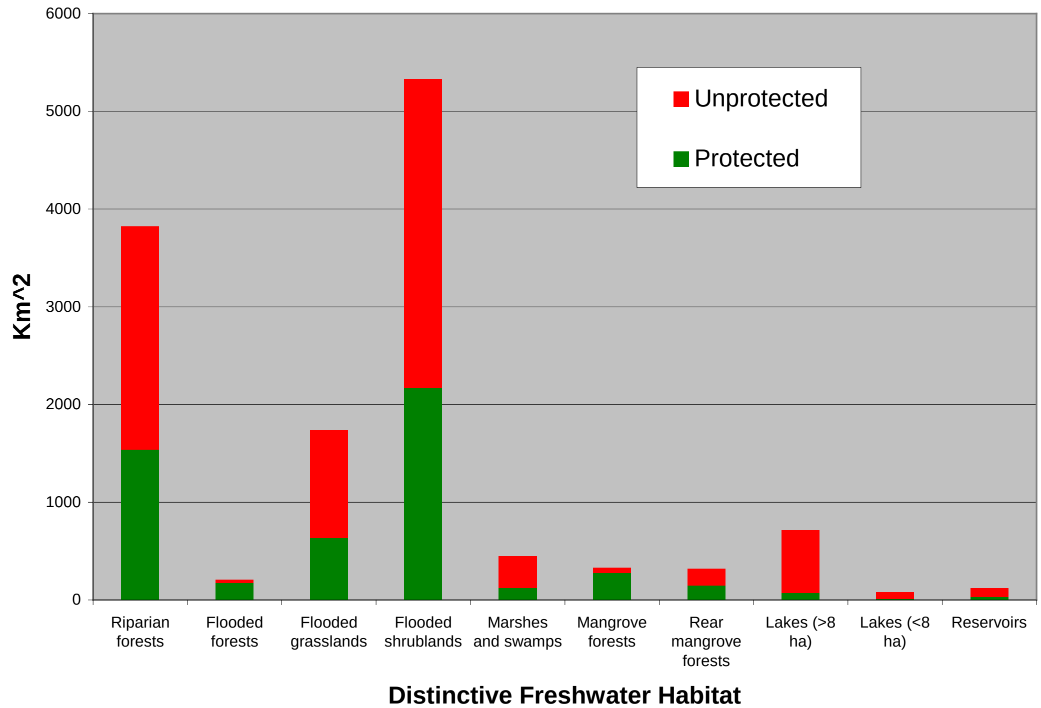
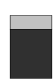
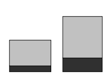
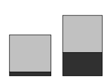
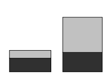
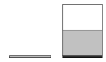
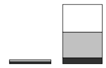
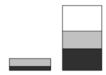
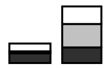
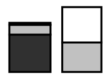


Figure 5-10. Protection status of 10 freshwater habitats.

Table 5-8. Distribution patterns, representation targets, status, and options for addressing representation gaps for focal freshwater ecological classes.

Feature	**Spatial Pattern**	**Representation Target** (% of Total Area)	**Current Protection Status**	**Options for Addressing Gaps**
Flooded forests	Highly Localised	90		
Flooded grasslands	Localised	70	***Compromised*** 	
Flooded shrublands	Extensive	70	***Compromised.*** 	
Marsh and swamps	Dispersed	50	***Inadequate.*** 	

Permanent lakes, ponds, and pools	Dispersed	25	***Inadequate.*** 	
Seasonal lakes, ponds, and pools	Dispersed	25	***Inadequate.*** 	
Permanent streams <18m wide	Dispersed	25	***Compromised.*** 	
Permanent streams >18m wide	Dispersed	25	***Compromised.*** 	
Seasonal streams	Dispersed	25	***Adequate.*** 	

Coastal / Marine BHUs

Broad habitat units in coastal areas such as mangroves and estuarine areas currently have significant rates of protection whereas highly diverse benthic communities such as seagrass beds and coral formations are poorly protected.

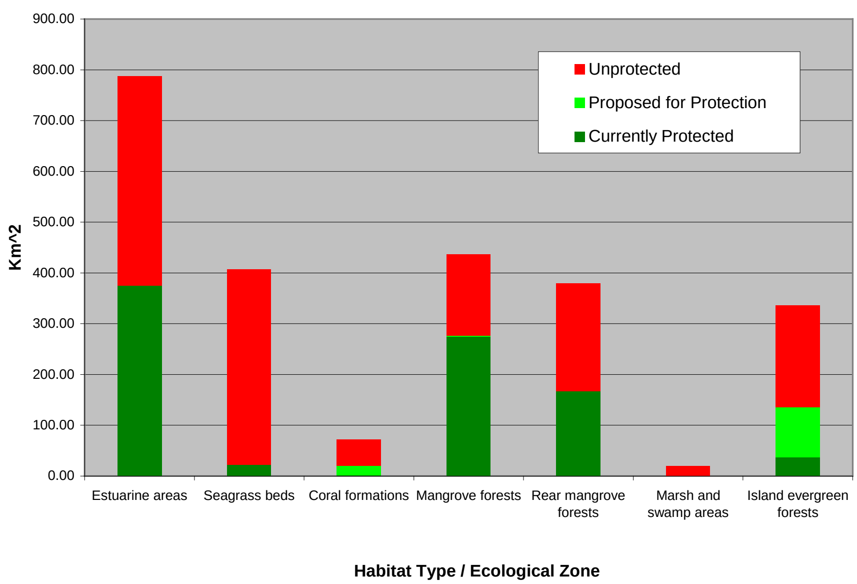
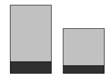
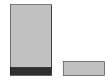
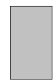
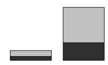
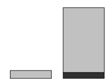
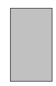
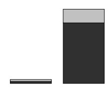
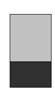
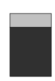


Figure 5-11. Protection status of 7 less extensive habitat types in the coastal/marine zone.

Table 5-9. Representation targets, status, and exemplary sites for focal marine habitats.

Feature	Spatial Pattern	Representation Target (% of Total Area)	Current Protection Status	Options for Addressing Gaps

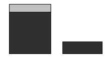
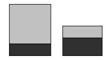
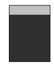
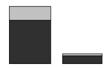
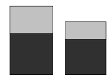
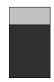
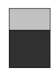
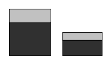
Estuarine habitat	Moderately L Localized	50		***Compromised.*** Near-coast reaches particularly compromised by development, etc.
Mangrove forests	Localized	50		***Compromised.***
Rear mangrove forests	Localized	50		***Compromised.***
Island evergreen forest	Localized	50		***Inadequate.***
Island grasslands	Localized	25		***Inadequate.***
Island Mangrove forests	Localized	50		***Compromised.***
Ocean 0-6 meter depth	Extensive	5		***No Viable Representation.***
Ocean 6-10 meter depth	Extensive	5		***No Viable Representation.***
Ocean 10-20 meter depth	Extensive	5		***No Viable Representation.***
Ocean 20-40 meter depth	Extensive	5		***No Viable Representation.***
Coral formations	Localized	50		***No Viable Representation.***
Seagrass Beds	Localized	50		***No Viable Representation.***

Fine Filter Targets: Mammals

Most mammals are well represented within the current conservation area network. Table 5-10 summarizes these patterns

Table 5-10. Representation status, targets, and options for focal mammal species.

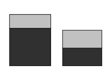
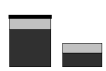
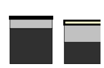
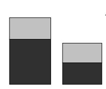
Feature	Spatial Pattern	Representation Target (% of Total Area)	Current Protection Status	Options for Addressing Gaps
Wroughton's Free-tailed Bat	Localized	0	***Compromised.*** Known from only one record	Conservation Area Planning for this species should be deferred pending additional understanding of its status in Cambodia
Douc Langur	Moderately Localized	70	***Adequate.***	
Banteng	Extensive	50	***Adequate.***	
Asian Wild Dog	Extensive	40	***Adequate.***	
Asian Elephant	Extensive	40	***Adequate.***	
Wild Water Buffalo	Localized	70	***Adequate.***	
Tiger	Extensive	40	***Adequate.***	
Eld's Deer	Formerly Extensive but now reduced to Localized occurrences	70	***Adequate.***	
Dugong	Localized	0		
Pileated Gibbon	Extensive	50	***Adequate.***	
Stump-tailed Macaque	Extensive	40	***Adequate.***	
Northern Pig-tailed Macaque	Extensive	40	***Adequate.***	
Yellow-cheeked Crested Gibbon	Extensive	50	***Adequate.***	
Pygmy Slow Loris	Localized	70	***Adequate.***	
Asiatic Black Bear	Extensive	40	***Adequate.***	

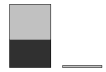
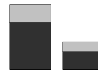
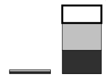
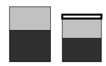
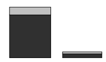
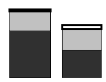
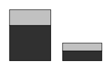
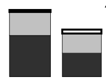
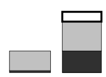
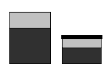
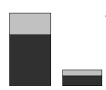
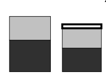
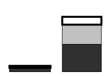
Gaur	Extensive	40	***Adequate.*** 	
Smooth-coated Otter	Localized	70	***Compromised.*** 	
Southern Serow	Localized	70	***Adequate.*** 	
Asiatic Golden Cat	Known sites limited in number and size	70	***Adequate.*** 	
Clouded Leopard	Known sites limited in number and size	70	***Compromised.*** 	
Marbled Cat	Known sites limited in number and size	70	***Adequate.*** 	
Fishing Cat	Known sites limited in number and size	70	***Adequate.*** 	
Malayan Porcupine	Extensive	40	***Adequate.*** 	
Hairy-nosed Otter	Localized	70		

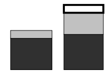
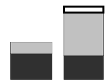
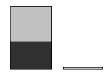
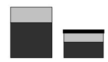
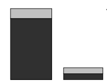
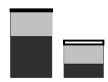
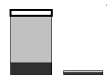
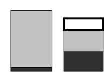
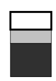
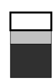
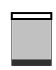
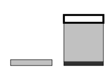
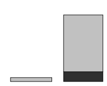
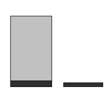
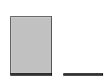
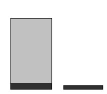
Fine Filter Targets: Birds

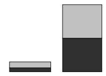
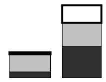
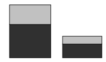
Representation of birds within the current CAN is fair but the distributions of several globally rare species are poorly represented. Table 5-11 summarizes these patterns by for each species.

Table 5-11. Representation status, targets, and options for focal bird species.

Feature	Spatial Pattern	Representation Target (% of Total Area)	Current Protection Status	Options for Addressing Gaps
Asian White-backed Vulture	Extensive	50	***Adequate.*** 	
Slender-billed Vulture	Extensive	50	***Adequate.*** 	
White-shouldered Ibis	Extensive	50	***Adequate.*** 	
Giant Ibis	Extensive	50	***Adequate.*** 	

Christmas Island Frigatebird	Localized	70	
Nordmann's Greenshank	Localized	70	
Orange-necked Partridge	Moderately Localized	70	***Adequate.*** 
White-winged Duck	Extensive	20	***Adequate.*** 
Bengal Florican	Localized	70	***Compromised.*** 
Greater Adjutant	Seasonally Localized	50	***Adequate.*** 
Chestnut-headed Partridge	Extensive	50	***Adequate.*** 
Sarus Crane	Extensive	50	***Adequate.*** 
Masked Finfoot	Extensive	50	***Adequate.*** 
Lesser Adjutant	Extensive	50	***Adequate.*** 
Milky Stork	Localized	70	
Spot-billed Pelican	Localized	70	***Compromised.*** 
Green Peafowl	Extensive	40	***Adequate.*** 
Germain's Peacock Pheasant	Relatively Localized	70	***Adequate.*** 
Pale-capped Pigeon	No documented viable occurrences	0	More surveys needed.
Indian Skimmer	No documented viable occurrences	0	More surveys needed.
Pallas's Fish Eagle	No documented viable occurrences	0	More surveys needed.
Greater Spotted Eagle	Extensive	40	***Adequate.*** 
Imperial Eagle	Localized	70	***Compromised.*** 

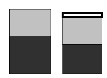
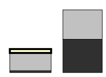
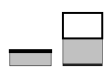
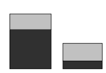
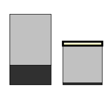
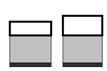
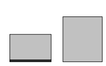
Silver Oriole	No documented viable occurrences	0	More surveys needed.
Manchurian Reed Warbler	Localized	70	***Compromised.*** 
Mekong Wagtail	Extensive (lengthy riverine distribution)	50	***Compromised.*** 
White-cheeked Laghingthrush	Localized	70	***Adequate.*** 
Grey-faced Tit-babbler	Moderately localized	70	***Adequate.*** 
Cambodian Laughingthrush	Moderately localized	70	***Adequate.*** 
Oriental Darter	Extensive	20	***Adequate.*** 
Black-headed Ibis	Localized	70	***Adequate.*** 
Painted Stork	Localized	70	
Lesser Whistling Duck	Localized	70	***Adequate.*** 
Comb duck	Localized	70	***Adequate.*** 
River Lapwing	Localized	70	***Compromised.*** 
Small Pranticole	Extensive (lengthy riverine distribution)	40	***Compromised.*** 
Whiskered Tern	Localized	70	***Compromised.*** 
Little Cormorant	Localized	70	***Compromised.*** 
Indian Cormorant	Localized	70	***Compromised.*** 
Great Egret	Localized	70	***Compromised.*** 

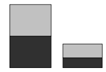
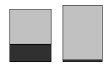
Intermediate Egret	Localized	70	***Compromised.*** 
Asian Openbill	Localized	70	***Compromised.*** 
Black-necked Stork	Moderately localised	70	***Adequate.*** 

<u>Fine Filter Targets: Reptiles</u>

Reptile distribution is summarized in table Table 5-12. Virtually all turtle species included in the analysis have localized ranges that are threatened by human impacts—often to key wetland habitats.

Table 5-12. Representation status, targets, and options for focal reptile species.

Feature	**Spatial Pattern**	**Representation Target** (% of Total Area)	**Current Protection Status**	**Options for Addressing Gaps**
Siamese Crocodile	Localized	50	***Adequate.*** 	
Mangrove Terrapin	Localized	70	***Compromised.*** 	
Hawksbill Turtle	Localized (nesting sites)	0	Moderate protection of some beach nesting sites. Open ocean and seagrass beds (key food resource) almost completely unrepresented.	
Green Turtle	Localized (nesting sites)	0	Moderate protection of some beach nesting sites. Open ocean and seagrass beds (key food resource) almost completely unrepresented.	
Yellow-headed Temple Turtle	Localized	70	***Compromised.*** 	
Elongated Tortoise	Localized	40	***Adequate.*** 	
Cantor's Giant Turtle	Localized	0		
Asiatic Softshell Turtle	Dispersed	70	***Compromised.*** 	
South Asian Box Turtle	Localized	70	***Compromised.*** 	
Giant Asian Pond Turtle	Localized	70	***Compromised.*** 	
Snail-eating Turtle	Localized	0		

Impressed Tortoise	Dispersed	0		***Adequate.***
Black Marsh Turtle	Localized	0		***Compromised.***

Fine Filter Targets: Amphibians

Amphibian representation is summarized in Table 5-13. The limited selection of amphibians included in the analysis is fairly well represented within Cambodia's current conservation area network.

Table 5-13. Representation status, targets, and options for focal amphibian species.

Feature	Spatial Pattern	Representation Target (% of Total Area)	Current Protection Status		Options for Addressing Gaps
Spiny Mountain Frog	Localized	70		**Adequate.** All known sites in remote, protected high elevation areas.	
Toumanoff's Wart Frog	Localized	70			
Annam Flying Frog	Localized	70			
Philatus Cardamonus	Localized	70			
Megophrys auralensis	Localized	70			
Rana faber	Localized	70			

Overall Representation and Design

The overall design of the protected area system is strong (Lacerda et al. 2005, this analysis) and more recent additions to the system (e.g. protected forests) have greatly enhanced such system-wide aspects as connectivity and redundancy for many conservation features. The original system sampled the landscape well but it is clear that some positive aspects of system design are merely the natural result of a relatively large conservation network.

There are, however, several weaknesses in system design. First, strategic trans-boundary protection has not been pursued until relatively recently and this has resulted in poor coordination of efforts across Cambodia's 3 international boundaries (with Thailand, Laos, and Vietnam). Secondly, there are some indications that the large size of the system is in fact a weakness by way of the common perception that the system is too big to be realistically managed and balanced with other development goals.

Finally, the lack of any true marine protected areas represents a significant gap in overall system design. This analysis highlights several potential focal areas for protection in the marine realm but a detailed analysis should be carried out focused exclusively on this important area.

Current Impacts and Threats

Though shifting agriculture has long been practiced in lowland areas of the country, the amount of forested area is high for the region. However, the last 40 years and in particular the last 15 years, has seen both dramatic declines in forest cover as well as substantial degradation of natural forests due to unsustainable forest practices. While a figure of 74% forest cover has been cited for the 1969 (Azima *et al.* 2000), the current figure (including degraded forests and forest plantations) is about 60%. Between 2000 and 2005, Cambodia had the 3rd highest primary forest deforestation rate globally (Food and Agriculture Organisation 2005). The forested areas that remain face extensive and growing areas of degradation.

Priority Sites for Conservation Action

Procedures for identifying priority sites for conservation resulted in the delineation of 42 discrete sites greater than 40 km^2 and of particularly high irreplaceability (Figure 5-12). While all of these sites should be considered priorities for conservation action, irreplaceability and vulnerability scores provided a means with which to schedule conservation action.

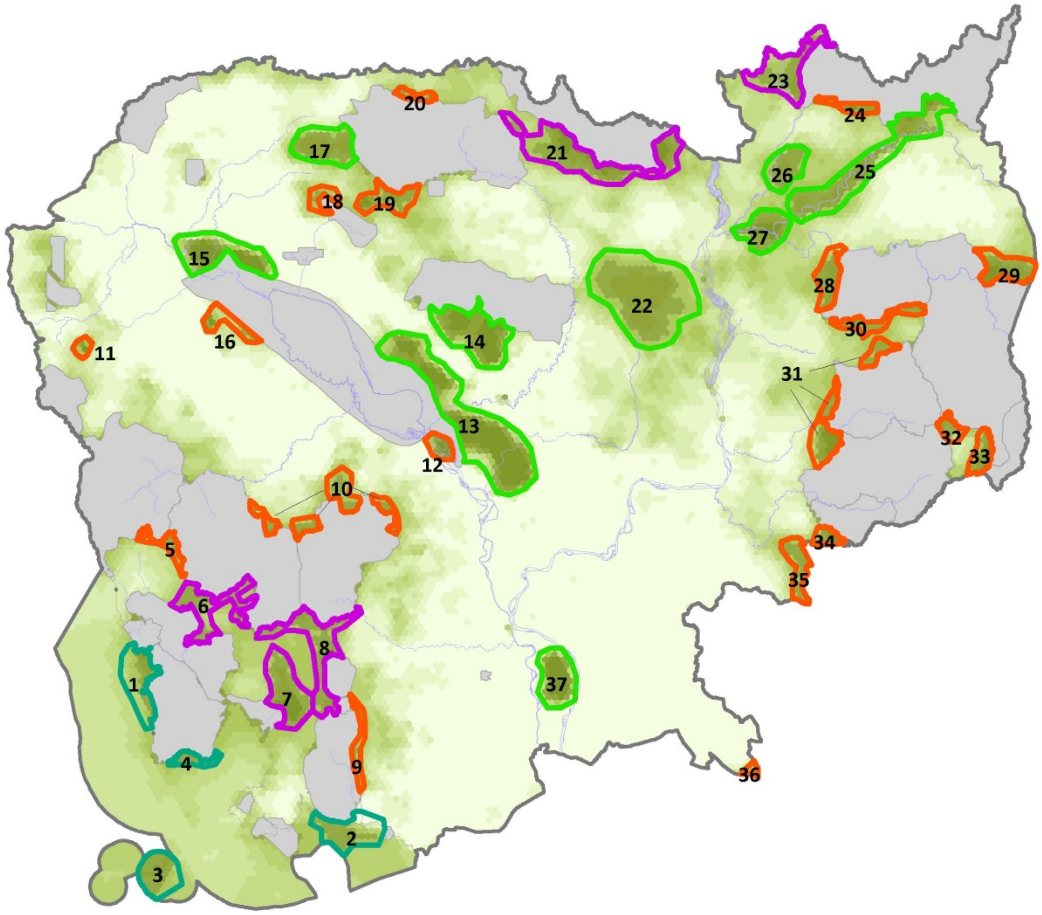


Figure 5-12. Priority sites for conservation action based on selection frequency, a common expression of irreplaceability. Areas outlined in green represent large sites of uniform irreplaceability value. Areas outlined in violet are also large and represent opportunities to greatly enhance connectivity of Cambodia's conservation network. Areas outlined in auqua represent the most irreplaceable sites within the country's marine realm. Remaining highly irreplaceable sites are outlined in gold.

Table 5-14. Priority sites for conservation action <u>outside</u> of the current protected area system. All sites are highly significant to achieving Cambodia's conservation targets. Indices of irreplaceability are used to assign priorities but will likely require divergent conservation area strategies due to unique characteristics and local conditions.

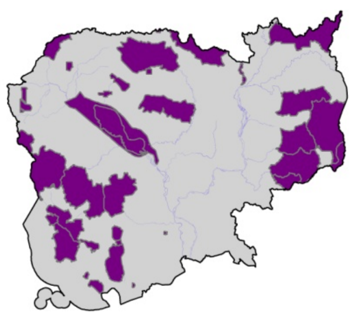
Map Ref.	Name	Configuration	Biodiversity Highlights / Irreplaceability Considerations	Vulnerability Considerations	Irreplaceability Index	Vulnerability Index	Urgency Rank
1	**Koh Kong Marine Zone**	Key Marine Zone	Supports extensive coral formations and seagrass beds	Estuarine pollution plume, harvest of mangrove forest.	2	1	2
2	**Kampot Seagrass Beds**	Key Marine Zone	Diverse and productive benthic community. Key dugong habitat.	Intensive harvest of seagrass and associated seaweed for export to food industry	1	1	1
3	**Koh Tang Offshore Islands**	Key Marine Zone	Unique offshore island habitat. Only national documented nesting area for Chistmas Island Frigatebird.	No major current threats.	1	2	3
4	**Botum Sakor Southern Coast and Estuaries**	Key Marine Zone	Mangrove habitat, estuarine inlets, relatively steep benthic gradient.Potentially important for Irrawaddy dolphin and dugong populations.	Increasing coastal fishing activity	2	2	4
5	**Tatai River Headwaters**	Extension to Existing CA	Scenic extension to Samkos with lowland moist evergreen and pine forests on sandstone and basalts as well as some of Southeast Asia's most remote, large, mountain rivers.	Fire. Logging for luxury timbers.	1	2	3
6	**Southwest Cardamom Corridor**	Corridor Area	Intact evergreen forests, key habitat for several rare large mammals and reptiles	Human encroachment.	2	1	2
7	**Sre Ambel Inland Estuary**	Corridor Area	Massive estuarine system supporting numerous birds and reptiles. If protected, also represents the lower part of a gradient from high mountain to ocean.	Growing human development, river pollution and modification.	1	1	1

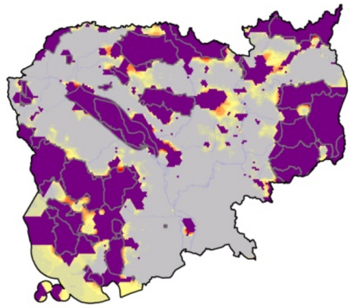
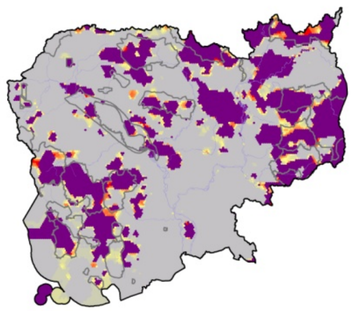
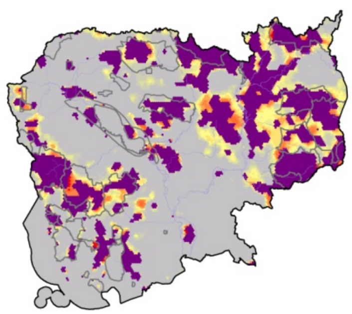
8	**Kirirom-Cardamoms Corridor**	Corridor Area	Mosaic of forest formations including deciduous and semi-evergreen forests, lowland moist evergreen forests on alluvia and organic sediments.	Logging for luxury timbers. Agricultural encroachment. Fire.	2	1	2
9	**Eastern Bokor Lowlands**	Extension to Existing CA	Lowland moist evergreen forests on alluvia and organic sediments.	Logging for luxury timbers. Fire.	1	1	1
10	**Aural Deciduous Forests**	Extension to Existing CA	Distinctive dry / moist forest mosaic on slopes and foothills.	Logging for luxury timbers. Fire.	2	2	4
11	**Pailin Semi-evergreen Forests**	Isolated but very diverse forest block	Complex mosaic of poorly represented dry forest types		2	1	2
12	**Tonle Sap River**	Extension to Existing CA	Distinctive river system with complex mosaic of flooded forests and shrublands	Increasing boat traffic, pollution. Potentially threatened by Mekong dam regime	1	1	1
13	**Kampng Thom Grasslands**	Extensive grassland landscape	Distinctive and extensive marsh and riparian habitats. Supports globally rare Bengal Florican and Lesser Adjutant Populations.		1	1	1
14	**Kampong Thom Wetland Mosaic**	Extensive forest/ wetland landscape			2	1	2
15	**Baray Grasslands**	Extension to Existing CA			2	1	2
16	**Sankae Shrublands**	Extension to Existing CA			2	1	2
17	**Kulen Promtep West Forest Mosaic**	Extension to Existing CA			2	1	2
18	**Banteay Srey Forest Mosaic**	Extension to Existing CA			2	2	4
19	**Svay Leu Forest Mosaic**	Extension to Existing CA			2	2	4
20	**Kulen Promtep North Semi-evergreen Mosaic**	Extension to Existing CA			2	1	2

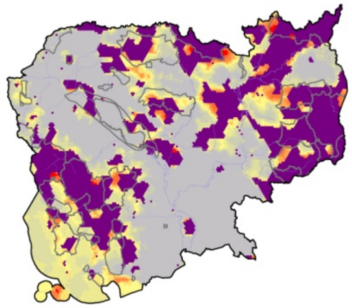
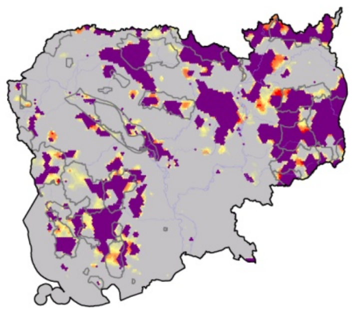
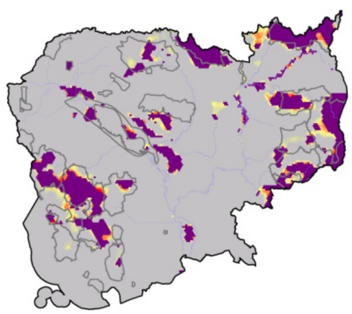
21	**Chaep Forest Corridor**	Important Corridor Area	Lowland dry evergreen forests and semi-evergreen forests on alluvia.	Renewal of commercial logging. Illegal logging for luxury timbers. Fire. Existing roads.	2	1	2
22	**Prey Long**	Large, isolated block	Best example of lowland dry evergreen forests on alluvia in Cambodia. Small yet very distictive swamp forests are scattered throughout this area. Last and largest example of primary lowland dry evergreen forest in the Indo-chinese floristic province. Also has areas of semi-evergreen forest on alluvia. Swamp forests within Cambodia.	Renewal of commercial logging. Logging for luxury timbers. Existing roads and road construction. Drainage or drying of swamp forests. Renewal of commercial logging. Fire.	1	1	1
23	**Virachey-Xe Pian Corridor**	Large block with trans-boundary connectivity significance		Dry and semi-evergreen forests on rhyolites flows.	2	1	2
24	**Lower Virachey Semi-evergreen Forests**	Extension to Existing CA			2	2	4
25	**Sre San River Corridor**	Large, contiguous block	Relatively intact river corridor. Dry evergreen forests on sandstone and basalt. Limited swamp forest development. Semi-evergreen forests on sandstone escarpments.	Resumption of commercial logging. Logging for luxury timbers. Fire.	1	2	3
26	**Sre Kong Dry Evergreen Mosaic**	Large, contiguous block	Dry and semi-evergreen forests on sandstone plains.	Resumption of commercial logging. Logging for luxury timbers. Fire.	2	1	2
27	**Stueng Treng River Confluence**	Large, contiguous block			2	1	2
28	**West Lomphat Extension**	Extension to Existing CA	Dry and semi-evergreen forests on basalt.	Logging for luxury timbers. Fire. Swidden agriculture.	2	2	4
29	**NE Lomphat Deciduous Forests**	Extension to Existing CA			2	2	4

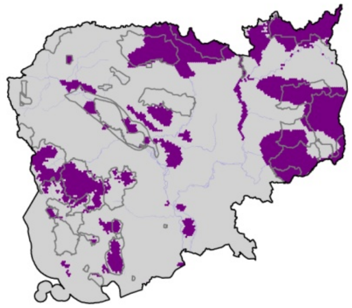
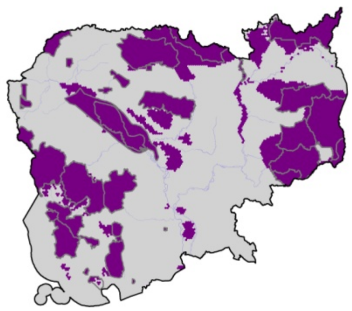
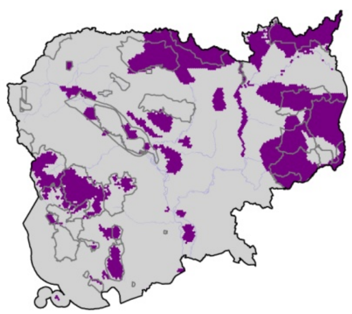
30	**Southern Lomphat Woodlands**	Extension to Existing CA			2	2	4
31	**Phnom Prich Forests Extensions**	Extension to Existing CA			2	2	4
32	**Sen Monorom Dry Forest Mosaic**	Extension to Existing CA			2	2	4
33	**Pech Chenda Semi-evergreen Forests**	Extension to Existing CA	Rare and relatively undisturbed sub-montane dry and semi-evergreen forest on basalt	This type of forest has been largely cleared from contiguous areas within Vietnam.	2	1	2
34	**Snoul South Dry Forest Mosaic**	Extension to Existing CA			2	1	2
35	**Memot Border Forest Mosaic**	Isolated Border Area			2	2	4
36	**Svay Rieng Marsh**	Isolated Border Area			2	1	2
37	**Bassac Marsh**	Large, contiguous block			1	1	1

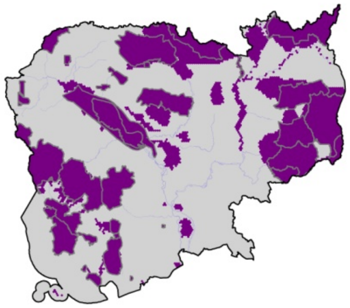
Table 5-15. Summary of descriptors of 11 actual, proposed, and modeled conservation area networks in Cambodia.

Conservation Area System/Proposal	Map	Area (Km^2 - Mainland Only)	Mainland % of National Area	Cost (Millions)	Impact Index	BHU Targets Met (%)	Spp Targets Met (%)	Total Targets Met (%)
Current CAN		49,648	27.3%	146,782	0.210	50%	69%	61%

Optimized Network - Building on Existing CAN		77,126	42.5%	238,371	0.230	100%	100%	100%
Optimized Network - PA Cost Constrained		25,499	14.0%	56,495	0.146	98%	99%	98%
Optimized Network - PA Area Constrained		50,518	27.8%	161,651	0.240	89%	97%	94%

Optimized Network - Unconstrained		59,014	32.5%	167,581	0.210	100%	100%	100%
Optimized Network – Based on Broad Habitat Types Only		46,226	25.4%	84,590	0.120	85%	42%	60%
Optimized Network – Based on Species Targets Only		25,499	14.0%	56,495	0.146	15%	85%	56%

IBAs (2003)		44,337	24.4%	131,659	0.220	44%	83%	67%
IBAs+ PAs		66,688	36.7%	219,185	0.249	72%	87%	81%
KBAs (2005)		46,422	25.6%	137,301	0.218	44%	85%	68%

KBAs + PAs		68,382	37.6%	223,784	0.247	70%	88%	81%

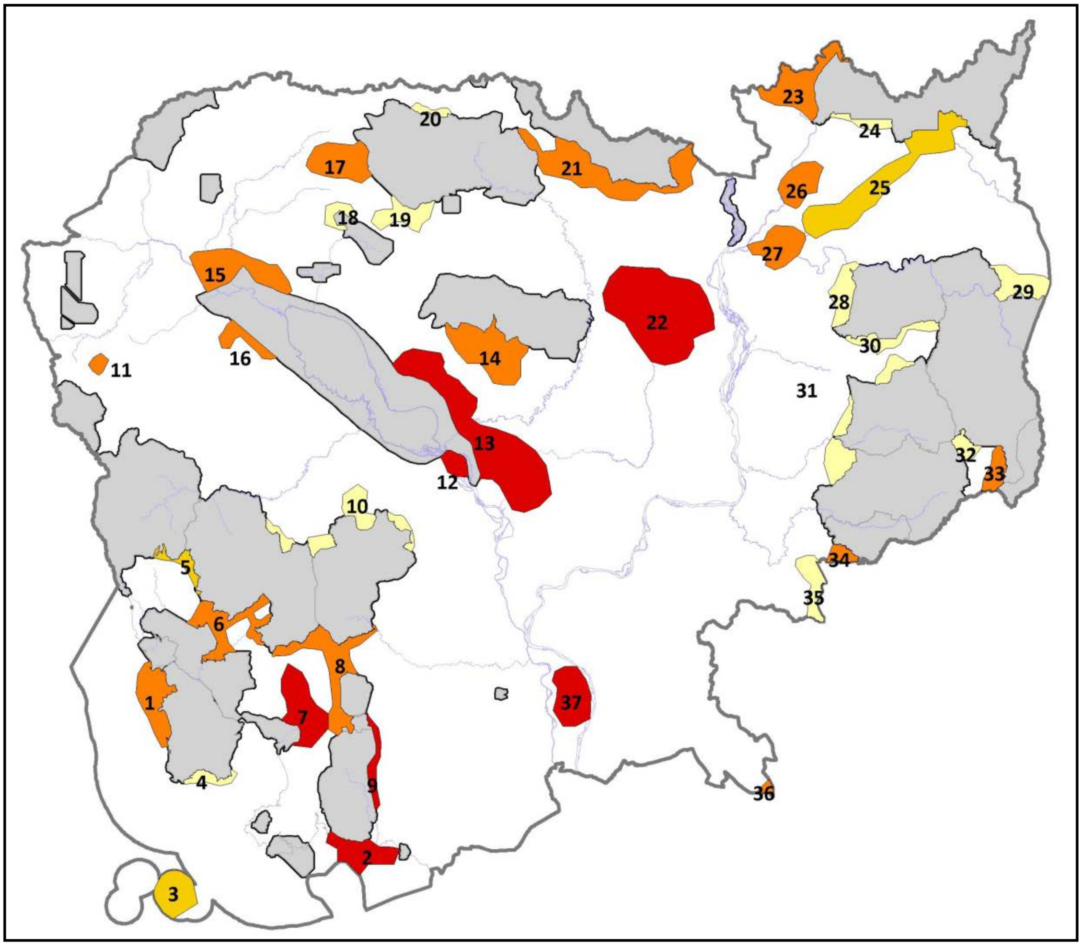


Figure 5-13. Urgency of conservation action among priority conservation sites for acheiveing biodiversity targets.

Contrasting Conservation Area Networks

Descriptors of 11 actual, proposed and modeled conservation areas are summarized in Table 5-15 and Figure 5-14. The current network can be contrasted with other proposed or modelled networks to highlight how changes in configuration might affect performance in terms of number of conservation targets achieved, area, cost, and condition of the network. For example, the current network meets 50 % of broad habitat unit conservation targets and 70% of species conservation targets yet is 3 times the cost and nearly twice the size of an optimized theoretical netword that could effectively meet all conservation targets.

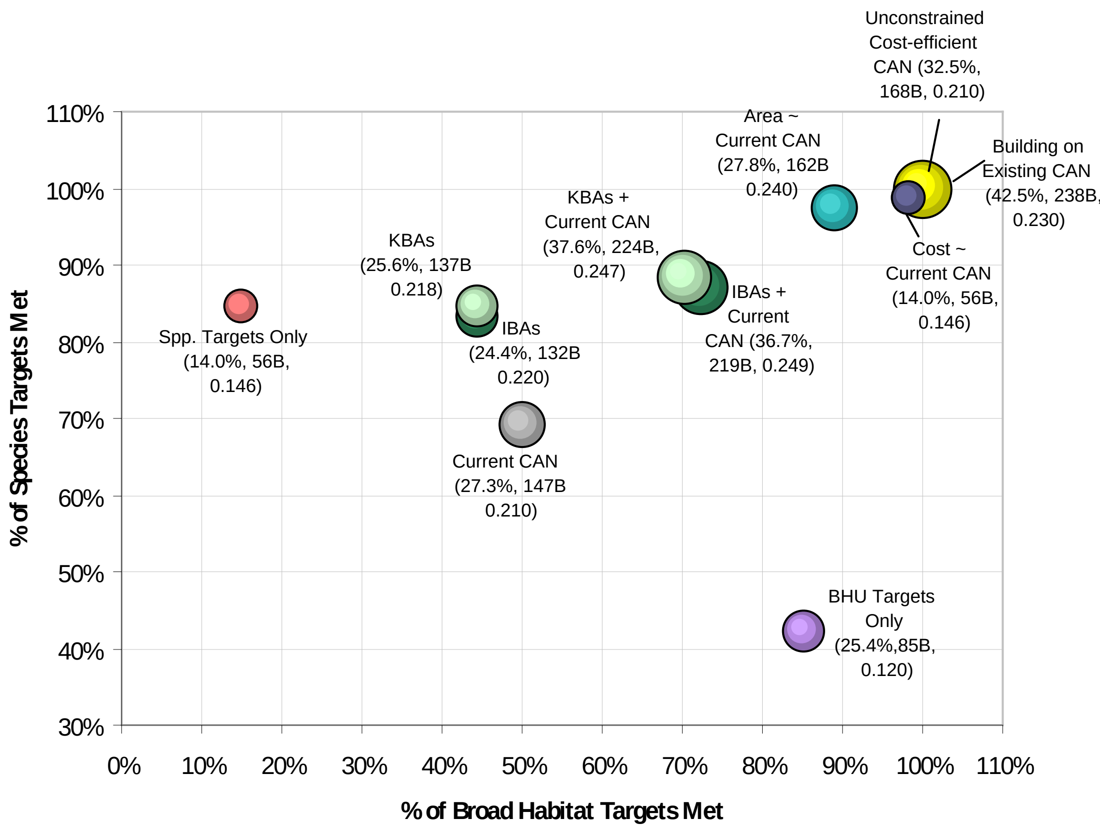


Figure 5-14. Represenation performance and relative Size of actual, proposed, and modeled conservation area networks in Cambodia. Labels indicate the name of each network and the size of points reflects the relative the amount of the country's land area covered by that network. Specific measures of size (% of country land area), relative cost (in Billions), and a relative index of condition (see text) are shown in each label.

Additional observations based on these comparisons are discussed below.

Discussion

Biodiversity Gaps in Cambodia's Conservation Area System

Based on the best available biodiversity data, this analysis has identified explicit gaps in the abitity of Cambodia's conservation area network to adequately represent numerous key elements of the country's biodiviversity. I used tools and procedures designed to be flexible, modular, and transparent. If used appropriately within a broader framework of systematic conservation planning, these tools have been shown to contribute significantly to the challenge of moving from objectives to on-the-ground conservation action.

Given the conditions under which Cambodia's original conservation area network was created, it is a credit to the original designers and those who have made subsequent contributions that it performs as well as it does with regard to many common measures. It is my hope that this analysis helps both to underscore these remarkable successs and to highlight some of the options and tradeoffs in working towards an even more representative network.

Filling Gaps

The protected area system and the features that it protects will always be subject to changing conditions. As I have emphasized above, the very nature of systematic conservation planning means that a change in the status of one area or one conservation feature may have complex and non-linear consequences for subsequent priority-setting. For this reason, I have intentionally kept the number of priority sites identified to a relatively small set of sites that appear to be irreplaceable under a variety of conditions. Planners and managers should understand that conservation action at these sites or clear changes in the biodiversity features they support should trigger re-evaluation of the network as a whole.

Urgent Priorities

A number of priority sites (see results) proved highly irreplaceable under a range of circumstances. The marine realm in particular is underrepresented in the currnet system and is clearly in need of a well thought out protection strategy. Given the phasing logic of irreplaceability and vulnerability provided by the principles of conservation planning (Margules and Pressy 2000), the following sites should be brought under protection as a matter of urgent priority:

- The island of Koh Kong and surrounding marine areas;
- The Prey Long forest block;
- Grasslands and wetlands east of the Tonle Sap Lake;
- The area to the west of Virachay National park and contiguous with Xepian National Protected Area (Laos);
- The Bassac marsh area straddled by lower portions of the Mekong and Bassac Rivers.

In identifying longer term priorities for action, it will be critical for planners to reanalyze gaps and threat priorities on an iterative basis.

Perhaps the most useful way to assess overall representation is through an inspection of the various actual, proposed, and modeled CANs compared in Table 5-15 and Figure 5-14. Given baseline targets used in this analysis, species targets are better served than are targets for broad habitat types but both feature classes fall short of overall targets. The demonstration that both targets could be met through a system that is approximately twice as spatially efficient should motivate planners and decisiionmakers to move toward a more efficient system.

Areas Within the Current Conservation Area Network

Areas of higher and lower biodiversity irreplaceability inside the current conservation area network provide planners with important insight and guidance with regard to zoning efforts and/or areas for potential degazzettement. As with all planning exercises, it will be important for decisions to be made based on updated, reiterated analyses to ensure that the basis for any decisions is current with regard to available data, changing conservation element and threat status, and protection status.

Data Needs

Both the coarse and fine filter aspects of this analysis use the best available objective data for mapping distributions and assessing the status of focal conservation features. However, there will always be deficiencies in these datasets. To address these deficiencies as effectively as possible, priority sites for further research should be identified and prioritized on an ongoing basis. Priorities should be based on known patterns of survey effort, immediate and anticipated impacts to conservation features of interest, and other factors.

Broadening the Scope Systematic Conservation Planning

The scope of this analysis is limited to elements of Cambodia's biodiversity. However, the methods used here are appropriate for informing multi-criteria decisions involving a diversity of objectives and variables. Ongoing systematic conservation planning efforts should seek to include a wider range of conservation targets. It will be particularly important to address issues in the following areas:

- biodiversity processes;
- identification and comparison of the specific contributions that protected areas make to the maintenance of ecosystem services and other values;
- detailed information on the operating costs of protected areas and associated costs incurred by protected area agencies;

- inclusion of additional species and potentially additional taxa as conservation features; and
- more detailed treatment of the cultural values of protected areas.

Biodiversity Processes

While biodiversity process are represented here to some degree by virtue of their being embedded in many of the conservation features considered, it would enhance future analyses to explicit attempt to map or otherwise set explicit objectives for expressing conservation needs for these. The Natural Capital Project (http://www.naturalcapitalproject.org/home04.html) has developed many relevant tools and approaches in this area and thus represents a logical starting point for being more inclusive of biodiversity processes in the overall planning process.

Ecosystem Services

In both development and conservation planning, there is an increasing acknowledgement that maintaining functioning ecosystems is essential not only for conserving biodiversity but for sustaining human populations (Blaschke 2006; Costanza et al. 1997; McNeely et al. 2005; Millenium Ecosystem Assessment 2005; Stokstad 2005). We know that protected areas play a key role in conserving ecosystem structure and function in Cambodia (ICEM 2003) yet very little detailed information is available on the actual value of functioning ecosystems vs. those that have been degraded. Recently, Cutter and Hean (2010) have shown that over longer time horizons (e.g. 20-30 years), the return on investment in conservation areas to secure otherwise faltering ecosystem services in Cambodia is massive. Recent technical advances now allow analysts to include a growing suite ecosystem service values in explicit spatial models (e.g. Tallis et al. (2008)).

Due to the far-reaching benefits of maintaining ecosystem structure and function, Increasing focus should be given to research activities aimed at measuring, valuing, and monitoring various features and processes associated with ecosystems. Such research should include, at minimum, the following key topics:

- Maintenance and regulation of water supply (and associated drought and flood prevention values)
- Conservation of hydro-electric generation potential
- Maintenance of carbon sequestration services (and potential carbon credit benefits under the Kyoto protocol and other international agreements)
- Maintenance of inland and offshore fisheries

- Maintenance of land-based agricultural production
- Maintenance of biodiversity and genetic resources
- Maintenance of tourism value
- Fire prevention
- Maintenance of non-timber forest product (NTFP) productivity

Cultural, Historic, and Sacred Sites

An analysis of the conservation area system's representation analysis of cultural, historic, and sacred sites was beyond the scope of this biodiversity-focused analysis. The unique blend of dramatic cultural sites and biodiversity values in many of Cambodia's landscapes is considered to present valuable opportunities for linking biodiversity and other conservation targets and should remain an active part of the ongoing dialogue on developing effective conservation strategies.

Improving the Process of Conservation Planning

A wide variety of information is needed to carry out systematic conservation planning effectively. Important information includes information on the distribution and status of biodiversity features, ecosystem processes, human population and development patterns, and institutional, legal, and policy issues. Depending on the resolution required, there will always be a trade-off between the time and resources invested in acquiring, managing, and analyzing relevant information and the need to get plans into the hands of decision-makers.

The ability to monitor change assumes a basic capacity to collect comparable data over time. With current capacity for information management low, protected area agencies must carefully prioritise how limited resources are to be used. By utilizing existing information resources, both protected areas and conservation features can already be placed in a monitoring context with future activities planned as iterations to these resources.

Data Collection and Information Management

The formulation of sound conservation and natural resource policy requires accurate and timely information from multiple sectors. Yet currently there is no coordinated national programme for the collection and management of biodiversity and ecosystem level processes and services. Much of the raw information used to carry out this analysis was obtained from non-governmental organisations—each operating at different scales and with sometimes divergent conservation objectives. Given the complexity and importance of these types of information, there is a clear mandate for relevant government agencies to coordinate their efforts to facilitate integrated planning and management. A logical center for such an effort may be at one of the country's universities.

Planning at the National, Cluster, and Site Level

Just as biodiversity is a hierarchical phenomena, the implementation of an explicit planning structure at the national, cluster, and individual conservation area level would provide a logical and effective nested design within which to manage both conservation areas and to assess biodiversity information patterns anc condition. Importantly, this will require agencies that have traditionally not worked closely together to share information and other management resources to work toward a more unified set of conservation goals.

Engaging Stakeholders

This project has engaged stakeholders at several key points but it is only the start of a broader process involving additional review and deliberation. The process outlined here provides a strong basis for a more transparent and systematic approach to conservation decision-making.

Fostering Ongoing, Adaptive Evaluation

Conservation planning, of which gap analysis is an important component, is a dynamic, iterative process whereby advances in techniques and knowledge will progressively reduce the chances of serious errors in planning (Margules & Pressey 2000). For this reason, this analysis should be viewed as a statement of the current situation and subject to periodic updates.

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APPENDIX 1. DIAGNOSTIC UTILITY OF FIELD TRACK MEASUREMENTS OF LARGE CATS IN SOUTHEAST ASIA

Track dimensions and other sign characteristics have been used extensively to draw conclusions about tiger (Panthera tigris) and leopard (Panthera pardus) sign encountered in the field and to subsequently apply those conclusions to conservation and other research questions. Most evaluations of such methods have focused on the Bengal tiger (P.t.tigris). Some argue that attempts to distinguish male from female tigers and tigers from leopards based on track measurements obtained in the field are fraught with problems and that claims of the ability to do so have not been substantiated by controlled studies. I compiled measurements of various sign characteristics of tigers and leopards of known age and sex to evaluate the diagnostic utility of these characteristics in interpreting data on track measurements in South and Southeast Asia. Of 6 measurements commonly available to field practitioners when tracks are encountered (e.g. pad width, total track width, total track length for front and hind tracks) all are independently capable of discriminating between the largest of adult leopards and adult tigers. Although distinctions between male and female tigers, and male and female leopards can be confounded by extremes in the standard range of measurements for the Southeast Asian sample, these diagnoses performed well at a 95% confidence interval for both South and Southeast Asian comparisons. Although there is overlap between some track dimensions of adult leopards and young tigers, the likelihood of encountering tigers within the age range sufficiently young for track dimensions to overlap with leopards (e.g. < 8 months old) and without associated tracks of the adult mother is remote and such occurrences would have little effect on track size-related inferences relating to relevant management questions.

Introduction

When animals move through an area, they often leave evidence of their passage in the form of tracks, feces, scrapes and other phenomena. Such evidence, referred to here as *sign,* can play an important role in the study of wild mammals (Kohn & Wayne 1997; Putman 1984). In addition to providing a range of ecological information, sign has been used to distinguish the species, sex, and in some cases, the individual identity of large felids in Asia (Karanth 1999a; McDougal 1977, 1999; Rabinowitz 1990; Santiapillai & Ramono 1987; Seidensticker 1987; Sharma 2003; Sharma et al. 2005; Smirnov & Miquelle 1999). Such information can be of great value—especially in the case of secretive, solitary animals that are difficult to detect using other means (Thompson 2004).

Although the use of tracks for making between- and within-species distinctions has been discussed at length for Bengal tigers (Das & Sanyal 1995; Karanth 1999a; Rishi 1997; Sagar & Singh 1990, 1991; Schaller 1967; Sharma 2003; Sharma et al. 2005) and to a lesser degree Siberian tigers (Riordan 1998; Smirnov & Miquelle 1999), interpretation of Indochinese tiger tracks has not been addressed in detail. As the Indochinese subspecies is generally regarded as smaller, it is reasonable to assume that various dimensions of their tracks may be significantly smaller as well.

To test this, as well as provide an objective reference for the interpretation of tracks observed in the field, I carried out a study of the tracks of tigers and leopards of known sex and age as part of a larger study of tiger and tiger prey distribution in western Thailand and compared these data with a similar dataset of tiger and leopard track measurements from Nepal.

In particular, I sought to address the following questions:

1. Can relatively simple field measurements of large cat tracks be used to distinguish male from female tigers and adult tigers from adult leopards?
2. Which basic measurements provide the highest diagnostic value for making these distinctions?

Sample Areas and Methods

I collected data on tigers and leopards from mainland Southeast Asia. This region is home to *Panthera tigris corbetti* (Indochinese tiger) and *Panthera pardus delacouri* (Indochinese leopard). I took measurements of tracks made by captive animals in Cambodia at Phnom Thamal Zoo and in Thailand at Khao Pratabchang Wildlife Confiscation and Breeding Center (Ratchaburi province), Khao Khieow Open Zoo (Chacheongsaow Province), Pattaya Crocadile Farm (Pattaya Province), and Pa Luang Tabua Temple (Kanchanaburi province) between 1999-2005. Additionally, during concurrent surveys for wild tigers in western Thailand, I used measurements from track occurrences representing a mother with one or more cubs. Smith (1993) showed that young tigers will move regularly with a parent until approximately the age of 18 months (and intermittently from age 18-24 months), and Karanth and Nichols (2002b) note that "tracks that look like leopard

tracks, but accompany definite tiger track, often indicate a tigress moving with her cubs". All measurements of Indochinese tiger sign in the wild were taken in the Western Forest Complex protected area system in western Thailand.

I used unpublished data from another study in Nepal (Smith et al. 1987; Sunquist 1981a) to provide comparisons with Bengal tiger track size ranges and to calculate the age at which tigers grow beyond the size range of large male leopards. The tigers (*P.t. tigris*) and leopards (*P.p. fusca*) in this region are both generally considered larger than their Southeast Asian counterparts. In the Nepal study, the age and sex of individuals responsible for track occurrences were assigned by matching sets of tracks with tigers whose sex and age had been extablished through capture and examination or through well-documented reproductive events. Matching was accomplished by associating tracks at camera stations with photos of known individuals or through deduction based on the coincidence of occurrences with independently documented ranging patterns or the recognition of distinctive track features associated with known individuals. Track measurements in this study were taken by a small number of experienced observers using similar methods to those used to generate the Southeast Asia dataset.

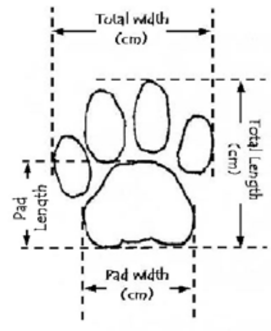


Figure 5-15. Dimensions measured in recording carnivore tracks.

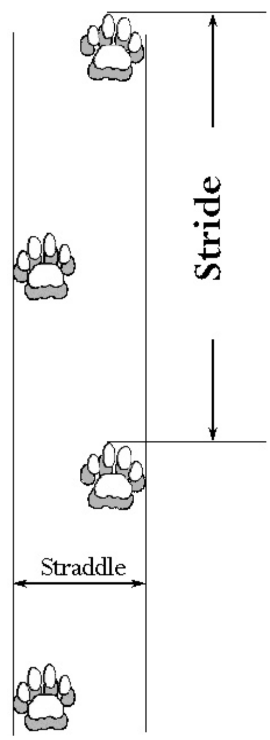


Figure 5-16. Dimensions used in recording stride and straddle of carnivore trackways.

For the Thailand dataset, I recorded the following track dimensions whenever possible: pad width, pad length, total track width, and total track length, stride length, and straddle width. I used the standard interpretation of stride length and straddle width—e.g. stride length being the distance from one track to the next track produced by the same foot of the animal) and the straddle width being the distance between the outermost point of left tracks to the outermost point of right tracks). Stride length measurements were taken along an axis parallel to the direction of travel as established by multiple tracks. Straddle measurements (the distance between the outermost point of left tracks to the outermost point of right tracks) were taken along an axis perpendicular to the direction of travel.

Stride and straddle values used in the analysis were the means of a minimum of 3 separate measurements from different points along a single trackway (Figure 5-15, Figure 5-16).

As the base of the pad portion of some tracks are lobed and do not provide a single clear point for measurements, a line tangent to the two outer lobes was constructed and measurements taken from the point at which that line intersected a line bisecting the pad and parallel to the direction of travel (**Error! Reference source not found.**).

To increase consistency between measurements, I took measurements from an explicit point on the "wall" of each track impression measured (Figure 5-17). All measurements involving track impressions were made from a point approximately 1/3 of the distance from the "floor" of the impression to the "crest" of the track -- a method that I found significantly reduced variance in track measurements taken from the same animal in different substrates.

Tracks included in the analyses were from healthy tigers walking at a normal gait in a straight line on level ground. In all captive situations, the substrate was hard-packed dirt covered by a shallow (2-5 mm) layer of fine, dry, sandy soil. I took all track measurements of captive individuals; measurements of sign in the field were taken by either me or one field assistant whom I had trained. All measurements were rounded to the nearest millimeter.

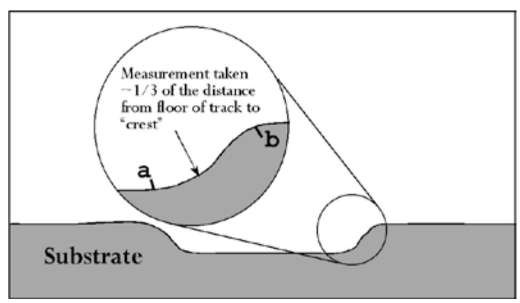


Figure 5-17. Details of track impression measurement.

The Nepal dataset included measurements of pad width, total length, and total width. While measurement techniques were not identical, tracks in this study were only collected under optimal field conditions (e.g. in situations where a shallow, dusty layer of soil occurred over a hardpacked lower layer).

To test whether demographic distinctions made using measurement thresholds established in the controlled study yeilded plausible male:female ratios in areas surveyed, I used geographic separation rules and track dimension guidelines (similar to an approach used by Miquelle et al (1999)) to generate male:female ratios from five independently collected sets of data. Four of these were sets of track occurrences that I collected in western Thailand during our 1997, 1998, 1999, and 2000 field seasons. A fifth dataset consisted of all tracks collected by a colleague in the same area (Robert Steinmetz, pers. comm.) in 2000. I first assigned sex and age to each set of tracks using size ranges established here in the following order of precedence: hind pad width, front pad width, front total length, hind total length, hind total width, and front total width. Using only adult male and adult female track occurrences, I then constructed radial buffers around individual sign occurrences (15 km buffers around males and 6 km around females) and merged these circular areas to derive discrete “detection zones” within which further comparisons were made. Buffer sizes were established based on radio collar data from the study area (Saksit Simcharoen, pers. comm.) suggesting that the maximum total distance traveled by a male from one end of his homerange to the other is approximately 30 km whereas the maximum distance traveled by females is approximately 11 km. If corresponding track measurements within a given detection zone differed by more than a threshold amount (5 mm for pad width measurements, 10 mm for pad length measurements, and 15 mm for pad width measurements, they were considered distinct individuals.

I compared male:female ratios derived using these rules with adult male:female ratios observed in other studies of tiger demographics.

Results

Southeast Asia Primary Track Measurements

Primary track measurements from Southeast Asian tigers and leopards are summarized in Figure 5-19. Of the six dimensions compared, all showed the ability to distinguish small female tigers from the largest male leopards. Additionally, both front and hind pad width, front total width, and front total length dimensions were able to discriminate male from female tigers at the 95% confidence interval.

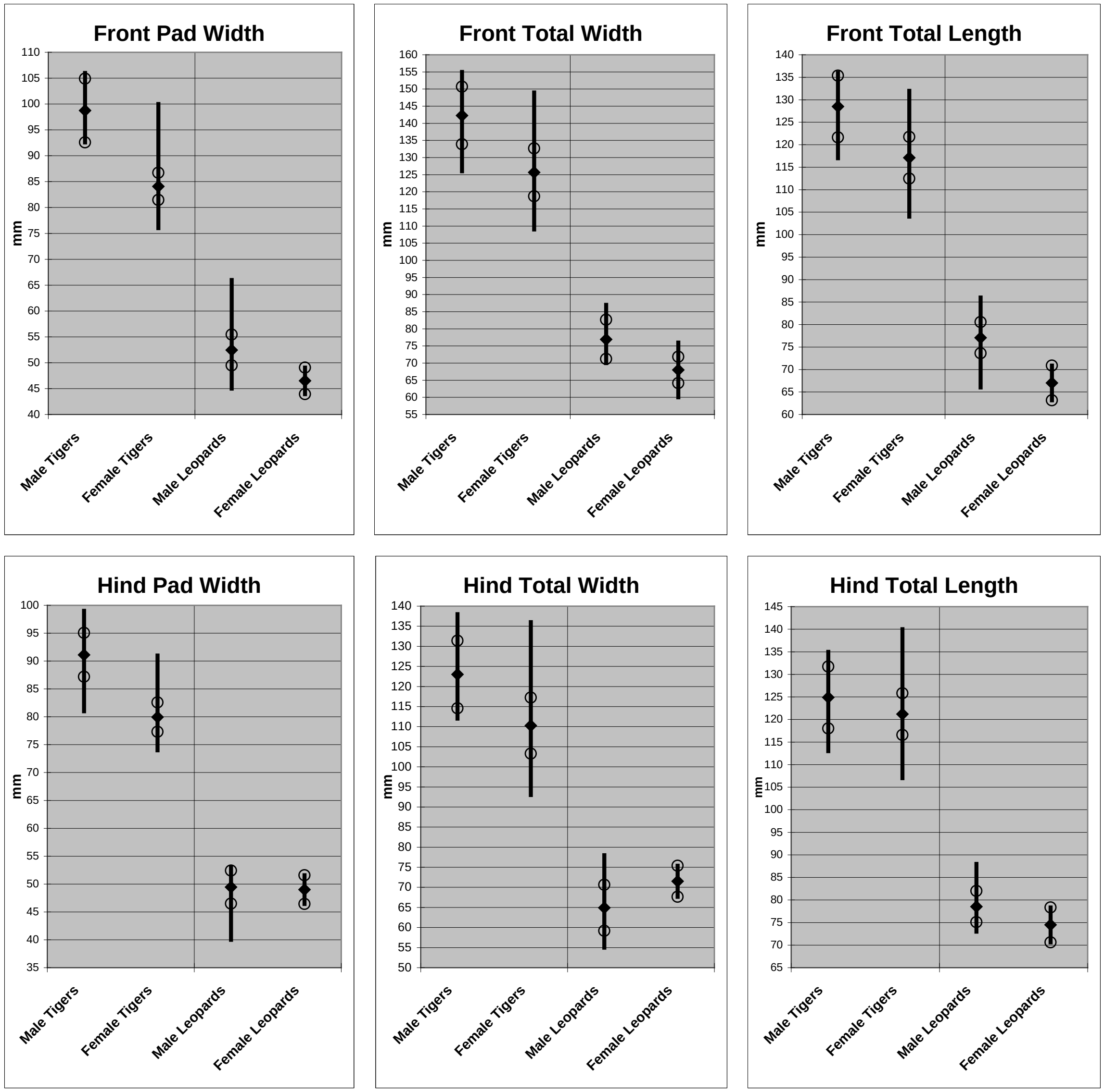


Figure 5-18. Summary of primary track measurements of Southeast Asian tigers and leopards. Diamonds are sample means, open circles are 95% confidence intervals, and the solid bars represent the range between smallest and largest values encountered in this sample. All values generated from pooled left and right side data.

South Asia Primary Track Measurements

Measurements of tiger and leopard sign from Nepal are summarized in Figure 5-19. As with the Southeast Asian sample, there is no overlap of adult tiger and leopard sign for any of the track dimensions considered. Hind total width was able to distinguish between male and female tigers with no overlap. All six dimensions were capable of distinguishing male from female tigers at the 95% confidence interval.

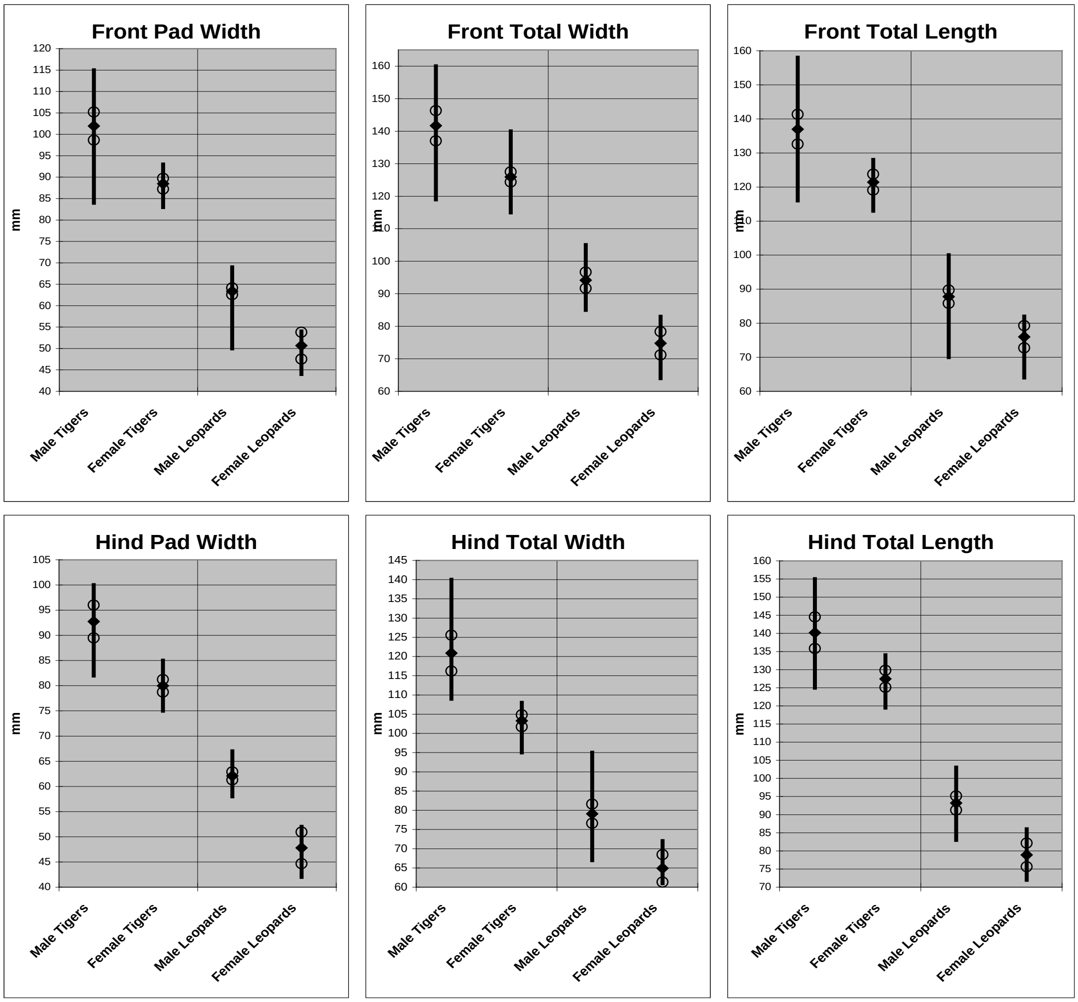


Figure 5-19. Summary of primary track measurements of South Asian tigers and leopards. Diamonds are sample means, open circles are 99% confidence intervals, and the solid bars represent the range between smallest and largest values encountered in this sample. All values generated from pooled left and right side data.

Other Measurements

Figure 18 summarizes 4 additional measurements taken during controlled surveys. Stride and straddle measurements were not recorded for leopards due to the fact that their movements within their enclosures were not comparable with those of the tigers measured (e.g. the tiger stride and straddle measurements were taken along trackways made by tigers moving in a straight line at a normal gait while leopards movements were, without exception, not representative of such a straightforward gait). Both front and rear pad lengths were capable of distinguishing tigers from leopards in all cases. Additionally, straddle width correctly separated male from female tigers in all cases although the sample size for this comparison was low (n=12 (4 males and 8 females)).

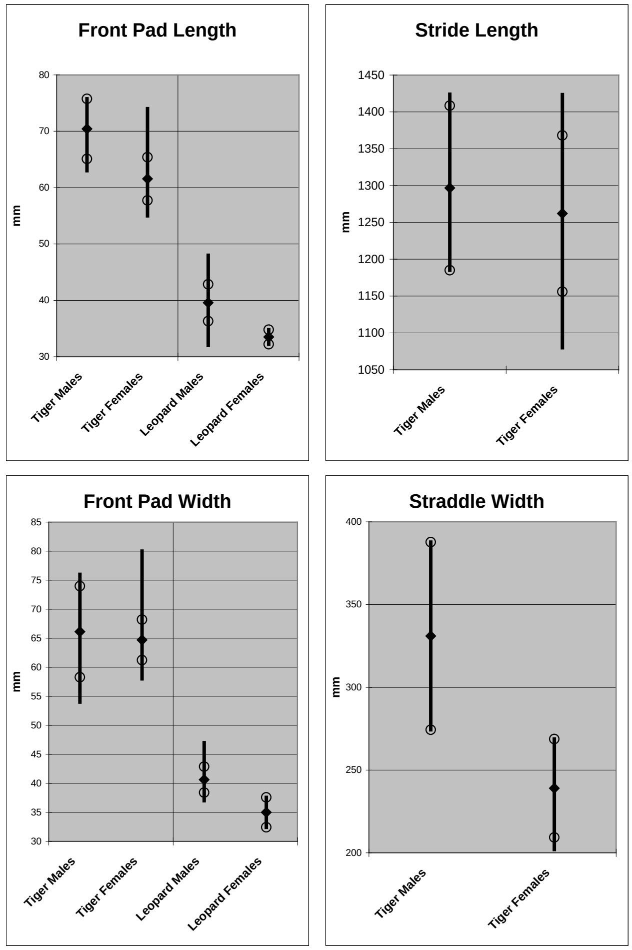


Figure 5-20. Summary of other sign measurements from Southeast Asian tigers and leopards. Diamonds are sample means, open circles are 95% confidence intervals, and the solid bars represent the range between smallest and largest values encountered in this sample. All values generated from pooled left and right side data.

Change in track size over time: Leopards vs. Tigers

Figure 5-21 maps the maximum age at which the size of young tiger tracks overlaps that of the largest adult leopards. The graph shows how the width of rear tiger pads changes with age. Given that tigers frequently "damage" their front tracks with their rear tracks as they walk, rear padwidth was the track feature that we could most consistently get clean measurements from in both wild and captive measurement settings.

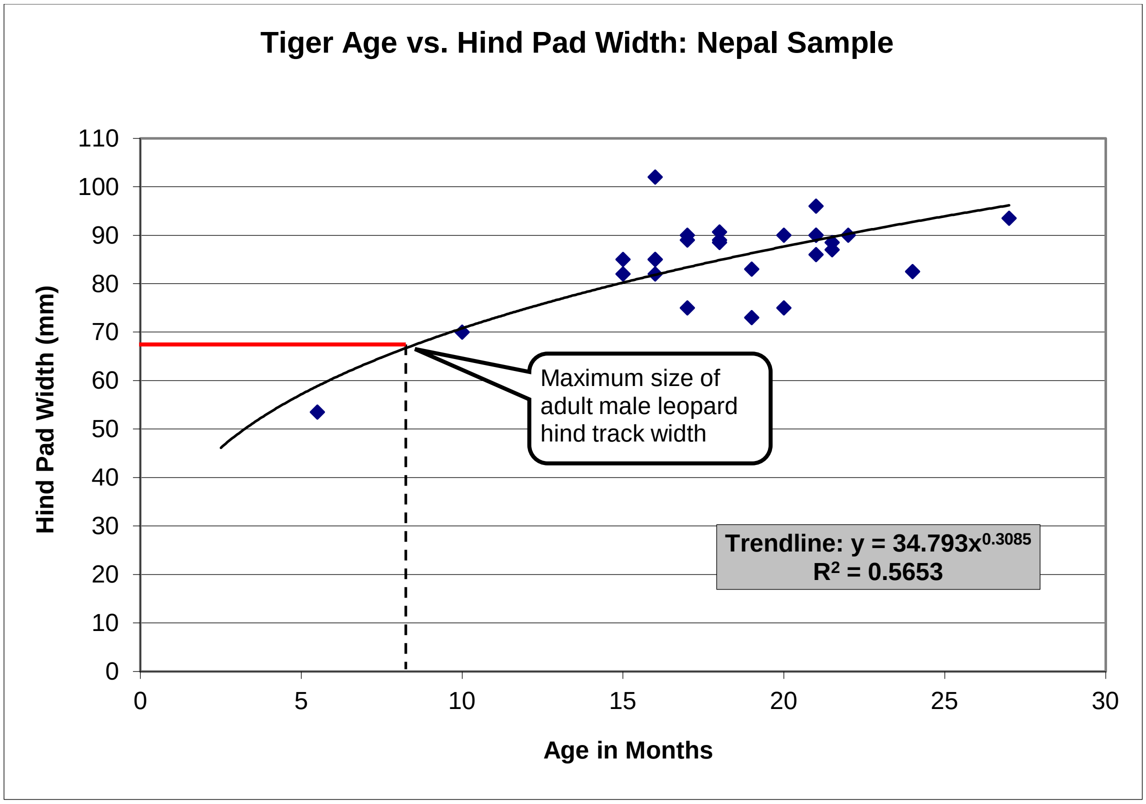


Figure 5-21. Change in rear pad with size as tigers mature. All points shown are from tigers. The red line represents the maximum rear pad width measurement of leopards in this study. Overlap in pad width size between young tigers and adult leopards does not extend beyond 8 months of age in tigers.

Figure 5-21 shows the age at which tracks of young tigers cease to overlap with leopards.

Male:Female ratios

Male:Female ratios for the two datasets considered are summarized in Table 5-16.

Table 5-16. Male:female ratios of sampled tiger populations derived from track measurements.

Survey Area	Dates	Male:Female ratios as deduced by track measurements
WFC Core Area (this study)	1997	2:5
WFC Core Area (this study)	1998	1:4
WFC Core Area (this study)	1999	5:9
WFC Core Area (this study)	2000	6:9
TYW Wildlife Sanctuary	2001	1:2 (1 indeterminate)

Discussion

This study illustrates the utility of track measurements in interpreting data readily available to researchers in the field without the need for specialized equipment or extensive training. When evaluated carefully, track data can contribute significantly to our understanding of the distribution and demographic makeup of tigers in an area. Because track dimensions are smaller in Indochinese tigers than in Bengal tigers, sizes and inferences described for studies involving Bengal tigers should be avoided when analyzing data collected within the geographic range of Indochinese tigers.

Several track dimensions allow one to make high confidence conclusions about the species and sex of the individual that deposited the track (see Figure 5-22). Such information can be used to estimate sex ratios and to increase the accuracy of abundance estimates based on sign data.

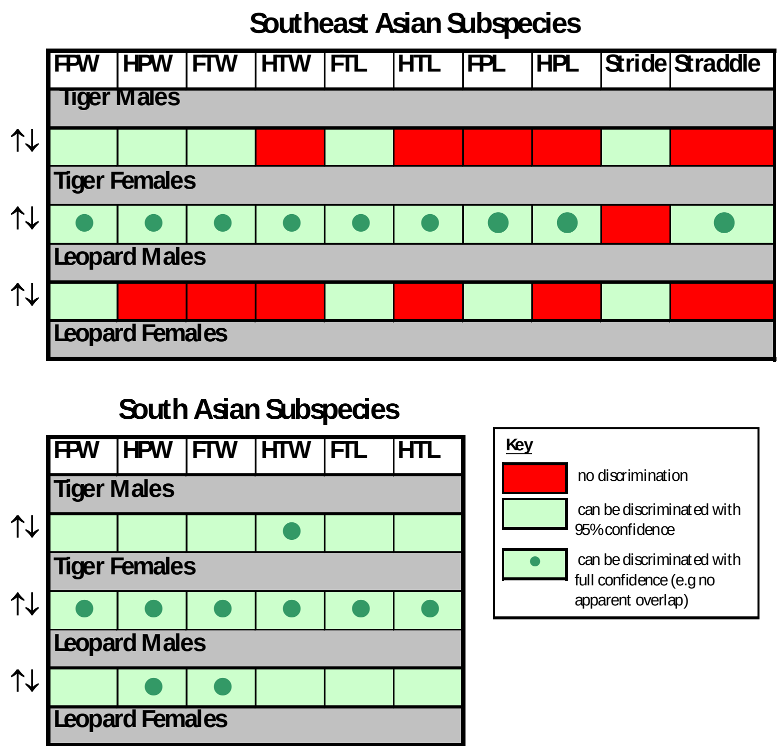


Figure 5-22. Ability of track measurements to discriminate between demographic categories of Southeast Asian and South Asian large cats.

Of the track dimensions considered, those with the strongest diagnostic value--e.g. rear pad widths--are also most likely to be encountered in the field as they are deposited ***over*** front tracks when tigers “directly register” in their normal gait.

The most stable dimensions (in terms of relative variability among several sources of variation) are front and hind pad width. These measurements are commonly collected in field surveys for large cats. These data therefore should give field researchers further confidence in their interpretations of both current data and of those from previous surveys. The correspondence of predicted male:female ratios with those measured in other studies is further evidence of the robustness of these guidelines.

There has been some concern among field practitioners that the size of tracks made by some tigers will overlap with the size range of tracks made by adult leopards—thus ruling out the use of track diagnostic techniques in areas where both tigers and leopards occur. On the contrary, data from this study suggest that the only demographic group of tigers that could possibly overlap with leopards is juveniles and that such overlap only occurs for a brief period in the tigers' development. Furthermore, it is likely that tiger tracks of sufficiently small size to overlap with the size range of leopards will accompanied by tracks of the adult mother.

The data presented here are from a relatively small dataset and to further develop these patterns, additional data should be sought from situations where the age and sex of tigers can be established independent of track dimensions. However, this conservative analysis of the data (i.e. 95 % confidence intervals) suggests that significant diagnostic power is available to investigators trying to maximize the value of a readily accessible source of field data.

Appendix 2. Summary of GIS Data Used in Developing Tiger and Tiger Prey Models in Western Thailand

Name of Theme	**Type** [a]	Data Attributes	**Extent**	**Notes** (Precision, resolution, geographic accuracy, base data, processing)	**Source** [b]
International boundaries	*polygon*	•	*Asia*		*3,6*
Thailand Protected Areas	*polygon*	• Name of protected area • Presence/absence of large mammal spp. Based on previous studies	*Thailand*		*4*
Thailand administrative units	*polygon*	• Name of administrative region • Name of province • Name of district	*Thailand*		*5*
Survey Units	*polygon*	• Survey effort (km of survey/km2 • Landcover diversity • Ruggedness • Prey quality index • Tiger Presence/absence	*Study area*	• *Attributes based on aggregated data based on other raster and vector data themes described here* • *Automated delineation based on DEM + procedure described in text*	*2*
Survey routes	*line*	• Date of survey • Distance	*Study area*	• *Acquired using handheld GPS* [d] • *Waypoints recorded at least every 200 meters*	*1*
Transect locations	*point*	• Date • Dung/pellet group amounts by species • Vegetation class	*Study area*	• *Acquired using handheld GPS*	*1*
Hunting routes	*line*	• Intensity of use	*Buffered study area*	• *Mapped in consultation with local hunters and other residents (see Methods)*	*1*
Human activity zones	*polygon*	• Intensity of use	*Buffered study area*	• *Mapped in consultation with local hunters and other residents (see Methods)*	*1*
Contours	*line*	• Elevation	*WFC*	• *From 1:50,000 scale maps with 20m between contours*	*4*
Elevation model	*TIN*	• Elevation	*WFC*	• *From contours, peak points, and streams as breaklines*	*2*
Elevation model	*DEM*	• Elevation	*WFC*	• *50 m cells* • *derived from triangular integrated network based on contour maps described above*	*2*
Slope	*grid*	• Degree slope	*WFC*		*2*

		• Percent slope			
Ruggedness	*grid*	• Ruggedness index (250 m, 500 m circular neighborhoods	*Western Forest Complex*	• *Ruggedness index is standard deviation (in meters) of grid centroids within a circular neighborhood of each cell* • *Edge effects within 500 meters of DEM surface used to generate grid*	*2*
Rainfall	*grid*	• Avg. annual amt. (20 year mean) • Avg. annual amt. (study period mean)	*Buffered study area*	• *20 years of monthly amouts* • *Interpolated from 9 point locations surrounding and within the study area*	*7,2*
Temperature	*point*	• Avg. annual	*Buffered study area*	• *20 years of monthly amounts* • *Interpolated from 9 weather station locations surrounding and within the study area*	*7,2*
Villages	*point*	• Male/female population • Education rate	*WFC*	• *Not all data attributed* • *Attribute data from ~1996*	*8*
Travel Routes	*line*	• Type of route	*Buffered study area*	•	*8,1*
Streams	*line*	• Class • Seasonality	*Study area*	• *Evidence that seasonality (i.e.permanent vs. ephemeral) is not accurate*	*8,1*
Forest cover	*polygon*	• Forest cover	*Asia*	• *History of data not known* • *Low precision (inaccuracies up to at least 10 km)*	*3*
Landcover	*polygon*	• Landcover class	*Study Area*	• *Based on visual interpretation of satellite and aerial photograph images.* • *Accuracy of landcover class attribute questionable (see discussion in text)*	*8,1*

[a] *Coverage types*: DEM = Digital elevation model; TIN = Triangulated irregular network
[b] *Sources:*

1. *Data collected in this study.*
2. *Data derived from other themes listed here.*
3. *World Conservation Monitoring Center.*
4. *Various sources including Thai Royal Survey Departement, Department of National Park, Wildlife, and Plant Conservation, Department of Rural Development (Thailand Ministry of Interior).*
5. *Department of Rural Development (Thai Ministry of Interior)*
6. *Environmental Research Systems Institute.*
7. *Thai Royal Meteorological Department*
8. *Department of National Park, Wildlife, and Plant Conservation*

Appendix 3. Field Data Sheets Used for Recording Wildlife Encounters in Western Thailand

การสำรวจเส้นทางเดินของเสือโคร่ง • Likely Tiger Travel Route Survey

สรุปข้อมูล • Summary Information

การสำรวจหมายเลข Survey ID	
ระยะทางที่เดินทั้งหมด (ก.ม.) Estimated total kilometers traveled	
จำนวนร่องรอยของเสือโคร่งที่พบ # of tiger signs encountered	
ความชัดเจนของรอยเท้าทั้งหมด Overall Tracking Quality Index	
ความหนาแน่นของร่องรอย (ร่องรอย/ก.ม.) Sign Density (# signs/km)	
ระยะเวลาที่ใช้ในการสำรวจเส้นทางนี้ Total time spent surveying this route	

วันที่ Date:	ชื่อผู้สำรวจ Name(s) of surveyor(s):
พื้นที่อนุรักษ์ Protected Area:	
หน่วยพิทักษ์ป่า Substation:	
จำนวนวันหลังจากฝนตกครั้งสุดท้าย Days since last Rain:	
ตำแหน่งที่สำรวจ (ถนน ทางเดินเท้า ลำห้วย) Feature Surveyed (Road, Trail, etc.):	

ชนิดป่า Forest Type	
MD	ป่าเบญจพรรณ
MB	ป่าเบญจพรรณ/ไผ่
DD	ป่าเต็งรัง
DB	ป่าเต็งรัง/ไผ่
HE	ป่าดิบเขา
DE	ป่าดิบแล้ง
ME	ป่าดิบชื้น
P	ป่าสน
G	ทุ่งหญ้า
S	ที่ราบทุ่งSavannah
2	พื้นที่ป่าถูกบุกรุก

ความชัดเจนของรอยเท้า Tracking Quality Index	
ระหัส Code	รายละเอียด Description
3	รอยเท้าชัดเจนดีมาก All footsteps clearly visible and well-defined
2	รอยเท้าชัดเจน 50% At least 50% of footsteps easily recognizable
1	รอยเท้าชัดเจนต่ำกว่า 50% Some footprints visible but less than 50% detectible
0	รอยเท้าไม่ชัดเจนเลย footprints indetectable

จุดที่ Way-point #	ตำแหน่ง UTM UTM Coordinates		ชนิดป่า Forest Type	ความชัดเจนของรอยเท้า Tracking Quality Index
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		

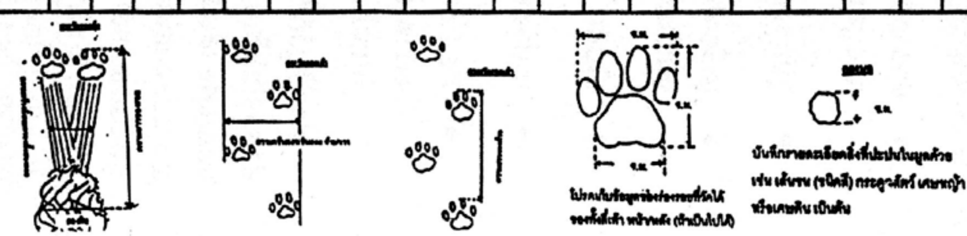
จุดที่ Way-point #	ตำแหน่ง UTM UTM Coordinates		ชนิดป่า Forest Type	ความชัดเจนของรอยเท้า Tracking Quality Index
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		

จุดที่ Way-point #	ตำแหน่ง UTM UTM Coordinates		ชนิดป่า Forest Type	ความชัดเจนของรอยเท้า Tracking Quality Index
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		
	E	N		

ตารางสำหรับบันทึกร่องรอยของเสือโคร่งอยู่ด้านหลัง Record tiger sign encounters on opposite side of this sheet

บันทึกการพบร่องรอยเสือโคร่ง • Tiger Sign Encountered

จุดที่ Way-point #	ชนิด Species	ลักษณะของร่องรอย Type of sign	ตำแหน่ง Placement		อายุของร่องรอย(ใหม่/เก่า) Age of sign (old/new)	การวัดขนาด Measurements																	หมายเหตุ Notes
						ขน/LF			ขล/LH			ขน/RF			ขล/RH			รอยคุ้ย Scrape		ช่วงก้าว Stride	ช่วง ข/ข Straddle	มูล Feces	การบันทึกภาพ มี/ไม่มี Photo? (Y/N) สิ่งที่ปะปนในมูล Feces Contents
						อก PW	กม TW	ยม TL	อก PW	กม TW	ยม TL	อก PW	กม TW	ยม TL	อก PW	กม TW	ยม TL	ก W	ย L				



ลักษณะของดินในตำแหน่ง Substrate Type	
DD	ฝุ่น
M	โคลน/ดินเปียก
H	ดินแข็ง
FS	ทรายละเอียด
CS	ทรายหยาบ
L	ซากใบไม้
S	ก้อนหิน
G	หญ้า

ตำแหน่ง Placement	
M	เป็นดินกลางถนน หรือระหว่างรอยล้อรถ
R	บริเวณรอยล้อรถ
E	นอกเส้นทาง

ชนิดสัตว์ป่า Species	
T	เสือโคร่ง
L	เสือดาว
J	หมาจิ้งจอก
D	หมาใน
B	หมี

หมายเหตุ: สำหรับสัตว์ชนิดอื่นที่ไม่ได้ระบุไว้ให้เขียนชื่อเต็ม

ลักษณะของร่องรอย Type of sign	
P	รอยเท้า
S	รอยคุ้ย
C	รอยข่วน
SP	ปัสสาวะ
F	มูล
DO	เห็นโดยตรง
B	ซากเหยื่อ
V	เสียงร้อง

APPENDIX 4. TRACK DATA USED IN THE ANALYSIS

Individual ID of animal	Zoo/Breeding Center/Protected Area*	Date of track measurements	male/female	Age class	Age at time of measurement (in # of months old)	PW	PL	TW	TL	PW	PL	TW	TL	PW	PL	TW	TL	PW	PL	TW	TL	Avg. Stride Length	Avg. Straddle length
F1	TYW		?	j		65		93	105	68													
F2	TYW		?	j						85		144	116	77		121	122	85		130	115		
F3	ENP		?	j		75	62	113	125														
F4	TYW		?	j																			
F5	TYE		?	j														70		104	105		
F6	TYE		?	j		78		90	121	71		110	112	75		110	126	73				1135	
F7	TYE		?	j																			
F8	TYE		?	j		75		105	120	68				75		105	130	70		105	115	1290	
F9	TYE		?	j										72		91	101						
PCF cub1	PCF		f	j										55		80	80	55		60	75		
PCF cub1	PCF		f	j										60		83	82	50		70	81		
PCF cub1	PCF		f	j						50		60	75										
Jade	PCF		f	j		62		92	101	59		101	98	62		94	113	63		104	105		
Sang ta wan	WLTB		f	sa		76	59	114	110	82		118		74	65	115	117	82	61	124			226
Dto	KP	29-May-99	f	a		81		115	125	89		140	128	83		117	128	86		140	125	1163	268
Thai	KP	29-May-99	f	a	108	78		98	113	81		114	113	76		99	107	81		125	118	1080	
TYW1	TYW	16-Jun-99	f	a						85		144	116	77		121	122	85		130	115		
Kmik	PT	6-Oct-00	f	a	180	75	60	93	120	80	64	109	122	75	62	95	120	77	61	112	114	1333	
Erawan1	ENP	6-Nov-00	f	a		81	69	131	133	90	74	140	132										
Tomi	PT	6-Oct-00	f	a	24	82	70	129	125	78	60		127	80	67	105	125					1423	255
Sai Rung	WLTB	14-Mar-02	f	a		83	63	107	115	87	61	116	115	86	67	108	119	88	65	115	110	1370	244
Jome na pa	WLTB	7-Dec-01	f	a	25	75	58	100	118	81	59	111	106	75	60	99	116	81	59	115	125	1217	202
Sang ta wan	WLTB	7-Dec-01	f	a	22	76	59	114	110	82		118		74	65	115	117	82	61	124		1195	226
Mup	PT	6-Oct-00	m	a	24	90	80	135	140	100		149		91	70	110	135	93	72	143	125	1315	
Pa yu junior	WLTB	3-Dec-01	m	a	29	85	54	115	113	99	65		136	86	63	112	126	97		126		1273	308
Payak	WLTB	7-Mar-02	m	a	34	95	72	126	127	100	75	150	135	96	76	127	135	98	75	145	132	1260	
Maek	WLTB	7-Dec-01	m	a	31	98	72	132	127	106	75	144		99	74	138	133	103	74	155	128	1424	310
Sai fah	WLTB	3-Dec-01	m	a	29	81	55	119	117	94	66	140	123	89	63	115	121	93	63	136	117	1230	375

TYW = Thung Yai Naresuan (West) Wildlife Sanctuary, TYE = Thung Yai Naresuan (East) Wildlife Sanctuary; ENP = Erawan National Park; PCF = Pattaya Crocadile Farm; WLTB = Luang Ta Bua Temple; KP = Khao Pratabchang Wildlife Confiscation and Breeding Center; PT = Phnom Thamal Zoo (Phnom Penh).

APPENDIX 6. CONSERVATION MANAGEMENT REGIONS IN CAMBODIA

To provide a framework for conservation planning (see chapter 6) and for ongoing monitoring and evaluation activities, a system of *Conservation Management Regions* based on patterns of physiography, climate, geology and soils, and vegetation is presented below. The regions are essentially those outlined by Ashwell (1997) with the addition of a coastal / marine zone and some minor adjustments. Although the boundaries of the original regions have been adapted by various authors to reflect different emphases, the regions have been used in numerous biodiversity and protected area planning documents (ICEM 2003a; Shields *et al.* 2004). The eight zones are as follows (also see Map 4).

Northern Plains: This extensively forested region has a mostly humid, hot climate with a medium to long dry season in which rainfall decreases significantly from west to east. Extensive humid low elevation dry and semi-evergreen forests occur primarily on old alluvial soils, and sub-humid deciduous forests of a range of soils types.

Eastern Forests: This extensively forested region has a very humid to humid hot climate with a medium length dry season. It is characterised by variable geology and soils though alluvial soils are generally not extensive. The region supports extensive deciduous forests and some humid lowland and medium elevation dry and semi-evergreen forests.

Kampong Cham: Kampong Cham is the centre of a relatively small and homogeneous landscape with a humid to very humid, hot climate and a medium length dry season. Productive latosol and regur soils derived from basalt now support extensive agriculture, particularly rubber, and some small remnant areas of humid lowland evergreen forest. Grey and cultural hydromorphic soils on older alluvium also support agriculture while brown alluvium and alluvial lithosol soils on recent alluvium support both flooded forest and agriculture.

Mekong Delta: This region features a dry to humid, hot climate with a medium length dry season and is generally characterised by extensive agriculture associated with high population density. Alluvial lithosols and brown alluvial soils also support flooded forest, grasslands and marsh in floodplain areas.

Southwestern Forests: This extensively forested area features very humid climates with a short dry season varying from hot in the lowland to cool at altitude.

Coastal and Marine: This area is largely open ocean but also includes the terrestrial/marine boundary, coastal plains, and coastal estuaries.

Northwest: This relatively small but heterogeneous landscape features a dry hot climate with a medium length dry season. It is comprised primarily of the Battambang Plain with fertile brown hydromorphic soils on recent alluvia supporting extensive agriculture and sub-humid deciduous forest. The Pailin - Phnom Malai plains area features limestone hills together with productive latosol soils on limestone and basalt supporting humid lowland evergreen forest and, increasingly, agriculture. The Samlaut Hills feature very humid low and medium elevation evergreen forests on poor sandstone soils similar to those of the Cardemom Ranges.

Tonle Sap: Annually flooded lacustrine alluvial soils dominate a singular landscape supporting flooded forest, marsh, grass savannahs and extensive agriculture. This area has a dry to humid, hot climate with a medium length dry season.

APPENDIX 7. METADATA FOR GEOSPATIAL DATASETS USED IN THE CAMBODIA GAP ANALYSIS.

Name	Author (Original Data)	Year	Source, Other Notes
Aerial Photo Database - Oblique Images	BPAMP	2005	BPAMP
Aerial Photo Database - Vertical Images	BPAMP (BPAMP)	2005	BPAMP
Amphibian Range Maps (Global Coverage)	Global Amphibian Assessment	2004	IUCN/SSC – CI/CABS Biodiversity Assessment Unit; Center for Applied Biodiversity Science; 1919 M Street N.W.; Suite 600; Washington , DC 20036, United States;Fax: 202-912-0772 iucn@conservation.org
Biodiversity Survey Effort by Taxa	BPAMP (BPAMP)	2005	BPAMP
Cambodia Boundary-Mainland	DoG?	?	Cambodia Department of Geography
Cambodia Boundary-Offshore Islands	DoG?	?	Cambodia Department of Geography
Cambodia Landcover and Vegetation Formations	BPAMP (JICA)	2005	BPAMP
Cambodia Reconnaissance Survey Digital Database (JICA-RSDD)	JICA (DoG and others)	2004	DoG [Large collection of Spatial Data available as a set including DEM / elevation (grid), Major rivers, administrative boundaries (province, district, commune, village), landcover, geology, transportation, etc.]
Commune Boundaries and Codes	DoG	?	Cambodia Department of Geography
Commune-Level Socio-economic Data	Seila	2005	Seila Programme http://203.189.130.76:8080/database/index_en.asp?language=en&pgid=13&title=0 Attribute data on population and many other indicators. Associated spatial data (commune boundaries with unique code) available from DoG
Coral Reef Distribution	DoF	2003	Cambodia Department of Forestry (MAFF)
Depth Zones of Cambodia Coastal Areas	BPAMP	2005	BPAMP
District Boundaries and Codes	DoG	?	Department of Geography (Ministry of Land Management, Urban Planning, and Construction)
Estuarine Areas	BPAMP	2005	BPAMP
Fisheries Concessions	MRC (DoF)	2002	MRC http://www.mrcmekong.org/tsd/map_list.htm
Forest Concession boundaries	MAFF	pre-2003	Department of Watershed Management (MAFF)
Geology			
Human Footprint	MIME	?	
Important Bird Areas (Target Conservation Areas for Birds)		2005	BPAMP (modelled human impact based on roads, villages, and aerial surveys)
Inundation areas	BirdLife International	2003	BirdLife Office-Phnom Penh
Key Biodiversity Areas	MRC	2004	Mekong River Commission http://www.mrcmekong.org/tsd/map_list.htm
Land / Economic Concession Boundaries	BPAMP (BirdLife International, CI)	2005	BPAMP
Landsat Satellite Images	BPAMP	2005	BPAMP
Large Roadless Areas	NASA	2005	NASA-authorised distributors
Legris and Blasco Vegetation Map	BPAMP	2005	BPAMP

MAFF Protected Forest Boundaries	F. Blasco M.F. Bellan D. Lacaze	1997	Ecocart http://www.ecocart.com
Mammal Range Maps of Southeast Asia	MAFF	2003?	MAFF
Mining Concessions	SE Asia Mammal Database	2004	SE Asia Mammal Database (SAMD) http://www.ieaitaly.org/samd/B5.htm
MoE Protected Area Boundaries	BPAMP	Various	BPAMP
Phnom Prich Vegetation Formations	MoE	2004	MoE
Potential Hydropower Sites	BPAMP	2005	BPAMP
Protected Area Archive of Satellite Images of Cambodia	BPAMP (MIME)	2005	BPAMP
Protected Area Boundaries	NASA	2004	NASA-Online information http://asterweb.jpl.nasa.gov/paa
Protected Area Stations	BPAMP (MoE+MAFF)	2005	BPAMP
Protected Area Threats	BPAMP	2005	BPAMP
Protected Area Values	BPAMP	2005	BPAMP
Protected Area Zoning	BPAMP	2005	BPAMP
Provincial Boundaries	BPAMP	2005	BPAMP
Rivers, ponds, and pools	DoG	?	DoG
Roads + Rail	DoG	2000?	DoG
Scanned, Georeferenced 1:50,000 scale topographic maps	BPAMP (JICA+detailed updates from various projects)	?	DoG
SEA Protected Area Boundaries and attributes	Ministry of Transport	various	MoPWT
Seagrass Bed Distribution	BPAMP (WCPA and Thailand Ministry of Environment)	2004	IUCN (information online) http://sea.unep-wcmc.org/wdbpa/
Seed-producing Focal Tree Locations	DoF	2003	DoF
Sensitivity to vegetation cover alteration	Treeseed Project/FA	2004	MAFF/Treeseed Project ctsp@online.com.kh
Snoul Vegetation Formations	MRC	2004	MRC http://www.mrcmekong.org/tsd/map_list.htm
Target Conservation Areas - Amphibians	BPAMP	2005	BPAMP
Target Conservation Areas – Freshwater Habitats	BPAMP	2005	BPAMP
Target Conservation Areas - Mammals	BPAMP	2005	BPAMP
Target Conservation Areas - Reptiles	BPAMP	2005	BPAMP
Target Conservation Areas – Vegetation Formations	BPAMP	2005	BPAMP
Vertebrate Point Occurrence Records	BPAMP	2005	BPAMP
Village-Level Socio-economic Data	BPAMP (Various NGOs/Government Agencies)	2005	NGOs, MoE, MAFF
Villages and cities	Seila	2005	Seila Programme http://203.189.130.76:8080/database/index_en.asp?language=en&pgid=13&title=0
Virachey Vegetation Formations	DoG	2002?	DoG
Watershed Boundaries	BPAMP	2004	BPAMP
Wetland Distribution	MRC with additions from MAFF	2005	MAFF Dept. of Watershed Management