UNIVERSITÉ DU QUÉBEC

CRÉATION D'UN SYSTÈME D'INFORMATION GÉOGRAPHIQUE POUR LA SÉLECTION D'AIRES PROTÉGÉES AU TOGO (AFRIQUE DE L'OUEST).

MÉMOIRE DE RECHERCHE

PRÉSENTÉ À

L'UNIVERSITÉ DU QUÉBEC À RIMOUSKI

Comme exigence partielle

du programme de Maîtrise en Gestion de la faune et de ses habitats

PAR

PIERRE-EMMANUEL CHAILLON

DÉCEMBRE 2006

AVANT-PROPOS ET REMERCIEMENTS

Il n'est pas de travaux sans remerciements ni de maîtrise qui puisse se résumer au simple contenu scientifique de celle-ci. Il m'est donc permis ici de combler à ces manques.

Il ne m'est jamais venu à l'esprit, sans doute par amour des chemins détournés, de faire mes recherches de maîtrise au Québec sous le fallacieux et trop facile prétexte d'être inscrit à l'Université du Québec à Rimouski. On n'arrive jamais très loin sans passion et c'est à l'assouvissement de cette dernière qu'était assujetti le choix de mon projet de maîtrise. Lorsque Sophie Durlot, alors directrice du Parc National de Fazao-Malafakassa, nous a contacté, mon frère et moi, pour faire quelques recherches sur le sol togolais, il m'a immédiatement semblé que l'Afrique conviendrait parfaitement, aussi bien pour assouvir ma curiosité scientifique que pour laisser mes humeurs vagabondes prendre leur juste liberté. Il eut été fort impensable dans bien des universités de part ce vaste monde d'imaginer mener à bien un tel projet parti de rien et même de juste l'imaginer. Mais, par chance, il y a à l'UQAR quelques professeurs qui osent l'originalité plus que d'autres et je dois remercier ici le Dr Richard Cloutier qui dès le départ nous a soutenu et aidé, me permettant de terminer mon diplôme l'esprit plus en paix… C'est donc sous sa direction et celle conjointe d'Alain Caron, qui s'avéra si souvent déterminante au

cours des années qui suivirent (béni soit le nom d'Alain sur sept générations), que je commençais ce projet. Mais le plus facile fût sans doute de commencer. Quand on commence, il y a toujours la même soif qu'on ne peut assouvir, cette même passion qui brûle et qui éclaire les chemins qu'on imagine. Car le désir ce n'est que cela, une flamme qui se nourrit d'air et de nouveauté et s'asphyxie dans les mondes clos. J'avais rêvé de l'Afrique et j'avais rêvé d'un projet comme celui-ci, et maintenant c'était là, à portée de la main. Il suffisait d'y croire et de continuer, continuer jusqu'à ce que l'imaginaire devienne essentiel, jusqu'à faire la réalité à sa façon. Dans cet exercice délicat qu'est la transformation du rêve en réalité, étrange alchimie du désir, mon frère Corentin fut plus qu'un soutien mais aussi un modèle. Rêver demande une grande lucidité, lucidité que j'ai toujours su trouver en lui. Encore aujourd'hui, dans nos aventures diverses, je lui dois beaucoup (mais peut-on attendre moins d'un frère jumeau ?).

Et puis il y eut l'Afrique.

Lentement, au fil des rencontres et des découvertes, au hasard des pistes et des villages, dans le berceau des jours ou dans la nuit la plus épaisse, des images, des sons et des couleurs sont venus me parler de cette terre que je découvrais et qui m'attachaient à elle. Bientôt, ce qui devait n'être que des prises de données scientifiques, des validations de terrain, griffonnées sur les pages d'un carnet un peu sale, prit une forme inattendue. Le travail avait cessé d'être vraiment un travail. Encore aujourd'hui tout ce que j'ai vécu là-bas, ce que j'y ai appris, les gens que j'y ai rencontrés, comptent plus que les résultats de n'importe quelles recherches ou enseignements formels. C'est avant tout à eux que je dédie cette maîtrise. J'étais venu chercher un diplôme, j'y ai trouvé une leçon de vie et d'humanité.

Il y avait des lacs qu'on croyait pouvoir tenir dans la main et des fleurs qui occupaient tout l'horizon. Il y avait des hommes bons et d'autres mauvais. Il y avait des mains tendues comme des ponts, des sourires comme des sorties de tunnels et des problèmes sans solution qui n'atteignaient pas le désespoir. Il y avait l'éphémère, la peur et la misère, comme un noyau dur au centre de tout et qui rehaussait toutes les couleurs et tous les parfums. Il y avait surtout cette liberté qui ne faisait aucune concession et qui défaisait toutes les chaînes et tous les complexes, qui abattait tous les murs, qui arrachait tous les liens, qui libérait l'homme de lui-même. Nous allions à la file indienne, Corentin, Boundjou, Romaric et moi-même, parfois ensemble, parfois chacun de notre coté, à la manière d'une lente procession, fouillant, explorant et remplissant carnets et fiches de terrain. Nous laissions se dérouler devant nous ce pays avec toutes ses collines qui ondulaient comme des vagues. Les jambes souffraient, les corps apprenaient. Toutes les lignes de fuite qui avaient jusqu'alors barrées ma vue se rejoignaient ici, sous les voûtes remuantes du ciel, entre les arcades mélangées des arbres, et je continuais d'avancer avec les autres. Les parcelles succédaient aux parcelles, les découvertes se multipliaient. L'horizon s'était agrandi jusqu'à occuper la grandeur d'un oeil, jusqu'à remplir l'espace d'un cœur. Il n'y avait plus que la brousse enivrante qui égratignait les certitudes et qui désapprenait l'homme. Le dépouillement polissait le monde, nous forgeait de nouvelles jambes et de nouveaux yeux. Il y avait aussi des hommes graves, pauvres de beaucoup de choses, mais pas de dignité ni de générosité. Des hommes sans artifices, sans grands apparats, mais des hommes riches parce qu'ils pouvaient tout offrir. Leur hospitalité est comme une couronne qui ferait rougir bien des rois mieux nantis.

Merci à Romaric, qu'un bienheureux hasard fit croiser ma route et qui jamais ne se départit de son sourire, même lorsque l'eau vint à manquer. Il ne connaissait que des amis et m'a ouvert une à une les portes de son pays, me faisant découvrir plus que ce que je pouvais imaginer découvrir. À ses côtés, je ne fut jamais un étranger et j'espère pouvoir lui rendre un jour ce qu'il m'a donné.

À Boundjou qui fut prodigue en conseils et en enseignements tant sur le terrain qu'en dehors et qui met tant d'acharnement à continuer ses rêves

À la brigade forestière de Kalaré et particulièrement Rabbi avec qui les courses-poursuites derrière les braconniers prennent vites des allures de Western.

Aux forestiers de Fazao et particulièrement le CB Agbodgi pour m'avoir montré que rien n'est jamais tranché dans la vie, même lorsqu'on court derrière des braconniers. C'était une chose de jouer aux gendarmes et aux voleurs, c'en était une autre que de

bousculer la vie d'une famille et de se heurter à la misère. Il n'y avait plus, certaine fois, de bien ou de mal, il y avait juste des hommes qui essayaient de vivre. Ce n'est pas grand chose essayer de vivre. Mais parfois c'est déjà beaucoup. Au nom de quel parc, de quel principe ou de quelles lois pouvait-on empêcher un homme de vivre ? Il n'y a pas beaucoup de livres ou d'articles scientifiques dans la longue bibliographie de ma maîtrise qui auraient pu me préparer à cela. La nature sans cette bête nécessité de survivre, on lui consacre des chapitres entiers, on lui met des tuteurs bien droits et des théories bien solides, mais pour tout le reste, il reste quoi ? J'ai compris un peu plus que les livres ne vivent pas toujours dans le même monde que les hommes. Des chercheurs dans leurs bureaux ou dans leurs campagnes douillettes avaient oublié les oubliés. Un détail sans doute ici, mais pas là-bas.

À toute la famille Landozz pour leur aide précieuse et l'accueil qu'elle nous a fait.

À Luc Sirois pour ses conseils et pour le prêt du photomètre.

À Dominique Berteaux et Éric Vidal pour leurs relectures attentives.

Enfin, merci

Aux matins africains. Quelques-uns de ces matins où un rayon de soleil fait l'or, où un café remplit un ventre, où un sourire fait le soleil, où les corps viennent se frotter au monde comme des chats qui se réveillent.

Ils sont privilégiés ceux que le soleil et le vent suffisent à rendre fous, ceux à qui un frisson de liberté suffit pour braver les plaines stériles de l'incertitude.

À la brousse, un monde préservé, un monde étranger au monde, où les pistes glissent silencieusement comme des fleuves sages, où le jour ne s'habille que de forêts, de savanes et de quelques parures colorées d'oiseaux rares. Un monde sans mémoire qui se recommence tous les jours, qui vit dans l'instant, qui se donne sans retenue et qui meurt sans regret. Là, nous allions à reculons de l'homme, à refaire toujours les mêmes gestes, ceux que chaque homme faisait dans la brousse depuis l'aube du premier jour. Nous réapprenions une seconde puis un jour. Le temps véritable. Autour, la savane courait à perdre haleine. Elle courait avec son pelage de hautes herbes et ses yeux de salines et de mares. Elle courait entre les bras luisants des rivières, venait se jeter contre les forêts-galeries et s'essoufflait sur les montagnes de l'ouest. Elle hérissait son poil d'herbes sèches et de ronces et laissait craquer son corps fumant qui réclamait de l'eau. Les bêtes passaient. Le vol sinusoïdal d'un calao entraîné par le poids de son bec, la chute précise de l'épervier, l'éclair rouge d'une gazelle. La vie sans cesse recommencée.

À la route, étrangère, instantanée. Elle se projette sans conscience, droit devant elle, dans la complexité du monde en progrès. Comme le jet parfait de la lance. C'est une porte horizontale, ouverte devant les autres. Il paraît que la route lave la tête. C'est vrai...

Au voyage où le présent est infini. C'est là et nul part ailleurs qu'il faut aller chercher le bonheur et le plaisir. « Rien n'est à espérer, tout est à vivre… ». Voilà sans doute la grande leçon d'humilité que nous offre le voyage, accepter l'incertitude et vivre la vie immédiate. Vivre, simplement vivre et ne rien désirer d'autre que la fulgurance de l'instant.

À tous ceux qui à coté, par leurs encouragements, leurs conseils et leurs soutiens me permirent de terminer presque dans les temps cette maîtrise et qui pour la plupart m'hébergèrent un jour, une semaine ou plus… Mes parents Odette et Jean-Pierre, mon frère Antoine, mes amis Mélanie, Marie-Pier, Greg, Célia, Niko, Nathaël, Pierrick, Delphine et la maison du bonheur, Maud et les filles du 26, Patrick, Geneviève, Tristan et Jacob, Jacques, Jacinthe et Nymphea, Maude, David et Soleil-Anne, Marie-Hélène. À mes camarades de Gestion de la faune et de ses habitats qui m'ont fait découvrir et aimer le Québec et blanchir quelques belles nuits.

À Monsieur Charbonnier et sa femme Maryse pour être une deuxième famille

RÉSUMÉ

Cartographier et prédire la biodiversité ainsi que les menaces qui pèsent dessus, sont des points cruciaux en conservation. Les méthodes pour la sélection des aires protégées doivent refléter ces priorités et intégrer la biologie de la conservation dans un contexte social et humain. Cependant, dans de nombreuses zones peu ou pas étudiées, comme au Togo, beaucoup de données ne sont pas disponibles et l'utilisation de substituts doit être généralisée.

Cinq objectifs de conservation ont été identifiés selon une revue exhaustive de la littérature. La conservation doit (1) éviter les zones les plus dégradées, (2) protéger le plus possible de biodiversité, (3) prendre en considération les attentes des populations locales et être capable de se projeter dans le futur, (4) anticiper les changements climatiques qui modifieraient la distribution des espèces dans l'espace et, finalement, (5) adopter un schéma d'aménagement compatible avec les précédentes exigences.

Les résultats de la présente étude montrent la possibilité de produire une cartographie fiable de la biodiversité à l'échelle de toute une région en utilisant de façon combinée l'imagerie satellitaire et une série d'inventaires de terrain. L'utilisation de l'imagerie satellitaire permet également de compléter une analyse du paysage et d'identifier les facteurs responsables des changements de l'environnement. Tous les facteurs répertoriés sur notre aire d'étude sont reliés directement ou indirectement au besoin croissant des populations locales d'exploiter les ressources naturelles. Les routes et les chemins représentent les vecteurs de la dispersion des effets de ces facteurs.

Finalement, un réseau d'aires protégées plus efficaces est redessiné en respectant les besoins des habitants de la région et en identifiant avec succès les zones perturbées défavorables à la conservation ainsi que les zones plus riches au niveau de leur biodiversité.

TABLE DES MATIÈRES

LISTE DES TABLEAUX

LISTE DES FIGURES

INTRODUCTION

L'ensemble des écosystèmes, des espèces et des gènes est appelé biodiversité (Wilson, 1988). Ces éléments de la biodiversité ne sont pas répartis uniformément sur l'ensemble de la planète, mais sont influencés par une multitude de facteurs environnementaux à différentes échelles spatiales et temporelles. Les foyers de biodiversité (« hot spots ») qui sont actuellement au nombre de 25 à travers le monde ne couvrent que 1,4 % de la surface terrestre (Brooks et al. 2002) et concentrent respectivement 44 % et 35 % de toutes les espèces de plantes et de vertébrés (Brooks et al. 2001). Pourtant, ces zones d'intérêt particulier abritent plus de 20 % de la population mondiale (Cincotta et al. 2000). La destruction et la dégradation importante d'habitats corrélées à la concordance évidente de ces zones à forte densité humaine et à fort potentiel biologique est la principale cause d'extinction des espèces (Wilson 1988 ; UNEP 1995 ; Balmford et al. 2001). Le rythme d'extinction des espèces est maintenant 100 à 1000 fois plus rapide qu'il ne l'était avant l'avènement de l'humanité (Wilson 1988). Depuis les deux dernières décennies, la biodiversité est donc devenue un enjeu central en conservation et un critère incontournable pour la sélection de nouvelles aires protégées (Myers 2000).

Depuis la création du premier parc national au Yellowstone en 1872 aux État-Unis, les objectifs de conservation ont changé. D'abord basées sur des critères récréatifs, touristiques, les aires protégées ont rapidement eu une vocation de refuge pour la faune et la flore devant le nombre croissant d'espèces menacées d'extinction à travers le monde. Les années 1990 ont marqué un tournant et les efforts de conservation se sont alors focalisés sur les habitats des espèces en voie de disparition au lieu des espèces elles-mêmes. Cette période est celle de la mise en place des thèmes du développement durable, qui accompagne un changement des pratiques de conservation.

Dès lors, la communauté scientifique internationale s'accorde pour reconnaître l'importance d'actions de conservation au niveau des écosystèmes et la sauvegarde de la biodiversité. Certaines méthodes, basées principalement sur l'utilisation d'algorithmes, ont tenté de répondre à une équation simple de protéger un maximum d'espèces pour un coût minimum C'est-à-dire sur le territoire le plus petit possible (Bedward et al. 1992 ; Reid 1993 ; Wilson 1994 ; Strittholt et Boerner 1995 ; Pressey et al. 2002a). Ces méthodes (e.g., analyse de carences) se sont avérées particulièrement efficaces pour répondre à cette question mais ont également montré leurs limites, surtout lorsqu'il s'agit de prendre en compte certains aspects spatiaux (Prendergast et al. 1999 ; Rodrigues et Gaston 2002 ; Oenal et Briers 2002) ou bien la persistance des espèces dans des zones de trop faible superficie ou situées à la limite de leur aire de répartition. Diverses méthodologies basées sur l'utilisation de Systèmes d'Information Géographique (SIG) ont vu le jour démontrant une réelle efficacité pour la prise en compte spatiale des données provenant de supports variés.

Cependant, quelles que soient les méthodes utilisées, on note certaines lacunes récurrentes dans les méthodologies proposées jusqu'alors. Une revue de littérature montre que la plupart des études réalisées à ce jour se focalisent sur des zones très documentées et dont le suivi scientifique est assuré de longue date (Lombard et al. 1997 ; Pressey et al. 1993, 1999). Cependant à l'échelle planétaire, ces zones sont plus rares et celles les plus riches en terme de biodiversité deumeurent parmi les plus méconnues (Ferrier 2002). La transposition de ces méthodologies à d'autres territoires reste donc limitée. Le deuxième point faible relevé dans la littérature est l'absence fréquente de prise en compte du facteur humain en dépit de son importance avérée dans la dégradation et la perturbation des systèmes naturels. Il existe donc un réel besoin de définir une méthodologie simple et transposable, basée sur une approche multicritère, et capable de s'adapter à des zones méconnues et sous-étudiées.

Bien que le Togo soit situé en bordure du point chaud guinéen, les données scientifiques disponibles concernant la richesse et l'écologie de ses écosystèmes sont rares, comme c'est souvent le cas dans de nombreux pays en voie de développement où les ressources financières allouées à la conservation sont limitées (Cincotta et al. 2000). Deux parcs nationaux, cinq réserves de la faune et 46 forêts nationales couvrent pourtant prêt de 20 % du territoire (Ministère de l'Environnement et des Ressources Naturelles du Togo, 1998). Malgré l'importance des superficies protégées, la biodiversité au Togo est gravement menacée et un nombre croissant de conflits dans l'utilisation des ressources apparaît en bordure ou au sein de ces aires de conservation. Depuis quelques années, un programme de réhabilitation des aires protégées a été entamé au Togo par le Ministère de l'Environnement et des Ressources Naturelles et sous le patronage de l'Union Européenne, afin de répondre à ce problème tant social qu'écologique.

C'est dans ce cadre particulier que deux maîtrises en Gestion de la faune et de ses habitats ont été menées à l'UQAR en collaboration avec la direction des parcs nationaux à Lomé au Togo. Pour des raisons de pratique et de faisabilité, ces travaux se sont limités à la région Centrale du Togo, où se situe le parc de Fazao-Malafakassa. Ce dernier est l'un des derniers grands parcs Togolais relativement bien préservés.

Aux vues de la richesse exceptionnelle de cette zone et sachant les risques importants de destruction, il était nécessaire d'acquérir une compréhension détaillée de la situation dans cette région et de prendre des mesures adaptées en terme de conservation. Le travail s'articule autour de deux objectifs généraux : (1) étudier la biodiversité dans la région Centrale du Togo (Chaillon, 2006) dans le but de comprendre les facteurs environnementaux influençant la répartition de la biodiversité à l'échelle locale et (2) déterminer des axes de conservation pour protéger cette biodiversité.

Le premier objectif a été de déterminer à l'aide d'une revue de littérature, les objectifs de conservation d'un réseau d'aires protégées. Ces derniers sont (1) d'éviter les zones les plus dégradées, (2) de protéger le plus possible de la biodiversité, (3) de prendre en considération les attentes des populations locales et être capable de se projeter dans le futur, (4) d'anticiper des changements climatiques qui modifieraient la distribution des espèces dans l'espace et, finalement, (5) d'adopter un schéma d'aménagement compatible avec les précédentes exigences.

La réalisation de chacun de ces objectifs de conservation passait, faute de données disponibles, par la création d'outils informatiques simples permettant de répondre le plus rapidement possible à ces besoins. Les progrès réalisés dans le domaine de l'imagerie satellitaire ont ouvert des opportunités pour étudier les écosystèmes et généraliser à l'échelle du paysage des données recueillies localement.

Au final, le présent manuscrit une méthodologie complète pour la sélection des aires protégées, facilement transposable à d'autres sites, basée sur une approche multicritère, et capable de s'adapter à des zones méconnues et sous-étudiées. Nous proposons également de nouveaux outils pour la sélection des aires protégées et de nouvelles pistes pour l'étude et la préservation de la biodiversité.

ARTICLE

L'article qui suit correspond au chapitre II de ce mémoire. Il a été écrit en anglais et formaté pour soumission dans la revue *Conservation Biology*.

How To Protect Unknown Territories? Protect Less To Protect More

PIERRE-EMMANUEL CHAILLON, CORENTIN CHAILLON, RICHARD CLOUTIER and ALAIN CARON. Département de biologie, Université du Québec à Rimouski, 300 Allée des Ursulines, Rimouski, Québec, Canada, G5l 3A1

Abstract: Our ability to predict species richness and threat is a central key for conservation. Methodology for selection of protected areas must express these priorities and integrate conservation with regional development. However, in Africa, biodiversity data were unavailable and surrogates have to be developed. Five conservation goals based on literature review have been identified: conservation program should (1) avoid most disturbed areas, (2) protect an optimal biodiversity, (3) take in consideration needs of the present-day local human population as well as the needs of their future generations, (4) anticipate global changes and (5) use appropriate conservation area design to maintain biodiversity. Our results suggest that it is possible to produce a reliable coarse biodiversity map at the landscape level using remote sensing data coupled with minimal field survey. Identified threats were linked to the need of inhabitants to harvest new lands. Roads and trails seem to be positively correlated with the spread of human disturbances. Finally, more efficient conservation networks can be designed with respect to inhabitant needs, proper identification of transformed areas and high biodiversity areas.

Introduction

Biodiversity is not distributed equally on earth and is influenced by many environmental factors at various spatial and temporal scales. Owing to the increasing pressure on worldwide biodiversity, conservation biology has received extensive interests for the past two decades. Conservation biologists have developed powerful tools for reserve selection and design of protected areas. Despite these efforts no consensus has been reached concerning conservation selection methods (Prendergast et al. 1999).

Most methods rely on (1) usage of well-known areas and (2) the lack of anthropic considerations. Most previous studies have focused on well-documented areas (Lombard et al. 2001; Pressey et al. 1993, 1999). Williams et al. (1996) and Lesica (1993) used important databases (e.g., inventory) in order to assess and choose conservation areas. However, as noted by Ferrier (2002), many regions are data-poor despite their high biodiversity value. Thus, transposition of methodologies from these previous studies remains limited. Considering anthropogene modifications, only few studies combine ecological data with fine spatial and temporal land use (Durbin & Ralambo 1994; Belbin 1995). Poor understanding of the ecosystem, lack of public consultations, unadapted policies and arbitrary established boundaries of protected areas could lead to failure of conservation territories (Noss & Harris 1986; Hoctor et al. 2000).

Algorithm selection techniques, gap analysis and complementarity-based methods have been developed for the identification and selection of priority conservation areas; gap analysis being the most widespread method (Bedward et al. 1992; Reid 1993; Wilson 1994; Strittholt & Boerner 1995; Pressey et al. 2002a). The use of algorithms and complementarity-based methods may help solving conservation problems especially when there is a need to identify a minimal number of sites containing a maximal number of species (Pressey & Cowling 2001, Rodrigues & Gaston 2002; Siitonen et al. 2002, 2003). The most frequent problems associated with such methods are (1) the necessity of reliable information not always available (Prendergast et al. 1999; Cabeza & Moilanen 2001) and (2) the lack of consideration of species extinction probability in small sites owing to small population size (Saetersdal et al. 1993). Furthermore, such methods could favor ecotones in which persistence of species is more hazardous (Brown 1991; Underhill 1994; Prendergast et al. 1999; Gaston et al. 2001; Rodrigues & Gaston 2002). Finally, no spatial considerations could cause some problems for final design (Oenal & Briers 2002). These problems are often linked to the exclusive use of α-diversity to the detriment of underling biodiversity processes, the β-diversity (Whitaker 1977; Reyers et al. 2002; Rouget et al. 2003).

Simultaneously, Geographic Information Systems (GIS) have gained in popularity and different methods were developed to take into account spatial distribution of biodiversity (Lombard et al. 1992; Menon & Bawa 1997; Hoctor et al. 2000) and as much as possible the β-diversity which is simpler and easier to sample than biota on a regional and national basis (Belbin 1993; Pressey et al. 2000).

The necessity to consider underlying biodiversity processes and spatial considerations lead to the development of methods using scoring procedures and GIS. These tools can be used successfully to design protected areas (Grumbine 1990; Lombard et al. 1992; Jones et al. 1997; Menon & Bawa 1997; Smith et al. 1997; Grabaum & Meyer 1998; Lathrop & Bognar 1998; Heijnis et al. 1999; Li et al. 1999; Hoctor et al. 2000; Dumortier et al. 2002; Rouget 2003). Although these approaches are not always providing optimal results in terms of size of reserve selection (Saetersdal 1994), they may easily take in consideration ecological, social and economical objectives and spatial optimization. These multi-parameters approaches are incontestable for biodiversity conservation and enhance the extrapolation of ecological information to wider areas (Luoto et al. 2002).

Togo presents a unique continuum with Guinean forest that is an important hotspot of biodiversity. Such ecotone is important for biodiversity and must be protected (Rouget et al. 2003). Despite important protected areas, the biodiversity in Togo is endangered and numerous conflicts on land use arise in the whole country. The national program of rehabilitation of protected areas in Togo is trying to design a new and efficient conservation network embracing ecology, economy, and social needs. This important process was equally the occasion to synthesize previous works and to develop a new methodology for the selection of protected areas in poorly-known territories.

In order to determine protected areas, precise conservation goals have to be identified *a priori*. We identified five conservation goals based on an exhaustive literature review

(Table 1). Conservation programs should: (1) avoid most disturbed areas (Araujo et al. 2002b), (2) protect an optimal biodiversity (Lesica 1993; Angermeier & Karr 1994), (3) take in consideration needs of the present-day local human population as well as the needs of their future generations, (4) anticipate global changes (Menon & Bawa 1997; Erasmus et al. 2002) and (5) use appropriate design to maintain biodiversity (Rapoport et al. 1986).

Facing an important lack of data and a short sampling period, we have to reach a consensus and find surrogates for unavailable data such as biodiversity and human disturbance. Our ability to predict species richness and threat is a central key for conservation of future landscapes (Luoto et al. 2002). A multicriteria approach based on five conservation goals, with a fine field study used for a rapid assessment of biodiversity (fine filter) and surrogates (broad filter) as satellite and environmental data to study landscape, may enable extrapolation of local data to the whole study area. Finally, we built a complete and transposable methodology for the selection of new reserve areas or the reevaluation of already existing areas.

Material and Methods

Study area

The tropical forest of West Africa in the Guinean hotspot was recognized as one of the 25 richest regions on the world (Myers 1990). Togo is a 600 km-long and 80 km-wide country bordering the Guinean hotspot. Two national parks (National Park of Fazao and La Keran National Park), five games sanctuaries and 46 national forests cover nearly 20% of the territory.

The Central region in Togo presents a huge environmental gradient from wooded savanna to tropical Guinean forest and riparian forest gallery. The region is irrigated by numerous rivers despite the fact that during the dry season only isolated and stagnant water remain in the smallest rivers. Aledjo and Atakora mountains traverse the study area on a SW-NE axis; most of the rivers have their sources in these mountains (Fig. 1). Six watersheds were identified in the study area. The Mô River springs up on the Aledjo Mountain and flows to the Volta Lake in Ghana. Most of the rivers of the central region flow into the Mô River. The Togo part of this watershed drains more than 7 700 km^2.

Thirteen classified forests and the National Park of Fazao-Malafakassa are located in the Central region and covered 298 512 ha on the $1.3x10^6$ ha of the study area. Numerous protected areas were severely or completely damaged by deforestation and other human perturbations. The National Park of Fazao profits of international non profit organizations and remain one of the last preserved conservation areas. The National Road 1 (RN1) cuts through the study area. Most of the villages are located along RN1 because it concentrates a great part of the economic activities.

Despite important protected areas, the biodiversity in Togo is endangered and numerous conflicts on land use arise in the whole country. The rehabilitation program of protected areas in Togo is the official response of Togo's government to a real social and ecological problem (EU reports, 2002). The original selection of conservation sites during the 1970's was arbitrary and lead to the expropriation of several inhabitants and translocation of complete villages. Thirty years later, no systematic studies have been conducted on the biodiversity of Togo and local discontents drive to a gradual degradation of protected areas. It is urgent to find rapid and efficient solutions because the important richness of this zone is endangered. We focus our study on the Central region of Togo where the National Park of Fazao is located. Furthermore the National Park of Fazao shares a common border with the Kiabobo National Park in Ghana and important species migration are observed between both parks.

Data Source

Inventories, abundance and distribution data are unavailable for biologists and consequently species and environmental data cannot be mixed as recommended by Pressey (2003) and Cowling and Pressey (2003). The present study use two types of surrogates: (1) satellite data and field data for fine scale and (2) environmental variables for a broad scale. This approach was used especially for biodiversity data and human activities data derived from satellite data.

Satellite data (Landsat 5 (December 1987) and Landsat 7 (February 2001)) were provided by the United Nation Program for Development in Togo. Six distinct bands at a 30 m spatial resolution have been used: visible blue in TM band 1 (visible blue), TM2 (green), TM3 (red), TM4 (NIR), TM5 (MIR), and TM7 (FIR). Thermal band (TM6) was not used in reason of weather dependency (Muldavin et al., 2001). Roads, rivers and villages were extrapolated from satellite image and associated with 1:200000 IGN maps (NC-31-VII-VIII and NC-31-I-II). Vegetation map was interpolated with Normalized Difference Vegetation Index, NDVI, a vegetation index based on satellite image.

Aspect, slope, elevation, and watershed data were obtained from East View Cartographic Inc. Digital Elevation Model. Climate data (precipitation and temperature) were provided by IRD (Institut de Recherche et de Développement, in France) and compiled into a single map. Geological and pedological data were furnished by the BRGM (Bureau de Recherches Géologiques et Minières in France) and digitized by UNPD (United Nations Program for Development) in Togo.

Field survey was carried out during the dry season from January to May 2002 with two principal objectives: (1) to validate satellite information and (2) to obtain a rapid assessment of biodiversity. A total of 260 survey sites were realized throughout the region with a more important sampling effort in the National Park of Fazao (159 survey sites) where the ecosystem is better preserved. A stratified and systematic sampling design has been use. Twelve transects were sampled around the park in public territories, 17 transects in wooded savannas and 12 transects in riparian forest across the entire National Park of Fazao. Each transect was randomly positioned. Over 500 m sampling interval between each survey site (10x50 m^2) was chosen to maximize the independence of sampling sites for biodiversity study. Thirty environmental variables (Table 2) and site's species abundance of wooded plant were recorded for each site. Diversity was calculated using the Shannon index (SI.s) for plants and birds. In addition, interviews about local perception of protected areas and conservation were carried out in villages of the study area. During the field survey, cultural and sacred sites were mapped to avoid potential conflicts between the future conservation network and the local interests.

Methodology

All of our five conservation goals were first translated in terms of one or several measurable variables (layers). Results were transformed subsequently to raster for easier calculations.

Three main steps are down: (1) the exclusion of less suitable areas (goal 1); (2) the selection of potential conservation areas (goals 2, 3, 4); and (3) final designs are done for each management alternative according to the importance of spatial considerations for protected areas (e.g., shape, size, connectivity) (goal 5) (Fig. 2).

Fragmentation and destruction of natural habitats are a great concern to conservationists and ecologists (Andrén 1994; Moilanen & Hanski 1998). Threats like fragmentation, urbanization and agriculture have been suggested as primary causes of biodiversity reduction (Soule & Simberloff 1986; Dale et al. 1994; Zheng & Chen 2000; Reyers et al. 2002). Belbin (1993) suggested it might be cost efficient to establish reserves in undisturbed broad ecosystems, because restoration works are expensive and difficult. Furthermore, undisturbed ecosystems are expected to support higher species abundances

(Whitaker 1977; Brown 1984; Araujo et al. 2002b) and to be more resilient to demographic stochasticity. It appears important to exclude all unsuitable and severely perturbed areas from our database (Bedward et al. 1992; Lathrop & Bognar 1998; Heijnis et al. 1999) and to focus our conservation actions in extensive areas of intact habitats (Cowling et al. 2003) and least disturbed areas (Bedward et al. 1992). Also, we used three parameters that play a crucial role in the preservation of biodiversity: fragmentation, landscape evolution, and human risks.

Finally, a gradient ranging from the most disturbed areas to undisturbed areas was provided by the compilation of all parameters; this gradient corresponds to the naturalness defined by Angermeier (2000). The resulting map was reclassified in to three conservation categories: (1) suitable for conservation, (2) in need of reasonable restoration, and (3) unsuitable for conservation. In our study, unsuitable areas were excluded and our efforts focused only on suitable areas. The restorable class is considered in the conservation issue in order to optimize the final design (e.g., buffer zones).

Conservation, especially in less developed countries, is complex and requires compromises between development and conservation (Lathrop & Bognar 1998). Several management options are created according to the relative importance given to ecological, economical and social parameters. For each management option it is possible to give more weight on specific layers. Three contrasted options (i.e., ecological, social and realistic) as well as two different target values were tested to validate our methodology and to better understand the potential of conservation in the region. The first management option is an ecological option that focuses on biological aspects with less consideration for social and economical parameters. On the opposite, a social option emphasizes social aspect. A realistic option, which is a conservative option, should allow a higher value to suitable areas, less vulnerable landscape classes and richest areas, and avoid disturbed and inhabited areas. In this option, conservation efforts were focalized to minimize disturbances for human population induced by modification of conservation areas and because resources are limited.

Finally the present study proposes some designs for each management option. All management options could serve as starting point for final discussion and negotiations among the different interveners at the local and national levels.

Planning Unit Justification

The selection and implementation of a reserve are influenced directly by the selection units (Pressey & Logan 1998). In fact, selection units must minimize variability inside the cell and maximize variability among cells. Fifteen layers were built from remote sensing (e.g., land cover, landscape analysis), digital elevation model (DEM) and general maps provided by various international groups (e.g., PNUD, IRD). All data layers were converted as raster image with a 30 -m-grid cell resolution (default in Landsat). This resolution allows a fine description for most of our variables and provides flexibility for final design in order to identify small areas of interest. Nevertheless, to conserve a biological meaning we have used a 2 -km- grid cell resolution for all the landscape analyses and a 4 -km- grid cell for heterogeneity measures. Two different grids (4 and 8 km) were also used for altitudinal gradient measures.

Study of the biodiversity

Three complementary approaches were used to define the globality and the complexity of the biodiversity: (1) Rapid Assessment of Biodiversity (RAB method) and satellite pictures were used to approximate biodiversity pattern at the pixel scale (30m), (2) environmental variables were compiled to define factors influencing β-diversity at the ecosystem scale, and (3) RAB and interviews of experts have contributed to highlight critical landscape components for biodiversity at the regional scale.

Remote sensing coupled with RAB should provide a relatively simple and direct approach to develop indices of biodiversity based on these observed relationships. Biodiversity data were unavailable for the complete territory but links among landscape structures, diversity and satellite data (e.g., NDVI) were inferred from multidimensional analyses (Chaillon et al. 2006. mémoire). Assessment of global biodiversity is based on avian diversity (Lawton et al. 1998). Despite high environmental complexity, the estimation of Shannon index is possible for the complete territory using a multiple regression model based on satellite data; the regression model was performed with Systat 9.01. The independent variables were NDVI, mean NDVI, the six bands of TM sensors, the slope, the altitude, and the landscape diversity value for each pixel representing each plot station. The dependent variable corresponds to the Shannon index calculated for birds in each plot station. Estimated Shannon index were calculated for each pixel of the satellite image based on the multiple regression equation. A pearson coeffecient of correlation was calculated between the estimated and the observed Shannon index. The estimated Shannon index was used to approximate α-diversity at the landscape level.

Because of the limited number of species inventory data, multiple environmental variables linked with β-diversity help to predict areas of biodiversity interest (Belbin 1993; Wessels et al. 1999; Cowling & Heijnis 2001; Cowling & Pressey 2003; Lombard et al. 2003; Pressey et al. 2003). Broad Habitat Units (BHU) classification (Cowling & Heijnis 2001) is a coarse filter based on elevation, climate, and soil data. In our study, 147 BHU were created by compiling environmental variables to capture the maximum of habitat diversity. Different parameters (e.g., heterogeneity, vulnerability, rarity, complementarity, priority and target) were extrapolated from BHU.

Heterogeneity : Hi

Heterogeneity represents the BHU diversity in a defined zone at a given scale. Habitats composed of spatially heterogeneous abiotic conditions provide a greater environmental diversity resulting in greater species diversity (Honnay et al. 2002, 2003). In consequence, the maintenance of maximum diversity is possible with maximum landscape heterogeneity. In our study, different cell sizes were tested and a grid with 4X4 km cells was chosen for an optimum heterogeneity representation (Margules et al. 1982). This grid was intersected with BHU's map and the heterogeneity represents the number of different BHU inside each cell.

Vulnerability : Vi

Landscape vulnerability classes is based on three conditions: (1) original extend, (2) previous landscape destruction, and (3) threats by future development. Assessment of unsuitable conservation areas was used to calculate landscape destruction. A value was attributed according to the proportion of degraded area for each BHU and corrected by future development prevision (see land-use). Loss of BHU area available for conservation was categorized in five classes. A second value was calculated according to the area of each BHU because small patches are more vulnerable than large patches. Finally, we overlapped both vulnerability maps to obtain the vulnerability index map reclassified in two management options: (1) the theoretical option, in which more importance was given to classes showing high vulnerability, and (2) the realistic option, which emphasised low vulnerability values because it is more profitable owing to weak conservation resources.

Rarity : Ri

Rarity expresses the importance of some landscape classes for representativeness of all BHU. Mean area patch by BHU (MPS), total area by BHU (PA) and number of patches by BHU were used to calculate the rarity index. Original areas were used without distinction of suitability or vulnerability. Final results were classified in five semi-ordinal classes (0 - "null" to 5 - "rare"). Landscape classes smaller than 100 ha were automatically classed as "rare". The following equation was used to calculate rarity:

$$R_i = \left(\frac{MP_iS}{MPS} + \frac{TP_iS}{TPS} \right) \times \left(a \times \sum patches_i \right) \quad \text{(EQ 1)}$$

i represents a given patch | *TPS =Total Patch Size*

a =coefficient | $\sum patches_i$ = number of patches *i*

Complementarity : Ci

Complementarity was calculated for each 2-km grid cell and represents the number of BHU unique to each cell divided by the total number of BHU. This measure completes the heterogeneity measure that indicates cells with maximum of BHU.

Priority : Pi

Priority was based on last four parameters (i.e., heterogeneity, complementarity, rarity and vulnerability) and indicates the necessity to quickly protect BHU.

$$P_i = \left(H_i + C_i + R_i \right) \times V_i \qquad \text{(EQ 2)}$$

A greater conservation priority should be attributed to BHU with high *Pi* value. Priority index was the resulting layer of the environmental approach and was used for our calculation of conservation areas.

Target : Ti

Conservation targets were often calculated from original extend of all BHU (Pressey et al. 2003) to assure the best representation of BHU. The representativeness is a measure of how accurately has been sampled the biodiversity in a protected area. It is a major consideration in assessments of protected area (Pressey & Taffs 2001). However, poor attention has been given to the feasibility of such calculation. In any given study area, large unsuitable zones for conservation occur because protection of all BHU was impossible. We have compared two conservation targets: (1) a theoretical target (*T1i*) based on original extend, and (2) a realistic target (*T2i*) based on available land for conservation.

$$T2i = 0{,}1A_{(original)} + kRi$$

$$T2i = 0{,}5A_{(available)} + kRi$$

A = area

k = an arbitrary coefficient

Sensitiveness : *Si*

The protection of aquatic and riparian ecosystems is an ecological priority (Johnson et al. 2001). Particular attention was given on water management with three combined layers. The first sensitiveness map (1) was done according to the distance to aquatic ecosystems. The second sensitiveness map (2) is designed to take into account watershed conservation. Watersheds of higher order were identified by selection of 40% of the higher elevation. High conservation value was given to these areas according to the necessity of watershed preservation. A riparian corridors map (3) was calculated to identify rivers that are important in maintaining regional biodiversity and connectivity (Forman & Godron 1981; Naiman et al. 1993; Cowling et al. 2003; Pressey et al. 2003). Main rivers are used as principal corridors between each main watershed and watershed of lower order. They are automatically added to our conservation planning owing to a higher conservation value in our weighting system.

Land Use

Landscape analyses (e.g., fragmentation, human risks, landscape evolution) are frequently ignored in reserve selection. However, there are considerable advantages to understand human impacts to avoid conflict between man and nature and to prevent any potential risks and changes in the future. Such information has to be taken into account for the long-term success of conservation areas. We have used four different factors to evaluate land-use impacts in the study area: (1) landscape evolution, (2) landscape fragmentation, (3) land use, and (4) land statutes.

Two Landsat 5 and 7 images (1987 and 2001) were compared to evaluate the landscape evolution (1). Dates were selected to capture great political disturbances and the landscape modifications in the 1990's. Topographic and vegetation maps from 1956 were used as complementary information to assess the observed changes. Satellite images were categorized in landscape classes using ArcView 3.2a and Image Analysis 1.1 extension. Each cell from 2001 was compared with the corresponding cell (30m) from 1987 Thus, we were able to identify unchanged zones, highly disturbed zones and the most important threats for the environment. Assessment of risks and threats was validated during field survey. The entire study area was mapped for landscape changes and then transformed in a raster image categorized in six classes from regeneration to highly disturbed.

Fragmentation effects are numerous and well documented. Fragmentation gives rise to an edge effect with respect to microclimate change and species invasion from surrounding vegetation (Menon & Bawa 1997; Zheng & Chen 2000). Furthermore, fragmentation affects the distribution and persistence of faunal species by reducing their core habitat and mobility, accelerates extinction because of factors such as demographic and environmental stochasticity, and leads to a decrease in genetic heterozygosity (Wilcove 1985; Robinson et al. 1992; Herkert 1994; With & Crist 1995; Menon & Bawa 1997; Wiens et al. 1997). Consequently we used recent satellite data (Landsat 7, 2001) and patch analyst on Arc View 3.2 to evaluate the landscape fragmentation (2). A 2-km- cell grid was added to the satellite view and fragmentation measures were calculated for each cell of the grid. We used unchanged patches of landscape as reference for fragmentation level and all cell results were reclassified in five classes in relation to an arbitrary zero fragmentation level. Area, patch density and size, edge and shape metrics were measured from the Landsat 7 image. Diversity and interspersion metrics were measured. A composite fragmentation index was elaborated from mean patch size (MPS), mean patch edge (MPE), mean shape index (MSI), mean proximity index (MPI) and Shannon diversity index (SDI).

Land use (3) and future human development represent crucial issues for conservation because of the important influence of human activities on nature and the need to have a local objective to succeed on conservation actions. Incorporating human development as a constraint to area selection can reduce substantially conflict or pressure (Araujo et al. 2002). To determine human influence, villages and roads were classified according to their relative importance. Concentric buffer zones were created around each of these structures and then clipped on the classified satellite image. We have compared each of the buffer zones together. We assume that important variation on landscape composition are linked to the transformation and the perturbation owing to the human pressure (e.g., harvesting, fire). A decrease of these landscape variations represents a decreasing human pressure. The anthropic effects are almost non-existent when the landscape variation rate becomes null. This method was applied to all anthropic elements of the landscape and results were validated during field survey. Thus, complete map of human disturbances was done. A value ranging from 5 (null influence) to 0 (major influence) is given according to the size and the proximity of villages and roads.

Land use was calculated for each class of villages thanks to satellite data analysis. It represents the actual need of the population. Comparison of land use for both satellite images at a given interval, and according to the growth rate of the population (doubling time of 23 years, census 1998), a zone of potential pressure was delimited and noted as less suitable for conservation.

Land statute (4) was classified as protected area or public area. Greater weight was put on existing conservation areas because of the price of the land acquisition and social disagreements of land loss in developed areas. Moreover, cultural areas could be easily taken in consideration based on the information furnished by village councils. A buffer zone was created around each site then noted as unsuitable for core zone area.

Global Change

Because of the peripheral situation of the Guinean hotspot, Togo is possibly more sensitive to global climatic changes than more central zones. The distribution of plant and animal species could be influenced by climatic changes (Menon & Bawa 1997; Erasmus et al. 2002). It becomes important to anticipate possible shifts of population distribution by maintaining as much as possible an important altitudinal or latitudinal gradient and managing corridors to mitigate the effects of rapid changes (Hobbs 1993; Shafer 1999). In such perspective, maintaining high altitudinal and environmental heterogeneity and a good connectivity on the conservation network can allow the persistence of refuges for sensitive species.

Results and Discussion

Biodiversity and Satellite Use

Multiple linear regression made for Shannon index shows moderate multiple R^2 value (0.311). However correlation between observed and estimated Shannon index was significant ($p = 0.03$). Higher values of the estimated Shannon index were found in the more preserved zones in the National Park of Fazao (Fig 3). High and moderate values were found in the south of Aloumbé and Azanadé villages and correspond to important relief areas. All these areas appear less transformed and degraded by human activities, most likely owing to a lower accessibility for human activities, and linked to the hydrographic network. Previous biodiversity assessment (Chaillon et al. 2006 mémoire) has underlined the richness of wetlands and the more intact areas. Effectively, six variables are positively correlated with Shannon index for birds: canopy closure, water distance, average size of trees, plant diversity, NDVI, and the number of tree of diameter greater than 20 cm. Canopy closure and number of trees of diameters greater than 20 cm were correlated with perturbation level ($r = 0.49$, $p < 0.001$). This result confirms that (1) less disturbed zones should maintain higher biodiversity values and (2) less accessible areas, such as mountainous areas or protected areas, are important for biodiversity. Similar results about richness of less disturbed patches of forest were found by Amarnath et al. (2003) in the

Western Ghates. Such areas can be used as refuge and act like small islands of higher biodiversity at the landscape level. They are source areas for biodiversity and contribute a lot for recruitments to future generations (Roberts 1998). On the contrary, most transformed areas are sink zones (Magoulick & Kobza 2003).

Biodiversity and Environmental Data

BHU were used to calculate variables linked to β-diversity (e.g., heterogeneity, vulnerability, rarity). A total of 176 of the 780 (22.56%) cells present heterogeneity higher than ten classes per cell and only 31 cells (3.97%) have heterogeneity higher than 20 classes (Fig. 4). Steep areas and mountains (e.g., Atakora Mountains in National Park of Fazao, Aledjo Mountains) enhanced heterogeneity. Therefore, plains along the National Road 1 are less heterogeneous. Important altitudinal gradient and higher landscape heterogeneity were present on the western part of the study area, along the Atakora Mountain and around the Aledjo Mountain. Fourteen of the 209 (6.7%) cells of the study area (8*8 km) have an altitudinal gradient greater than 500 m. There are 41.09 % of the 147 BHU highly vulnerable and most are located in the perturbed area bordering National Road 1. Only 15.75% of the BHU present high rarity values and 41.78% moderate rarity value (Fig. 5).

Only 4.11% of the BHU present on the study area have a very high priority index value, and 15.06% have a high priority index value (Fig. 6). BHU with high priority values were located primarily on mountainous areas where an important environmental gradient provides a great diversity of landscapes. This landscape diversity is linked to the β-diversity and the natural processes that drive evolution and persistence of diversity patterns. Heterogeneity, complementarities and rarity are higher. It is important to consider mountainous areas in order to increase landscape heterogeneity, which could potentially allow future shifts in species distribution. The concordance between priority index and the estimated Shannon index was hugh. This correlation is biased because the information from the digital elevation model was used for both index of biodiversity. Nevertheless, ecological explanations were important. Effectively, most of the unprotected areas in the country are intensively used for agricultural practice and wood harvesting. Perturbed areas around villages are important even trespassing the edges of protected areas. The last well preserved areas remained in less accessible areas, far from roads or villages, where ecosystem integrity and landscape diversity are higher.

BHU and priority index have been frequently used to assess biodiversity value and conservation areas (Wessels et al. 1999; Reyers et al. 2000; Cowling & Heijnis 2001; Gaston et al. 2001). The congruence of results for both methods confirms the efficiency of our biodiversity index based on satellite data.

Landscape Analysis

Landscape transformations are a major threat for species survival and their diversity in many habitats (Lindborg & Eriksson 2004). Our temporal study using satellite and field data allowed us to show the importance of the changes that has taken place over the past 20 years in Central region of Togo. Important landscape transformations were observed along the main roads of the study area, principally the north-south axis along the National Road 1. Two large parts of the National Park of Fazao are largely transformed (Fig. 7 A-B).

Most transformed areas were highly fragmented. Patch size and mean shape index decrease whereas the number of patches and diversity of patch increase. Bigger patches of forest or savanna were observable in the unchanged zones of the National Park of Fazao; these patches serve as reference for our study. The analysis of the Landsat images and the field survey show that landscape transformations are related to human pressures (e.g., set up of new villages and new crops cultivation). In order to increase our understanding of the perturbations, we have investigated the landscape transformations according to the distance of roads and villages (Fig. 8). A decrease of the landscape variations (y) between two adjacent buffers around villages and roads was systematically noted when the distance (x) from human features increase (for roads, $R^2 = 0.993$, $p < 0.05$, $y = 0.167x^2 - 1.1931x + 2.7105$). A stabilization of these landscape variations after 3 to 4 km suggests minimal anthropic effects, under the detection level. A disturbance gradient on the landscape mosaic ranges from highly disturbed to unchanged away from villages and roads. Therefore, results were less precise for class 1 urban centers, most likely owing to a background "noise" resulting from the peripheral aggregation of small villages.

Land-use changes are difficult phenomena to predict (Reyers 2004). Although they represent a major challenge for biodiversity conservation for the next decades. The recent human pressure on the environment has been calculated for every class of road and village. The extrapolation of these results with the population increase data (doubling time of 23 years, census 1998) and human pressure calculated for 1987, have shown that for a village with an influence of 3 km, its radius will increase to 4.25 km in a period of 23 years. Expected development areas have to be considered less suitable for conservation because of the risk of conflict between man and nature.

Cultural data were incomplete owing to the large area of the study area. An important lost of cultural sites was noted around the National Park of Fazao, most likely linked to the village translocation 30 years ago. Concentration of cultural sites was noted in the Aledjo area. All the cultural data were summarized on a map then transformed in raster. Areas around cultural sites were noted as unfavorable for the future conservation network.

These landscape analyses help identifying areas that are most threatened as proposed by Smith et al. (1997), Menon & Bawa (1997) and Fox et al. (1996). All the identified threats on the study area were linked to the need of inhabitants to harvest new lands. Roads and trails seem to be positively correlated with the spread of human disturbances as noted by Peres & Terborgh (1995). With increasing human populations, resource demand increase (Reyers 2004). In Togo, cultivation techniques and high population growth rate lead to the gradual exodus of population. Natural habitats were transformed by the creation of new harvesting areas, the settlement of farms in protected areas, wood harvesting, the introduction of alien species and wildlife poaching. This trend was clearly identified by remote sensing analysis and confirmed by field survey. All these threats related to human impact are serious threat to the biodiversity (Soule & Simberloff 1986; Dale et al. 1994; Brooks et al. 2002; Miller & Hobbs 2002; Reyers et al. 2002; Ayyad 2003). Landscape transformations should provide the primary basis for assessing biological integrity and show us the divergence from native conditions (Angermeier & Karr 1994). Therefore, information on landscape temporal changes, their intensity and causes are crucial for conservation (Myers 1995; Miller & Hobbs 2002).

For many developed countries (e.g., Togo), the lack of information about land-use changes is hindering conservation efforts. The rehabilitation of conservation network without appropriate development's support could not solve conservation problems (Hardin, 1968). The accurate delimitation of actual and potential conflict areas between human development and natural conservation could avoid similar problem in future networks (Reyers et al, 2002, Millers et al., 2002).

Management Alternatives

Special consideration was given on spatial implications because of the importance of maintaining processes in a long-term perspective of biodiversity conservation. Main ideas about spatial design of protected areas were summarize in the Appendix 1. Once all the land-use and biodiversity data were mapped, management alternatives can be calculated with variable emphasis for each conservation goal. Four management alternatives were compared (Fig. 9): (A) a conservation network, (E) an ecological alternative, (S) a social alternative and (C) a compromise alternative. Actual protected areas cover 23.3% of the study area; 53.06% of all BHU were protected. Mean efficiency calculated from Target A – original extend- was 40.76%. An ecologic alternative was calculated given weak emphasis to social considerations. The total protected area drops to 18.08% without significant decrease in the number of protected BHU (48.29%) and mean efficiency (38.16%). Area weighting of efficiency value show higher values for the ecological option (*mean*=2.02 *versus actual mean*=1.74). The social alternative was calculated with major emphasis on social aspects and human development. The protected area decreases to 15.27% of the total area and efficiency drops to 25.27%. The compromise solution takes into consideration ecological and social parameters. The protected area decreases from 23.3 to 17.7% and efficiency decrease 38.16 to 28.9%. The more realistic alternative management is the compromise solution. Because of the important transformation of the study area around the National Park of Fazao and national forests, large areas were unavailable for conservation and restoration, and efficiency remains moderated for all alternatives. Despite a lower efficiency, ecological and social goals were considered and critical development areas were avoided in the compromise solution. If only the available areas for conservation were considered, the efficiency values (Target B) increase from 28.9 to 47.9% for the compromise solution and area weighting efficiency becomes higher than that of the actual conservation network.

Differences between each management alternative were moderate because of the irreversible landscape transformations, which prevent any major modifications of the conservation network. Nevertheless more transformed areas and large unbroken tracts of forest habitat were successfully identified by landscape analysis and could be taken into consideration for the final design. Our study has shown the importance of the human induced perturbations on the biodiversity and its distribution.

Percentage of protected areas could be reduced without important efficiency decrease, especially if we consider efficiency weighting by area. Moreover, it may be advantageous to spent financial resources on management, education and some conservation policies rather than acquiring additional reserves (Margules et al.1982). In our study, large conservation areas encompassing all the range of regional environment are conserved and smaller complementary areas were identified and linked by corridors.

Efficiency is just an indication of how well was sampled the β-diversity and the representativity. It does not take into account advantages from a social point of view of decreasing and concentrating conservation areas. Our new design could be more effective because of the following: (1) more space is allocated for development, (2) conservation resources are concentrated on the richness areas, (3) conflict area are avoided. We can except that discontent will be decrease and co-operation with local people will be increase. In this situation, reducing conservation areas should increase real efficiency of them.

Conclusion and Recommendations

Our study shows that it is possible to produce a reliable coarse biodiversity map at the landscape level with only few data by using remote sensing coupled with an intensive field survey. Remote sensing provides the best tool to analyze, map, and monitor ecosystem patterns and processes (Gould 2000; Reddy 1993; Muldavin et al. 2001). Rapid biodiversity mapping method could be use to assess dynamic faunal and floral refuge in order to complement static reserves as suggested by Bengtsson et al. (2003) and to monitor the evolution of ecosystems. However, our results have to be tested especially on better-documented areas because of the possibility of direct validation with existing database. Furthermore our method could be improved by using satellite imagery with better pixel resolution that enhances a better landscape definition and a higher relationship between our model and the observed Shannon index. Nevertheless such surrogate represents a first step for the design of protected areas in poorly documented areas.

The various management alternatives could be used as the starting point for future public consultation. The proposed global approach and tools developed in this study show that it is possible to take into account ecological, social and economical factors, avoid perturbed areas and maintain similar or higher efficiency. Surrogates make possible to consider efficient and quick reservation of poorly known territory and encompass the lack of inventory data. Our study highlight the increasing necessity to integrate conservation with regional development (Prendergast et al. 1999). It suggests a more balanced approach in conservation biology to take into account the effects of human land-use on biodiversity. The inclusion of land transformation data leads to viable conservation networks and highlights areas of potential conflict between biodiversity conservation interests and human land-use issues (Reyers et al. 2002).

Acknowledgement:

Thanks to the UQAR Fonds Institutionnels de la Recherche à l'UQAR, Ministère des ressources naturelles au Togo, la direction des parcs à Lomé, FFW and National Park of Fazao, BRGM, Programme des Nations Unies pour le Développement. Thanks to professor K. Addade, K.T. Agbodji to have shared their experiments, S. Durlot, Romaric Landozz, Peter and Innouss Landozz for their assistances in the field. Thanks to Luc Sirois, E. Vidal, Dominique Berteaux, Patrick Morin, Julien Lambrey De Souza for their advices and to have kindly commented earlier versions of the manuscript.

Literature Cited

Amarnath, G., M. S. R. Murthy, S. J. Britto, G. Rajashekar, and C. B. S. Dutt. 2003. Diagnostic analysis of conservation zones using remote sensing and GIS techniques in wet evergreen forests of the Western Ghats - An ecological hotspot, Tamil Nadu, India. Biodiversity and Conservation. **12**:2331-2359.

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos **71**:355-366.

Angermeier, L. P. 2000. The Natural Imperative for Biological Conservation. Conservation Biology. no. **2**:373-381.

Angermeier, P. L., and J. R. Karr. 1994. Biological integrity versus biological diversity as policy directives. Protecting biotic resources. Bioscience **44**:690-697.

Araujo, M. B., P. H. Williams, and A. Turner. 2002. A sequential approach to minimise threats within selected conservation areas. Biodiversity and Conservation. **11**:1011-1024.

Arthur, J. L., M. Hachey, K. Sahr, M. Huso, and A. R. Kiester. 1997. Finding all optimal solutions to the reserve site selection problem: Formulation and computational analysis. Environmental and Ecological Statistics. **4**:153-165.

Ayyad, M. A. 2003. Case studies in the conservation of biodiversity: degradation and threats. Journal of Arid Environments. **54**:165-182.

Bedward, M., R. L. Pressey, and D. A. Keith. 1992. A new approach for selecting fully representative reserve networks: Addressing efficiency, reserve design and land suitability with an iterative analysis. Biological Conservation. **61**:115-125.

Belbin, L. 1993. Environmental representativeness: Regional partitioning and reserve selection. Biological Conservation. **66**:223-230

Belbin, L. 1995. A multivariate approach to the selection of biological reserves. Biodiversity and Conservation. **4**:951-963.

Bengtsson, J., P. Angelstam, T. Elmqvist, U. Emanuelsson, C. Folke, M. Ihse, F. Moberg, and M. Nystroem. 2003. Reserves, Resilience and Dynamic Landscapes. Ambio **32**:389-396.

Boecklen, W. J. 1997. Nestedness, biogeographic theory, and the design of nature reserves. Oecologia. **112**:123-142.

Briers, R. A. 2002. Incorporating connectivity into reserve selection procedures. Biological Conservation. **103**:77-83.

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. Da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat Loss and Extinction in the Hotspots of Biodiversity. Conservation Biology. **16**:909-923.

Brown, J. H. 1984. On the relationship between abundance and distribution of species. American Naturalist **124**:255-279.

Cabeza, M., and A. Moilanen. 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology & Evolution. **16**:242-248.

Cowling, R. M., and C. E. Heijnis. 2001. The identification of Broad Habitat Units as biodiversity entities for systematic conservation planning in the Cape Floristic Region.

Cowling, R. M., and R. L. Pressey. 2003. Introduction to systematic conservation planning in the Cape Floristic Region. Biological Conservation. **112**:1-2.

Dale, V. H., S. M. Pearson, H. L. Offerman, and R. V. O'Neill. 1994. Relating patterns of land-use change to faunal biodiversity in the central Amazon. Conservation Biology **8**:1027-1036.

Diamond, J. 1986. The design of a nature reserve system for Indonesian New Guinea. Conservation Biology: The Science of Scarcity And Diversity. Soule, ME

Dumortier, M., J. Butaye, H. Jacquemyn, N. Van Camp, N. Lust, and M. Hermy. 2002. Predicting vascular plant species richness of fragmented forests in agricultural landscapes in central Belgium. Forest Ecology and Management **158**:85-102.

Durbin, J. C., and J. A. Ralambo. 1994. The role of local people in the successful maintenance of protected in Madagascar. Environmental Conservation **21**:115-120.

Earn, D. J. D., S. A. Levin, and P. Rohani. 2000. Coherence and conservation. Science **290**: 1360-1365.

Ehrlich, P. R., and E. O. Wilson. 1991. Biodiversity studies: Science and policy. Science **253**:758-762.

Erasmus, B. F., A. S. Van Jaarsveld, S. L. Chown, M. Kshatriya, and K. J. Wessels. 2002. Vulnerability of South African animal taxa to climate change. Global Change Biology **8**:679-693.

Ferrier, S. 2002. Mapping spatial pattern in biodiversity for regional conservation planning: Where to from here? Systematic Biology **51**:331-363.

Forman, R. T. T., and M. Godron. 1981. Patches and structural components for a landscape ecology. Bioscience **31**:733-740.

Fox, J., P. Yonzon, and N. Podger. 1996. Mapping conflicts between biodiversity and human needs in Langtang National Park, Nepal. Conservation Biology **10**:562-569.

Franklin, J. F. 1993. Preserving biodiversity: Species, ecosystems, or landscapes? Ecological Applications **3**:202-205.

Gaston, K., A. Rodrigues, B. Van Rensburg, P. Koleff, and S. Chown. 2001. Complementary representation and zones of ecological transition. Ecology Letters **4**:4-9.

Goetmark, F., and M. Thorell. 2003. Size of nature reserves: densities of large trees and dead wood indicate high value of small conservation forests in southern Sweden. Biodiversity and Conservation **12**:1271-1285.

Gould, W. 2000. Remote sensing of vegetation, plant species richness, and regional biodiversity hotspots. Ecological Applications **10**:1861-1870.

Grabaum, R., and B. C. Meyer. 1998. Multicriteria optimization of landscapes using GIS-based functional assessments. Landscape and Urban Planning **43**:1-3.

Grumbine, E. 1990. Protecting biological diversity through the greater ecosystem concept. Natural Areas Journal **10**:114-120.

Gustafson, E. J., and R. H. Gardner. 1996. The effect of landscape heterogeneity on the probability of patch colonization. Ecology **77**:94-107.

Hannah, L., B. Rakotosamimanana, J. Ganzhorn, R. A. Mittermeier, S. Olivieri, L. Iyer, S. Rajaobelina, J. Hough, F. Andriamialisoa, I. Bowles, and G. Tilkin. 1998. Participatory planning, scientific priorities, and landscape conservation in Madagascar. Environmental Conservation **25**:30-36.

Hanski, I. 1994. Patch-occupancy dynamics in fragmented landscapes. Trends in Ecology & Evolution **9**:131-135.

Hansson, L., and P. Angelstam. 1991. Landscape ecology as a theoretical basis for nature conservation. Landscape Ecology **5**:191-201.

Harrison, R. L. 1992. toward a theory of inter-refuge corridor design. Conservation Biology **6**:293-295.

Heijnis, C. E., A. T. Lombard, R. M. Cowling, and P. G. Desmet. 1999. Picking up the pieces: a biosphere reserve framework for a fragmented landscape - The Coastal Lowlands of the Western Cape, South Africa. Biodiversity and Conservation **8**:471-496.

Herkert, J. R. 1994. The effects of habitat fragmentation on midwestern grassland bird communities. Ecological Applications **4**:461-471.

Hobbs, R. J. 1993. Effects of landscape fragmentation on ecosystem processes in the Western Australian wheatbelt. Biological Conservation **64**:193-201.

Hoctor, S. T., H. M. Carr, and D. P. Zwick. 2000. Identifying a Linked Reserve System Using a Regional Landscape Approach: the Florida Ecological Network. Conservation Biology **14**:984-1000.

Honnay, O., K. Piessens, W. Van Landuyt, M. Hermy, and H. Gulinck. 2003. Satellite based land use and landscape complexity indices as predictors for regional plant species diversity. Landscape and Urban Planning **63**:241-250.

Honnay, O., K. Verheyen, J. Butaye, H. Jacquemyn, B. Bossuyt, and M. Hermy. 2002. Possible effects of habitat fragmentation and climate change on the range of forest plant species. Ecology Letters **5**:525-530.

Johnson, N., C. Revenga, and J. Echeverria. 2001. Policy forum on ecology: Managing water for people and nature. Science **292**:1071-1072.

Jones, P. G., S. E. Beebe, J. Tohme, and N. W. Galwey. 1997. The use of geographical information systems in biodiversity exploration and conservation. Biodiversity and Conservation **6**:947-958.

Kunin, W. E. 1997. Sample shape, spatial scale and species counts: Implications for design. Biological Conservation **82**: 369-377.

Lathrop, R. G., Jr., and J. A. Bognar. 1998. Applying GIS and landscape ecological principles to evaluate land conservation alternatives. Landscape and Urban Planning **41**:27-41.

Lawton, J. H., D. E. Bignell, B. Bolton, G. F. Bloemers, P. Eggleton, P. M. Hammond, M. Hodda, R. D. Holt, T. B. Larsen, N. A. Mawdsley, N. E. Stork, D. S. Srivastava, and A. D. Watt. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. Nature **391**:72-76.

Lesica, P. 1993. Using plant community diversity in reserve design for pothole the Blackfeet Indian Reservation, Montana, USA. Biological Conservation **65**:65-75.

Li, W., Z. Wang, Z. Ma, and H. Tang. 1999. Designing the core zone in a biosphere reserve based on suitable habitats: Yancheng Biosphere Reserve and the red crowned crane (Grus japonensis). Biological Conservation **90**:167-173.

Lindborg, R., and O. Eriksson. 2004. Historical Landscape Connectivity Affects Present Plant Species Diversity. Ecology **85**:1840-1845.

Lombard, A. T., P. V. August, and W. R. Siegfried. 1992. A proposed Geographic Information System for assessing the optimal dispersion of protected areas in south Africa. S. Afr. J. Sci./S.-Afr. Tydskr. Wet. **88**:136-140.

Lombard, A. T., R. M. Cowling, R. L. Pressey, and P. J. Mustart. 1997. Reserve selection in a species-rich and fragmented landscape on the Agulhas Plain, South Africa. Conservation Biology **11**:1101-1116.

Lombard, A. T., R. M. Cowling, R. L. Pressey, and A. G. Rebelo. 2003. Effectiveness of land classes as surrogates for species in conservation planning for the Cape Floristic Region. Biological Conservation **112**:1-2.

Lomolino, M. V. 1994. An evaluation of alternative strategies for building networks of nature reserves. Biological Conservation **69**:243-249.

Luoto, M., T. Toivonen, and R. K. Heikkinen. 2002. Prediction of total and rare plant species richness in agricultural landscapes from satellite images and topographic data. Landscape Ecology **17**:195-217.

MacArthur, R. H., and E. O. Wilson 1967. The theory of island biogeography. Princeton University Press, Princeton, N.J.

Magoulick, D. D., and R. M. Kobza. 2003. The role of refugia for fishes during drought: a review and synthesis. Freshwater Biology **48**:1186-1198.

Margules, C., A. J. Higgs, and R. W. Rafe. 1982. Modern biogeographic theory: Are there any lessons for nature reserve design? Biological Conservation **24**:115-128.

Menon, S., and K. S. Bawa. 1997. Applications of geographic information systems, remote-sensing, and a landscape ecology approach to biodiversity conservation in the Western Ghats. Current Science **73**:134-145.

Miller, J. R., and R. J. Hobbs. 2002. Conservation Where People Live and Work. Conservation Biology **16**:330-337.

Moilanen, A., and I. Hanski. 1998. Metapopulation dynamics: Effects of habitat quality and landscape structure. Ecology **79**:2503-2515.

Muldavin, E. H., P. Neville, and G. Harper. 2001. Indices of Grassland Biodiversity in the Chihuahuan Desert Ecoregion Derived from Remote Sensing. Conservation Biology **15**:844-855.

Myers, N. 1990. The biodiversity challenge: Expanded hot-spots analysis. Environmentalist **10**:243-256.

Myers, N. 1995. Population and biodiversity. Ambio. Stockholm **24**:56-57.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403**:853-858.

Naiman, R. J., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecological Applications **3**:209-212.

Noss, R. F. 1983. A regional landscape approach to maintain diversity. Bioscience **33**:700-706.

Noss, R. F., and L. D. Harris. 1986. Nodes, networks, and MUMs: Preserving diversity at all scales. Environmental Management **10**:299-309.

Peres, C. A., and J. W. Terborgh. 1995. Amazonian nature reserves: An analysis of the defensibility status existing conservation units and design criteria for the future. Conservation Biology **9**:34-46.

Prendergast, J. R., R. M. Quinn, and J. H. Lawton. 1999. The Gaps between Theory and Practice in Selecting Nature Reserves. Conservation Biology **13**:484-492.

Pressey, R. L., and R. M. Cowling. 2001. Reserve Selection Algorithms and the Real World. Conservation Biology **15**:275-277.

Pressey, R. L., R. M. Cowling, and M. Rouget. 2003. Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. Biological Conservation **112**:99-127.

Pressey, R. L., T. C. Hager, K. M. Ryan, J. Schwarz, S. Wall, S. Ferrier, and P. M. Creaser. 2000. Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. Biological Conservation **96**:55-82.

Pressey, R. L., C. J. Humphries, C. R. Margules, R. I. Van-Wright, and Williams. 1993. Beyond opportunism: Key principles for systematic reserve. Trends in Ecology & Evolution **8**:124-128.

Pressey, R. L., and V. S. Logan. 1998. Size of selection units for future reserves and its influence on actual vs targeted representation of features: a case study in western New South Wales. Biological Conservation **85**:305-319.

Pressey, R. L., H. P. Possingham, and J. R. Day. 2002a. Effectiveness of alternative heuristic algorithms for identifying indicative minimum requirements for conservation reserves. Biological Conservation **80**:207-219.

Pressey, R. L., H. P. Possingham, V. S. Logan, J. R. Day, and P. H. Williams. 1999. Effects of data characteristics on the results of reserve selection algorithms. Journal of Biogeography **26**:179-191.

Pressey, R. L., and K. H. Taffs. 2001. Sampling of land types by protected areas: three measures of effectiveness applied to western New South Wales. Biological Conservation **101**:105-117.

Reddy, M. A. 1993. Remote sensing for mapping of suspended sediments in Krishna Bay Estuary, Andhra Pradesh, India. International Journal of Remote Sensing **14**:2215-2221.

Reid, W. V. 1993. The economic realities of biodiversity. Issues in Science and Technology **10**:48-55.

Reid, W. V. 1994. Formulating a future for diversity. American Zoologist **34**:165-171.

Reyers, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa.Biological Conservation **118:**521-531

Reyers, B., D. H. Fairbanks, A. S. Van Jaarsveld, and M. Thompson. 2001. Priority areas for the conservation of South African vegetation: a coarse-filter approach. Diversity and Distributions **7**:79-95.

Reyers, B., D. H. K. Fairbanks, K. J. Wessels, and A. S. Van Jaarsveld. 2002. A multicriteria approach to reserve selection: addressing long-term biodiversity maintenance. Biodiversity and Conservation **11**:769-793.

Reyers, B., A. S. Van Jaarsveld, and M. Krueger. 2000. Complementarity as a biodiversity indicator strategy. Proceedings of the Royal Society of London, Series B: Biological Sciences **267**:505-513.

Roberts, C. M. 1998. Sources, sinks, and the design of marine reserve networks. Fisheries **23**:16-19.

Robinson, G. R., R. D. Holt, M. S. Gaines, S. P. Hamburg, M. L. Johnson, H. S. Fitch, and E. A. Martinko. 1992. Diverse and contrasting effects of habitat fragmentation. Science **257**:524-526.

Rodrigues, A. S. L., and K. J. Gaston. 2002. Optimisation in reserve selection procedures--why not? Biological Conservation **107**:123-129.

Rouget, M. 2003. Measuring conservation value at fine and broad scales: implications for a diverse and fragmented region, the Agulhas Plain. Biological Conservation **112**:1-2.

Rouget, M., R. M. Cowling, R. L. Pressey, and D. M. Richardson. 2003. Biodiversity Research: Identifying spatial components of ecological and evolutionary processes for regional conservation planning in the Cape Floristic Region, South Africa. Diversity and Distributions **9**:191-210.

Saetersdal, M. 1994. Rarity and species/area relationships of vascular plants in deciduous woods, western Norway--Applications to nature reserve selection. Ecography **17**:23-38.

Saetersdal, M., J. M. Line, and H. J. B. Birks. 1993. How to maximize biological diversity in nature reserve selection: plants and breeding birds in deciduous woodlands, western Norway. Biological Conservation **66**:131-136.

Schwartz, M. W. 1999. Choosing the appropriate scale of reserves for conservation. Annual Review of Ecology and Systematics **30**:83-108.

Shafer, C. L. 1999. National park and reserve planning to protect biological diversity: some basic elements. Landscape and Urban Planning **44**:2-3.

Shafer, C. L. 2001. Inter-reserve distance. Biological Conservation **100**:215-227.

Siitonen, P., A. Tanskanen, and A. Lehtinen. 2002. Method for Selection of Old-Forest Reserves. Conservation Biology **16**:1398-1408.

Siitonen, P., A. Tanskanen, and A. Lehtinen. 2003. Selecting forest reserve with a multiobjective spatial algorithm. Environmental Science and Policy **6**:301-309.

Simberloff, D. 1986. Design of nature reserves. Wildlife Conservation Evaluation. Usher, MB.

Simberloff, D., and J. Cox. 1987. Consequences and costs of conservation corridors. Conservation Biology **1**:63-71.

Smith, A. P., N. Horning, and D. Moore. 1997. Regional biodiversity planning and lemur conservation with GIS in Madagascar. Conservation Biology **11**:498-512.

Soule, M. E., and D. Simberloff. 1986. What do genetics and ecology tell us about the design of nature reserves? Biological Conservation **35**:19-40.

Strittholt, J. R., and R. E. J. Boerner. 1995. Applying biodiversity gap analysis in a regional nature reserve the Edge of Appalachia, Ohio (U.S.A.). Conservation Biology **9**: 1492-1505.

Turner, M. G., R.H Gardner, V.H Dale and R.V. O'Neill . 1989. Predicting the spread of landscape disturbance across heterogeneous landscapes. OIKOS **55**:121-129.

Underhill, L. G. 1994. Optimal and suboptimal reserve selection algorithms. Biological Conservation **70**:85-87.

UNEP 1995. global biodiversity assessment. Cambridge University Press.Cambridge.

Wessels, K. J., S. Freitag, and A. S. Van Jaarsveld. 1999. The use of land facets as biodiversity surrogates during reserve selection at a local scale. Biological Conservation **89**:21-38.

Wessels, K. J., B. Reyers, and A. S. Van Jaarsveld. 2000. Incorporating land cover information into regional biodiversity assessments in South Africa. Animal Conservation **3**:67-79.

Whitaker, R. H. 1977. Evolution of species diversity in land communities. Evolutionnary Biology **10**:1-67.

Wiens, J. A., R. L. Schooley, and R. D. Weeks, Jr. 1997. Patchy landscapes and animal movements: Do beetles percolate? Oikos **78**:257-264.

Wilcove, D. S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology **66**:1211-1214.

Wilcox, B. A., and D. D. Murphy. 1985. Conservation strategy: The effects on fragmentation on extinction. American Naturalist **125**:879-887.

Williams, P., D. Gibbons, C. Margules, A. Rebelo, C. Humphries, and R. Pressey. 1996. A comparison of richness hotspots, rarity hotspots, and complementary areas for conserving diversity of British birds. Conservation Biology **10**:155-174.

Wilson, E. O. 1988. The current state of biological diversity. Pages 3-20. Biodiversity. National Academic Press, Washington, DC.

Wilson, E. O. 1994. Biodiversity: Challenge, science, opportunity. American Zoologist **34**:5-11.

Wilson, E. O., and E. O. Willis. 1975. Applied biogeography. Pages 522-534 in H. U. Press, editor. In M. L. Cody, and J. M. Diamond, editors. Ecology and evolution of communities, Cambridge, Massachusetts.

With, K. A., and T. O. Crist. 1995. Critical thresholds in species' responses to landscape structure. Ecology **76**:2446-2459.

With, K. A., R. H. Gardner, and M. G. Turner. 1997. Landscape connectivity and population distributions in heterogeneous environments. Oikos **78**:151-169.

Zheng, D., and J. Chen. 2000. Edge effects in fragmented landscapes: a generic model for delineating area of edge influences (D-AEI). Ecological Modelling **132**:175-190.

Table 1. Data layers used for the selection of conservation areas in the central part of Togo

Goals	Layers	Variables	Units
Landscape analysis (Exclusion of less suitable areas)	fragmentation	patch area index shape index Shannon's index proximity index number of patches index	2*2 km grid cell
	landscape evolution		30*30 m
	human risks	human disturbances for roads human disturbances for villages potential land-use	30*30 m
Biodiversity (Selection of the richest areas)	priority index	rarity complementarity heterogeneity vulnerability	2*2 km 2*2 km 2*2 km 30* 30 m
	biodiversity index		30*30 m
	particularly rich ecosystems	sensitiveness riparian corridors watershed	 30*30 m
Anthropic data (respect population needs)	land statute	private and public land, protected areas	30*30 m
	cultural sites		30*30 m
Global change	Global heterogeneity	altitudinal gradient Heterogeneity (BHU)	4*4 km 2*2 km
Design		Shape, connectivity, number, corridors.	

Table 2 : Description of structural variables measured in plots station of the study area in central Togo

Measurements	Units	Kind of data
Value from satellite image (band values, NDVI, iNDVI)		Quantitative
Plant species richness		Quantitative
Water		
Distance from water	m	Semi quantitative : (1) > 200 m; 150 m < (2) < 200 m; 100 m < (3) < 150 m; 50 m < (4) < 100 m; 0 m < (5) < 50 m
Disturbance		Semi quantitative (5classes)
Rocks cover		
Rocks larger than 20 cm	Percent	Semi quantitative (5 classes)
Rocks between 2 cm and 20 cm	Percent	0% < (1) < 10%; 10% < (2) < 25%; 25% < (3) < 50%;
Rocks smaller than 20 cm	Percent	50% < (4) < 75%; 75% < (5) < 100%
Density		
Trees	Nb/500 m^2	Quantitative
Shrubs	Nb/500 m^2	Quantitative
Tree smaller than 5m	Nb/500 m^2	Quantitative
Regeneration	Nb/500 m^2	Quantitative
Dead trees	Nb/500 m^2	Quantitative
Trees of diameters greater than 20 cm	Nb/500 m^2	Quantitative
Diameter		
Average tree diameter	cm	Quantitative
Height (average)		
Trees	m	Quantitative
Shrubs	m	Quantitative
Trees smaller than 5 m	m	Quantitative
Grass	m	Quantitative
Plant cover		
Trees	Percent	Semi quantitative (5 classes)
Shrubs	Percent	0% < (1) < 10%; 10% < (2) < 25%; 25% < (3) < 50%;
Grass	Percent	50% < (4) < 75%; 75% < (5) < 100%
Canopy closure	Percent	Quantitative

Figure captions

Figure 1. Study area, conservation area and topography.

Figure 2. Methodological schematic representation of this study including the three main steps with associated goals: (1) perturbation definition, (2) biodiversity mapping, (3) design of conservation areas.

Figure 3. Diversity Index. Biodiversity in degraded areas appears lower. Nevertheless less accessible areas, like mountainous areas or protected areas, present higher diversity value.

Figure 4. Heterogeneity index. Mountainous areas on the west part of the study area presents higher heterogeneity value.

Figure 5. Vulnerability index. Vulnerability is more important in the lowland along the National Road 1. Protected areas or mountainous areas present lower vulnerability index.

Figure 6. Priority index. Priority index (based on vulnerability, rarity, complementarity, and heterogeneity) indicates the necessity to quickly protected BHU.

Figure 7. Fragmentation index. Zone A and B represent particularly degraded areas on the National Park of Fazao.

Figure 8. Road perturbations. Road perturbation represents vegetation changes according to the distance of the road.

Figure 9. Management alternatives. Three management alternatives were tested: Compromise proposition (C), Ecological proposition (E), and Social proposition (S).

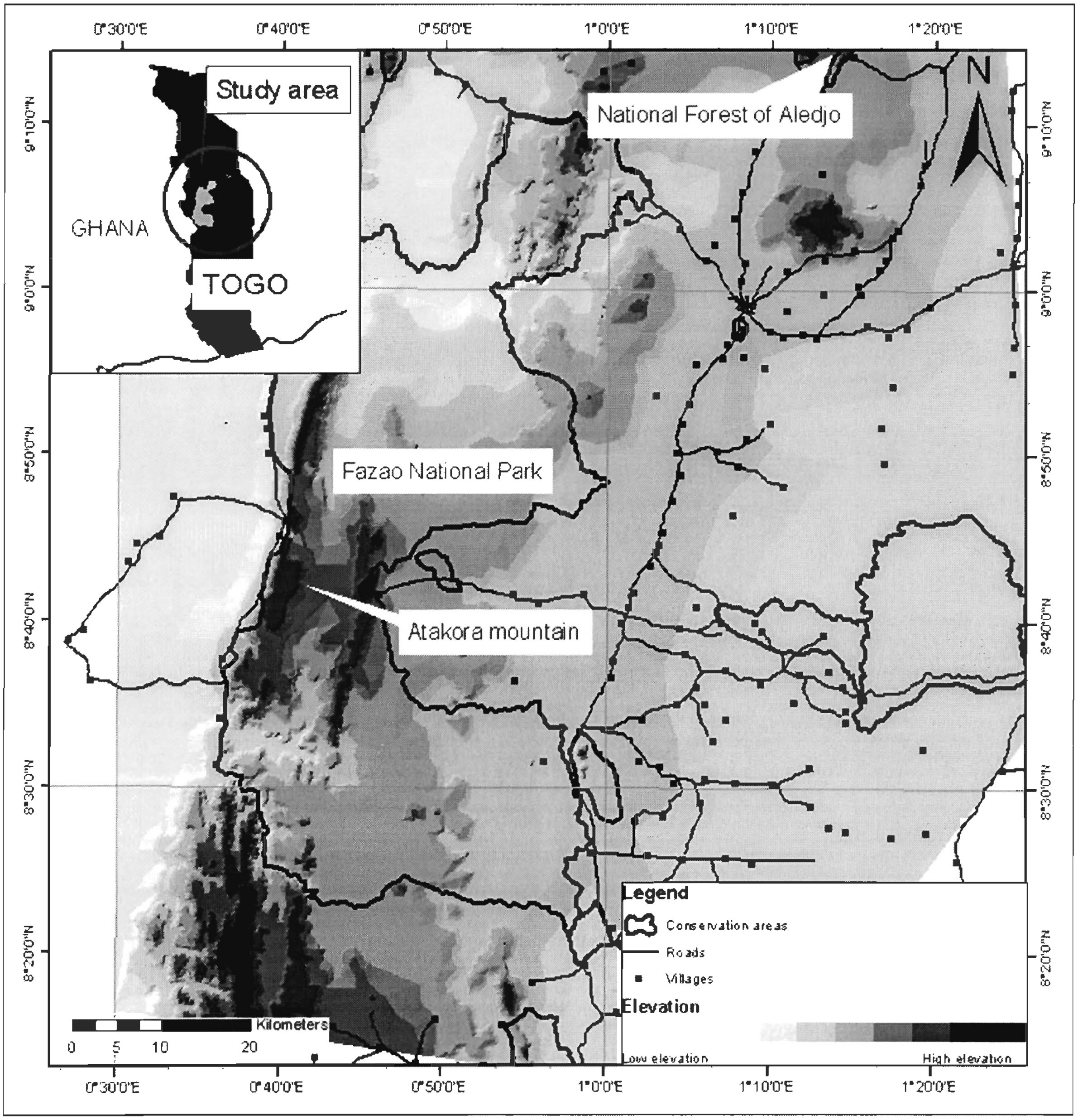

Figure 1 : Study area, conservation areas and topography.

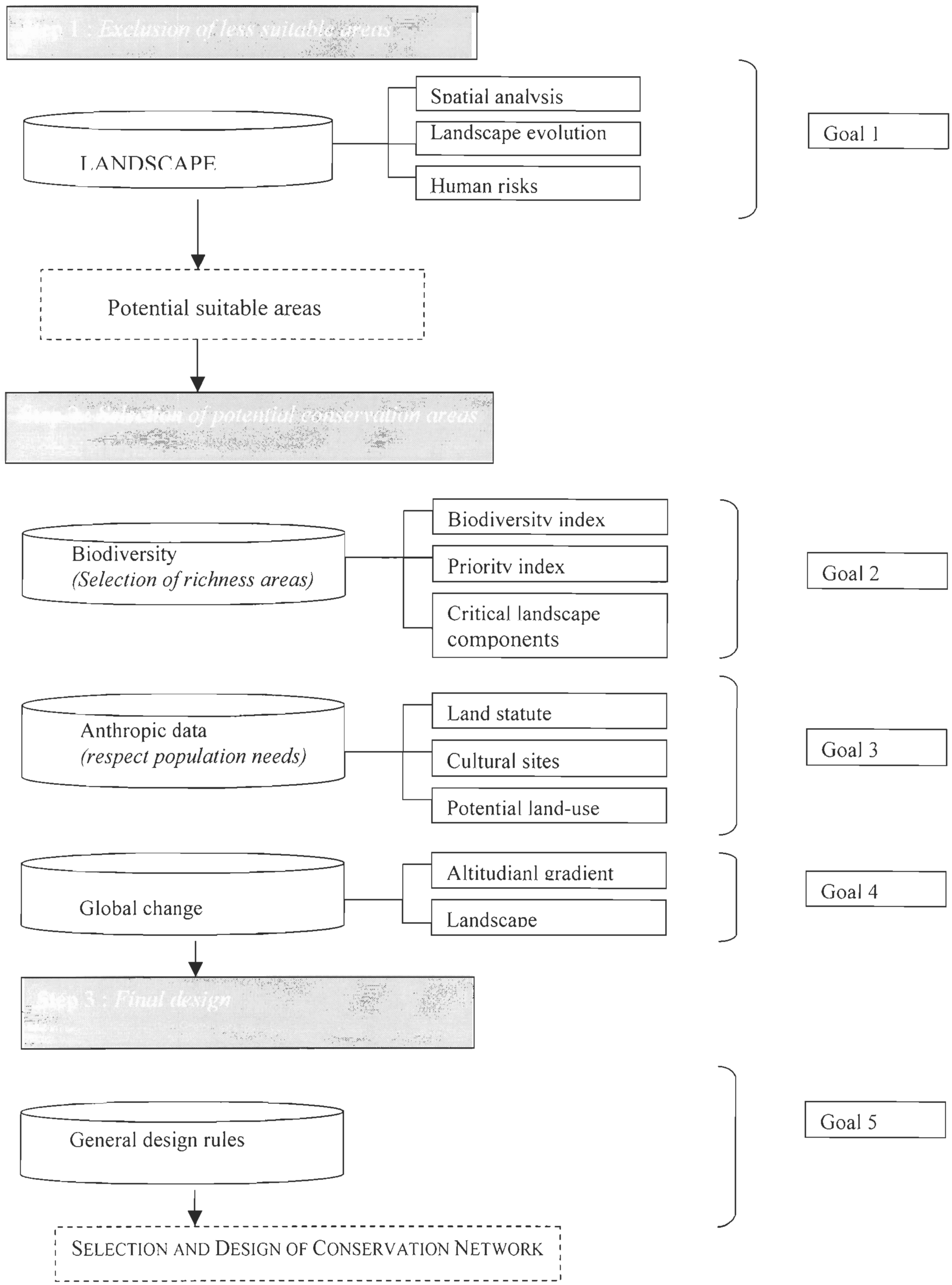
1 : Exclusion of less suitable areas
Spatial analysis
Landscape evolution
Human risks
LANDSCAPE
Goal 1
Potential suitable areas
of potential conservation areas
Biodiversity index
Priority index
Critical landscape components
Biodiversity
(Selection of richness areas)
Goal 2
Land statute
Cultural sites
Potential land-use
Anthropic data
(respect population needs)
Goal 3
Altitudianl gradient
Landscape
Global change
Goal 4
3 : Final design
General design rules
Goal 5
SELECTION AND DESIGN OF CONSERVATION NETWORK

Figure 2

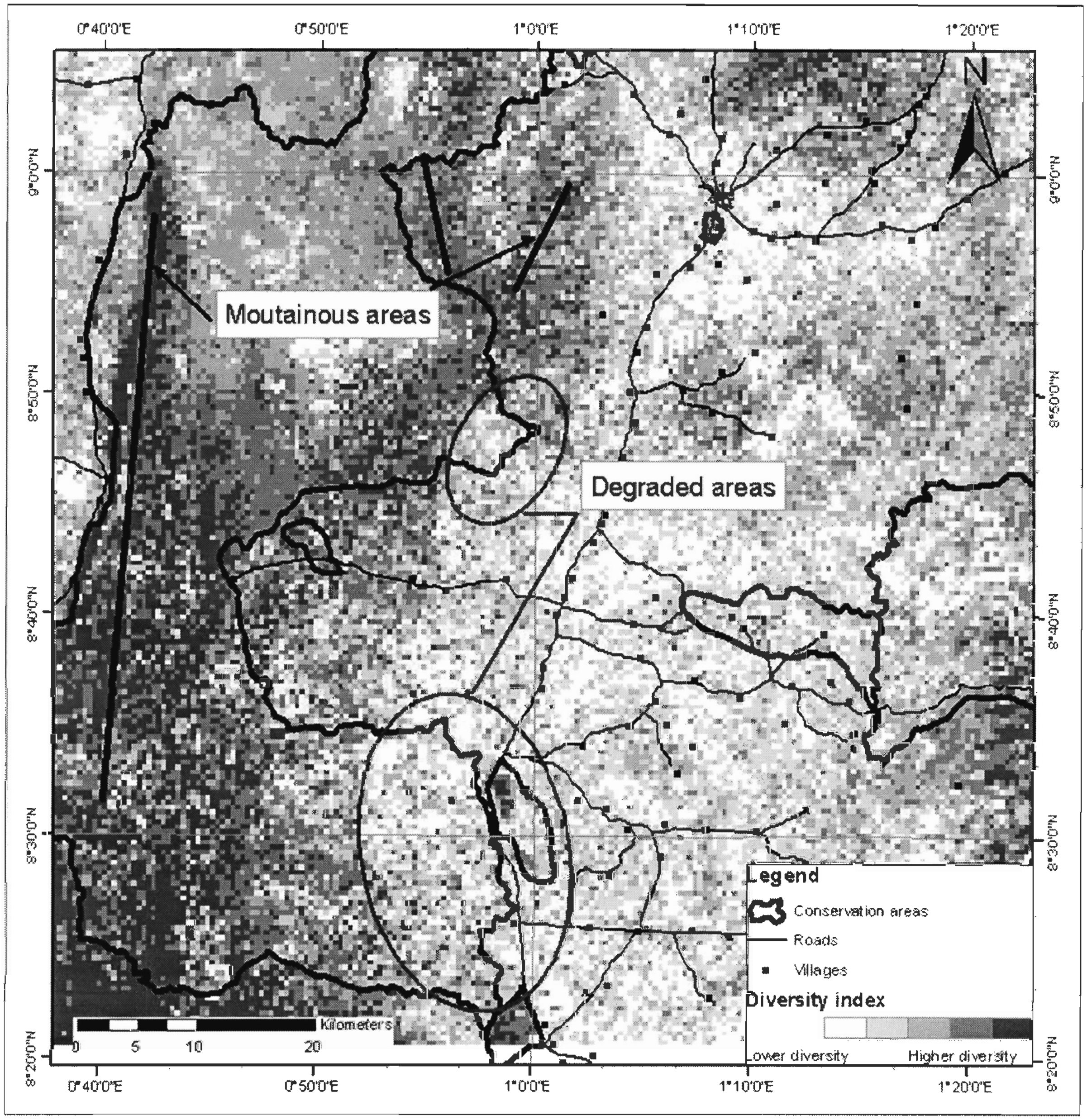

Figure 3 : Diversity index. Biodiversity in degraded areas appears lower. Nevertheless less accessible areas, such mountainous areas or protected areas present higher diversity value.

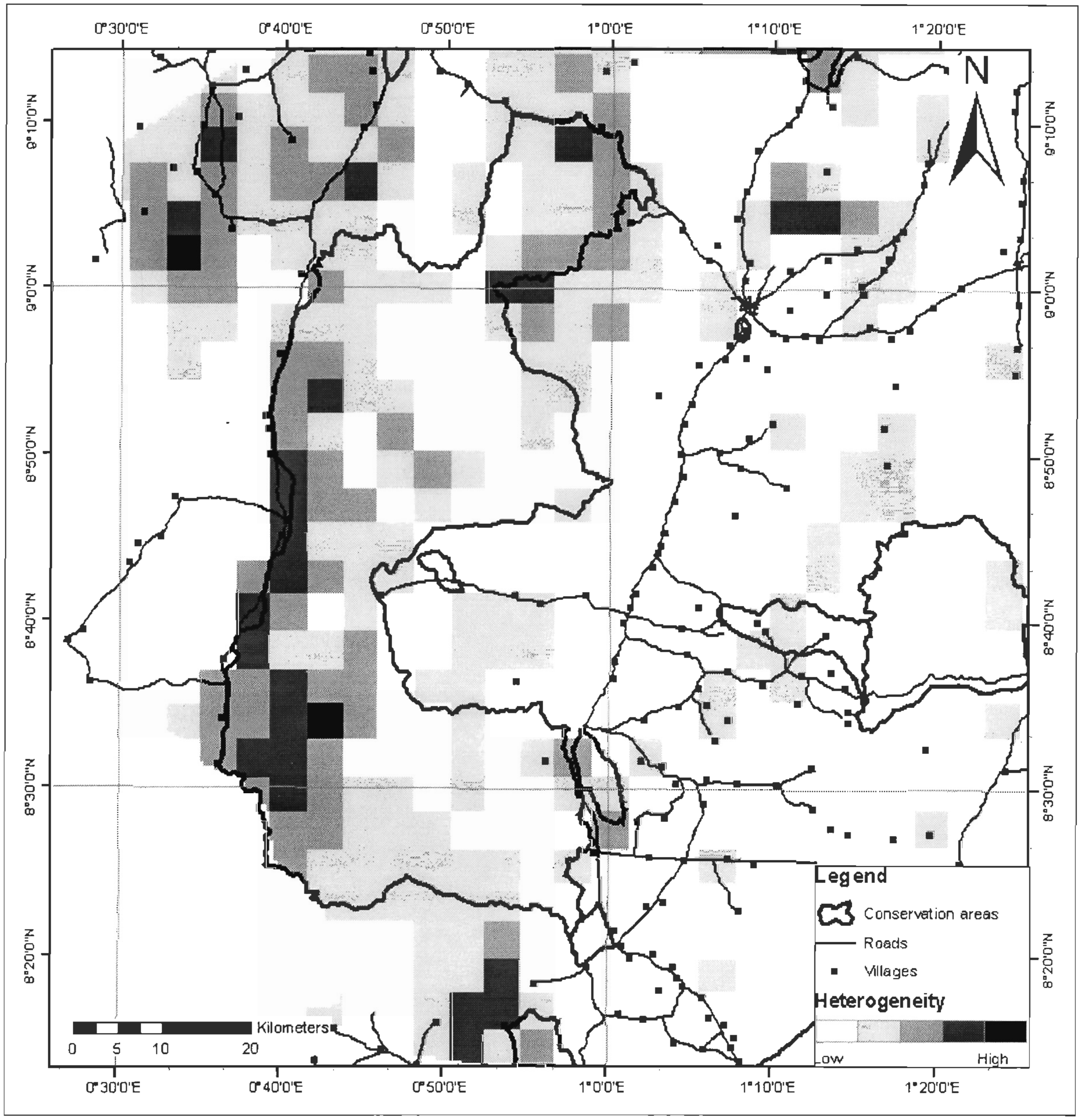

Figure 4 : Heterogeneity index.

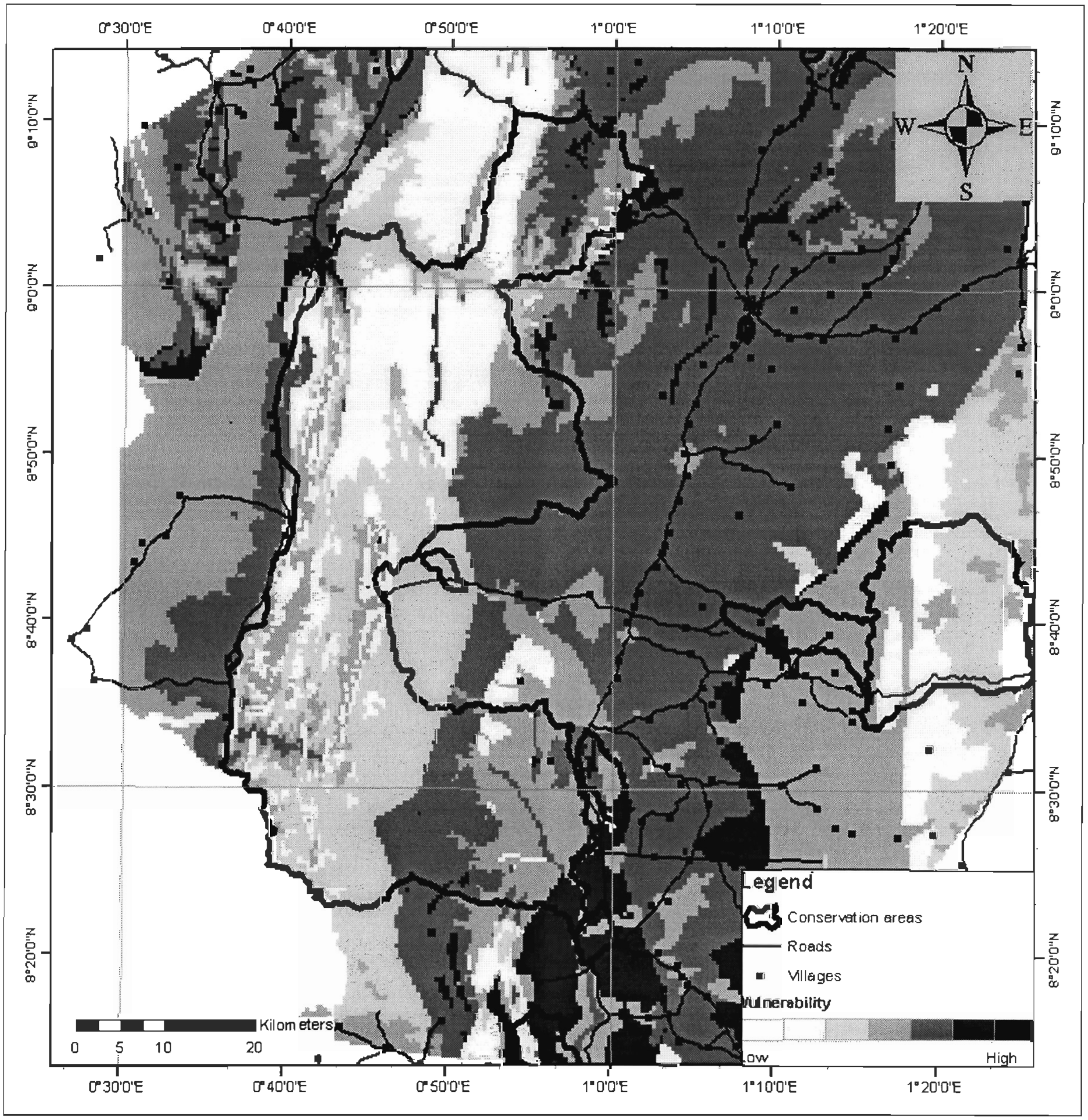

Figure 5 : Vulnerability index.

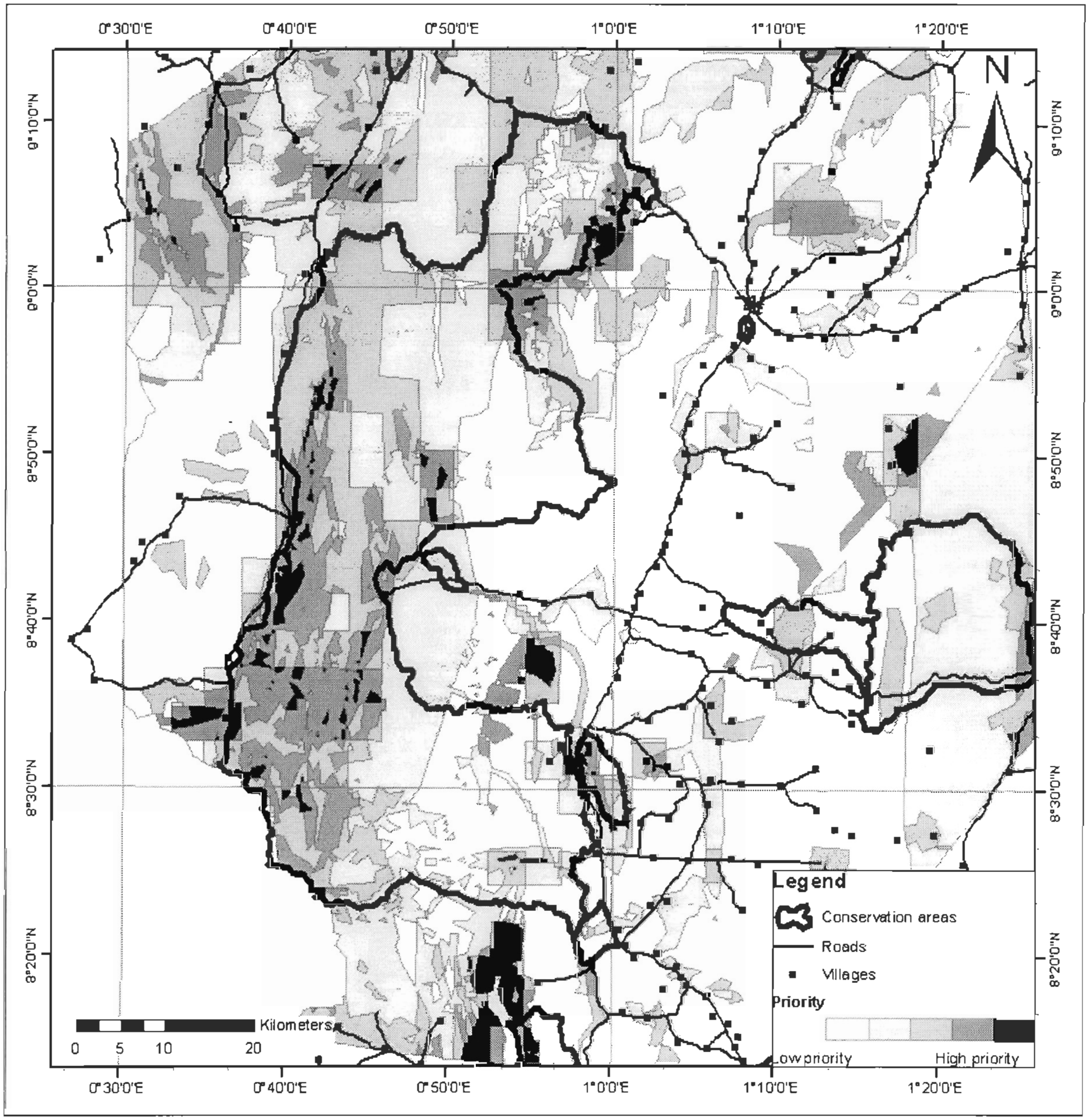

Figure 6 : Priority index.

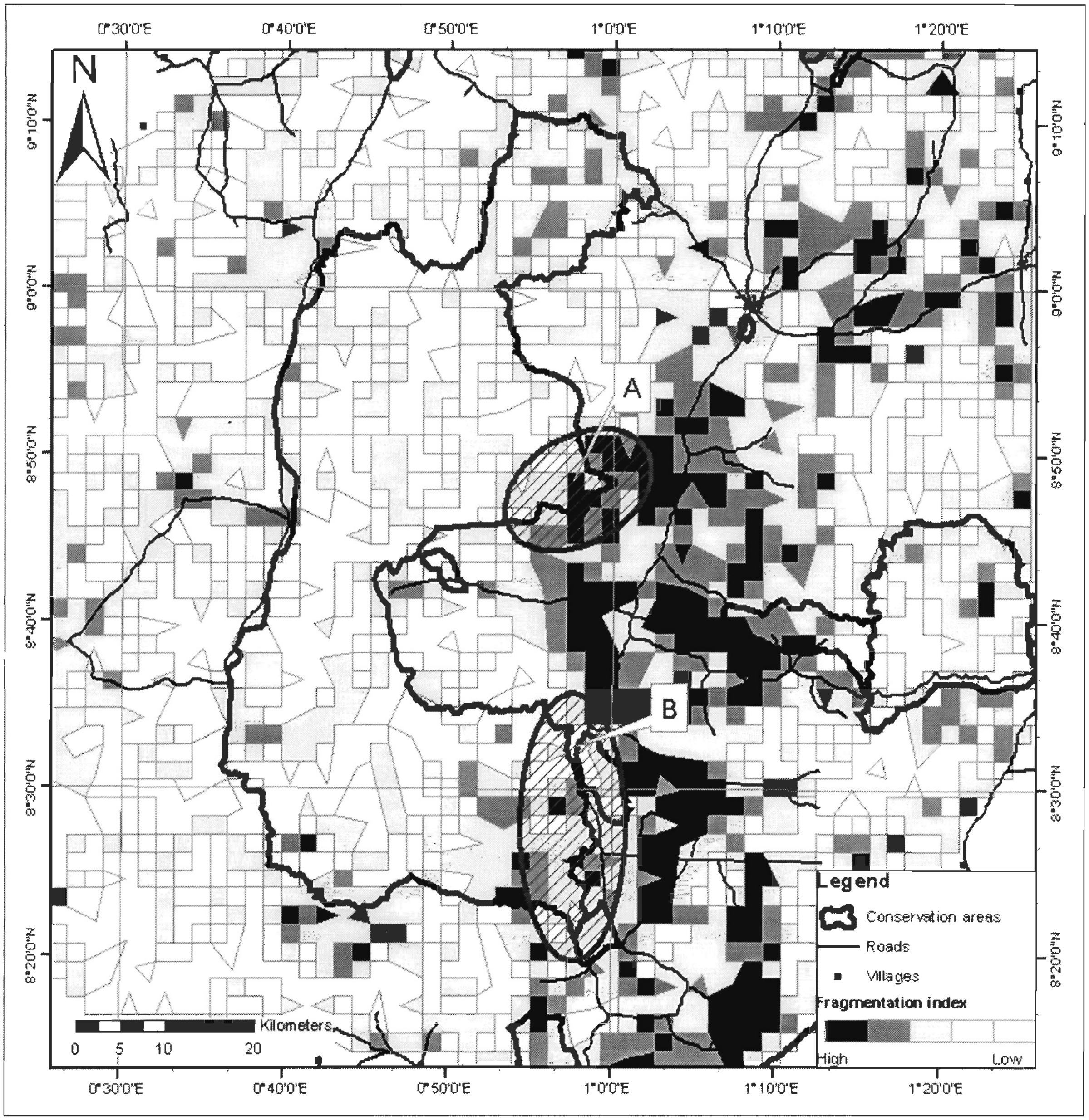

Figure 7: Fragmentation index. Zone A and B on the map represent particularly degraded areas of the Fazao National Park.

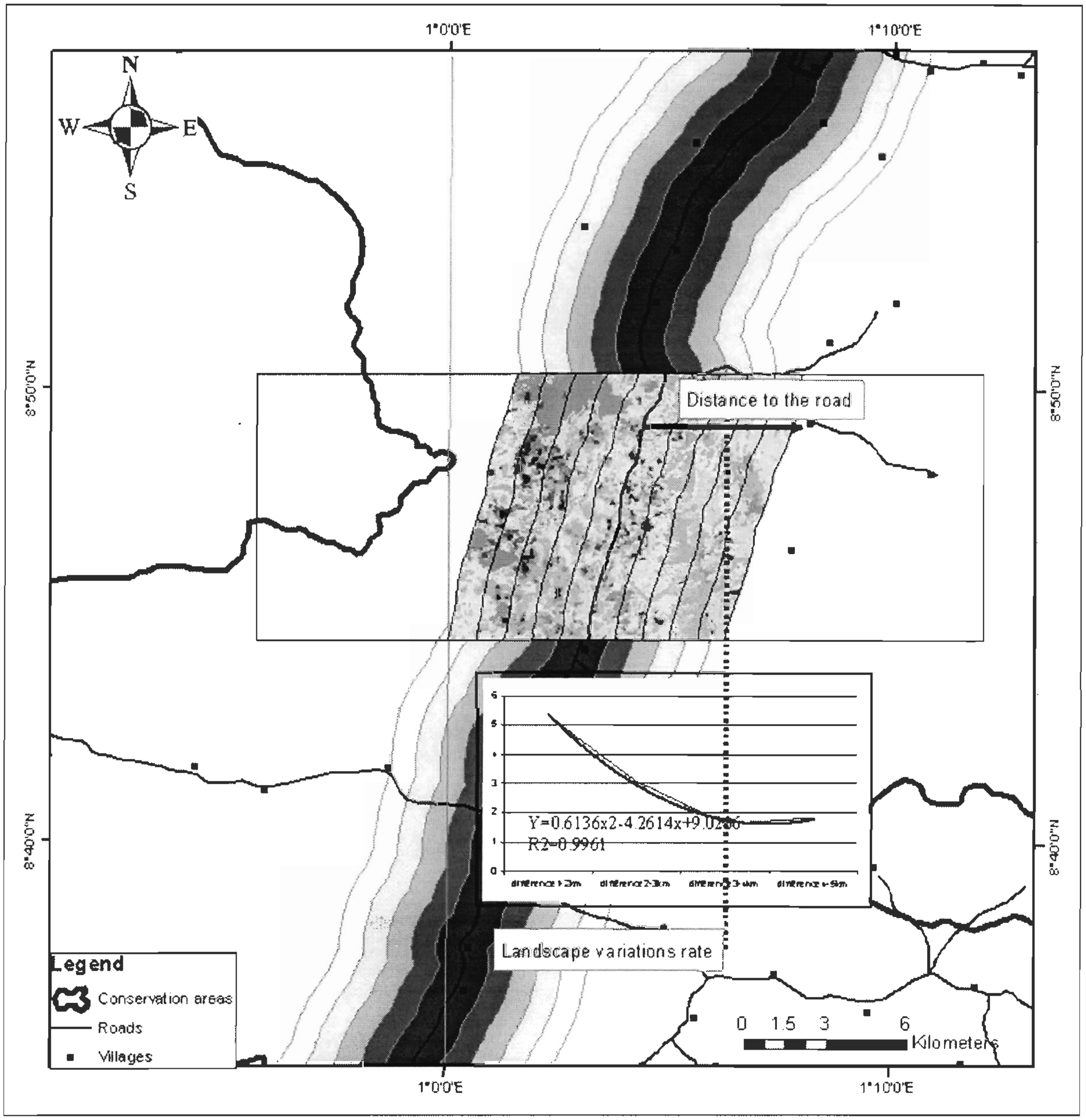

Figure 8 : Road perturbations.

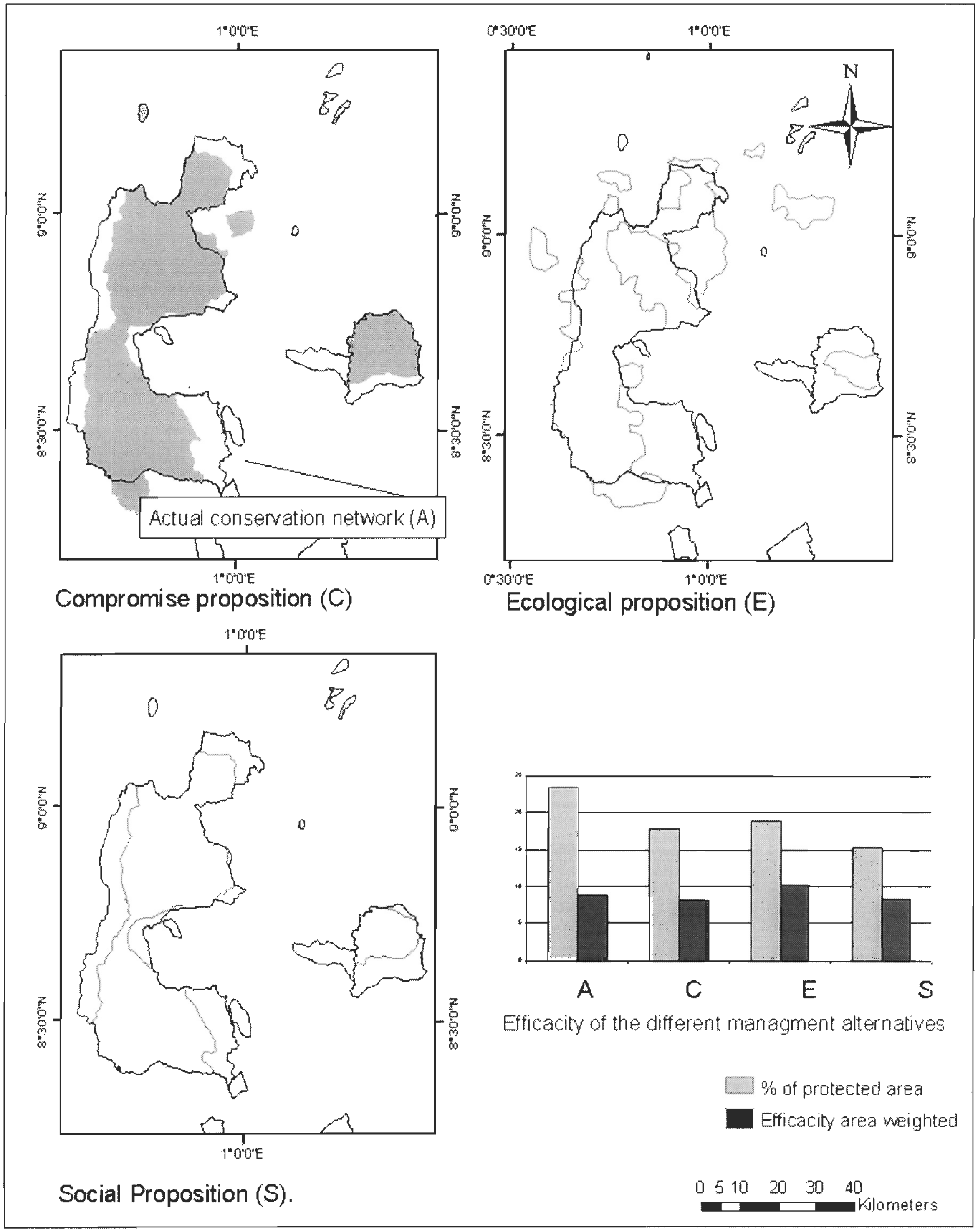

Figure 9 : Managment alternatives

Appendix 1: Spatial considerations for design of conservation network

For the past 40 years, the use of Single Large or Several Small conservation areas (SLOSS) has been debated (MacArthur & Wilson 1967; Margules et al. 1982; Wilcox & Murphy 1985; Diamond 1986; Soule & Simberloff 1986; Lomolino 1994; Boecklen 1997). This theoretical and applied issue refers to the best method to maintain maximum biodiversity (Saetersdal et al. 1993; Lomolino 1994). However, no consensus has been reach yet because of the diversity and uniqueness of empirical examples (Prendergast et al. 1999).

Large areas are commonly preferred because they will encompass more species (Margules 1982) and reduce risks of local extinction (Mac Arthur and Wilson 1967, Margules 1982, Shafer 1999, Shafer 2001, Bedward et al., 1992). Furthermore, large areas are less vulnerable to pillaging (Soulé 1986, Shafer 1999), could be beneficial to migration (Kunin 1997) and facilitate natural processes management (Shafer 1999). However, Margules (1982) and Cabeza and Moilanen (2001) argued for compact reserves based on economic considerations. Moreover, there is no evidence that any extinction in reserve is linked directly with a decrease in protected area (Gilbert 1980). Numerous authors have stressed the importance of large reserves (Goetmark & Thorell 2003, Miller & Hobbs 2002, Shafer 1999, Hansson & Angelstam 1991), they also have noted the supportive role of small reserves to preserve rare species and ecosystems. Small reserves are complementary to larger reserves; they should not be considered as substitute (Shafer 1999; Miller & Hobbs 2002).

Considering the actual failure of very large protected areas in Togo, we have accepted a relative decrease in size of the conservation areas, without minimizing the importance of large and continuous zones. Small areas are considered according to their biodiversity value and their complementarity to the main protected areas.

The shape of reserve area is also a debate topic. Compact reserves with regular shape favor the persistence of interior species by reducing the ratio perimeter/area that is linked to the edge effect (Wilson & Willis 1975; Kunin 1997). Nevertheless, Game (1990) suggested maximizing this ratio to increase the rate of interception (from passive dispersal). Edge effect has influences on microclimate, predation and composition of plant and animal communities (Menon & Bawa 1997; Zheng & Chen 2000; Hansson et al., 1991). Small and irregularly-shaped patches are more affected by edge effects than hugh continuous patches (Zhenh & Chen 2000). Moreover, abrupt transitions between two adjacent patches favor important edge effect (Zheng & Chen 2000; Shafer 1999).

Honnay et al. (1999) have argued that irregularly shaped patches contain generally more plant species because of their higher number of environmental gradients. Elongated shape is promoted by Simberloff (1986) because of the size of the interface that favors potential immigrants, especially if it is oriented perpendicular to the likely flow of immigrants. Nevertheless, Kunin (1997) has shown that the advantages of elongation are largely scale independent and the only documented disadvantage (edge effect) is highly scale dependent. Consequently, small reserves are more influenced by edge effect and need a more compact shape. Beyond a certain size, edge effect tends to be less important. Large reserves have advantages to become elongated to capture a greater diversity of conditions and, consequently, a greater number of species (Kunin 1997).

The National Park of Fazao is an elongated reserve that plays a crucial role for species migration; elephants (*Loxodonta africana*) and monkeys [e.g., eastern black and white colobus (*Colobus gereza*)] migrate through the Kiabobo National Park in Ghana. This elongated shape has to be maintain for large areas whereas if smaller patches are identified a more compact design will be apply.

MacArthur and Wilson's theory (1967) assumes that migration is distance dependant. Having individual sites close together facilitates dispersal and recolonization; this pattern increases the probability of regional persistence (Cabeza & Moilanen 2001). Consequently, long-time reserve planners have try to favor small inter-reserve distance (Shafer 2001). However, risk of disease and natural catastrophes could have more impacts if reserves are close together. With respect to these risks a greater inter-reserve distance could be advantageous (Shafer 2001). In the case of Central country in Togo, the importance of species migration, risk of global changes and landscape transformations require a network of interconnected reserves to minimize all the possible impacts of long inter-reserve distance.

Landscape connectivity refers to the functional relationship among habitat patches owing to the spatial contagion habitat and the movement responses of organisms to landscape structure (With et al. 1997). Although Siberloff and Cox (1987) have used island analogies to illustrate advantages of isolation, connectivity and corridors play a crucial role in the persistence of biodiversity at the landscape level. However, Noss (1987) has demonstrated the role of corridor as a cost-effective complement to the strategy of large and multiple reserves in real-life landscapes. A corridor can generally be considered to be a linear feature, that differs of the surrounding environment, connecting at least to patches that were connected historically (Hobbs 1993). Corridors are important in order to minimize local extinction, predation and genetic isolation (Noss & Harris 1986; Harrison 1992; Hobbs 1993; Hannah et al. 1998; Shafer 1999; Earn et al. 2000; Shafer 2001; Rouget 2003). Nevertheless, movement corridors are often specie–specific and hard to identify (Gustafson & Gardner 1996).

Main rivers and riparian ecosystems in Togo will serve to maintain connectivity between each conservation area. Corridors will allow migration and possible shifts in population distribution. It is difficult to recommend optimal width of corridors without reliable information; however distance of 250 m of each side of riparian systems was arbitrary considered (Rouget et al., 2003).

CONCLUSION GÉNÉRALE

Bilan de l'étude

La conservation de la biodiversité est intimement liée à la compréhension que l'on peut avoir de celle-ci et à notre capacité à prédire sa distribution dans l'espace et le temps. L'étude que nous avons menée dans la région Centrale avait pour but de mettre en place une nouvelle approche de conservation et des outils qui permettraient de soutenir le programme de réhabilitation des aires protégées du Togo. Nos objectifs visaient à (1) définir des objectifs de conservation, (2) développer des outils pour acquérir les données manquantes rapidement et à moindre coût (3) définir un nouveau réseau d'aires protégées basé sur une approche multicritère capable de protéger efficacement et durablement la biodiversité de la région Centrale au Togo.

Étude du paysage

Une première analyse du paysage a été décomposée en trois axes distincts afin de comprendre l'évolution de la biodiversité dans la région Centrale ainsi que les menaces qui pèsent dessus :

- **Une étude des changements historiques** par l'étude de chrono-séquence d'images Landsat, validée par une étude de terrain ;
- **Une étude de fragmentation** basée sur les données satellites les plus récentes ;
- **Une mesure des impacts environnementaux** liés à la présence de villages et de routes basée sur l'analyse d'images Landsat.

Les résultats montrent clairement une dégradation des habitats en limite et dans les aires protégées au cours des années 1990. Dans les zones dégradées, les indices de fragmentation augmentent, la taille des parcelles diminue, le couvert forestier diminue. Les principales causes de dégradation des habitats sont la déforestation, les feux, la mise en culture de nouvelles terres et le braconnage. On note que ces impacts sont très marqués le long des routes et autour des villages et l'étude des images satellites permet de déterminer avec efficacité la distance jusqu'à laquelle se répercutent ces impacts négatifs (e.g., 3 à 4 kilomètres). Cette mesure, ainsi qu'une meilleure compréhension des risques qui pèsent sur la biodiversité doivent permettre d'écarter du réseau d'aires protégées les zones trop dégradées ou celles susceptibles de l'être rapidement et assurer la pérennité à long terme de celles-ci. Ce paramètre trop peu souvent considéré est une clé pour la conservation optimale des écosystèmes.

Par ailleurs, trois approches complémentaires ont été utilisées pour déterminer de façon aussi précise que possible les zones importantes pour la biodiversité dans la région.

1-L'équation d'un modèle de régression multiple utilisant les différentes bandes spectrales des images Landsat, les données du modèle d'élévation numérique, ainsi que les relevés de diversité effectués sur le terrain, a permis de calculer un indice de biodiversité pour l'ensemble du territoire.

2-Un indice de priorité de conservation, recoupant les données de vulnérabilité, de rareté, d'hétérogénéité et de complémentarité des différentes classes de paysages a été élaboré. Cet indice permet de cartographier les zones importantes pour la diversité β et le maintien des processus liés à la biodiversité.

3-L'étude des patrons de biodiversité réalisée par C. Chaillon (2006) ainsi que les informations collectées auprès des experts ont permis de déterminer des éléments du paysage important pour la biodiversité.

Toutes ces informations ont permis de cartographier avec succès les zones importantes pour la biodiversité. Les recoupements observés entre l'indice de priorité, indice reconnu, et l'indice de biodiversité calculé permettent de valider ce dernier. Les similitudes importantes observées, peuvent également s'expliquer par le fait que seules les zones les moins accessibles, c'est-à-dire les zones montagneuses présentant un important gradient altitudinal et paysagé, restent relativement préservées.

Des informations concernant les sites culturels et religieux, les possibles impacts liés à la prévision de l'accroissement démographique et le statut des terres ont également été cartographiés. Les possibles changements climatiques selon certains modèles connus ainsi que les considérations spatiales liées à la délimitation des aires de conservation ont également été considérés.

L'ensemble des résultats obtenus a été incorporé à un Système d'Information Géographique pour produire différentes alternatives de gestion mettant l'emphase respectivement sur les aspects écologiques et sociaux. Les superficies protégées diminueraient de 5 à 8% passant de 23.3% à l'origine, à 15.27% pour l'alternative « sociale ». Cette diminution des superficies protégées ne s'accompagne pas d'une baisse d'efficacité en terme de représentativité des paysages. On observe même, dans le cadre de l'option dite « écologique », une augmentation de l'efficacité, particulièrement si celle-ci est pondérée par la superficie. Par ailleurs, l'efficacité réelle, en terme de conservation des écosystèmes, devrait augmenter significativement grâce à l'évitement des zones les plus perturbées ou susceptibles de l'être et à la réduction significative des superficies protégées.

Au final les différentes alternatives proposées doivent pouvoir servir de base pour les futures concertations pour la réhabilitation des aires protégées. Les outils développés et la méthodologie proposée ont démontré qu'il était possible de prendre en compte les facteurs sociaux, économiques ou culturels, d'éviter les zones défavorables à la conservation tout en maintenant une efficacité similaire voir supérieure à ce qu'elle est actuellement.

Références citées

Araujo, M. B. 1999. Distribution patterns of biodiversity and the design of a representative reserve network in Portugal. Diversity and Distributions **5**:151-163.

Araujo, M. B., P. H. Williams, and R. J. Fuller. 2002a. Dynamics of extinction and the selection of nature reserves. Proceedings of the Royal Society of London, Series B: Biological Sciences **269**:1971-1980.

Balmford, A., J. L. Moore, T. Brooks, N. Burgess, L. A. Hansen, P. Williams, and C. Rahbek. 2001. Conservation conflicts across Africa. Science **291**:2616-2619.

Bedward, M., R. L. Pressey, and D. A. Keith. 1992. A new approach for selecting fully representative reserve networks: Addressing efficiency, reserve design and land suitability with an iterative analysis. Biological Conservation. **61**:115-125.

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology. **16**:909-923.

Bruner, A. G., R. E. Gullison, R. E. Rice, and G. A. B. da Fonseca. 2001. Effectiveness of parks in protecting tropical biodiversity. Science **291**:125-128.

Chaillon, C. 2006. Étude des processus responsables des patrons de répartition de la biodiversité avienne dans le parc national de Fazao. Mémoire de Maîtrise, UQAR, Rimouski.

Church, R. L., D. M. Stoms, and F. W. Davis. 1996. Reserve selection as a maximal covering location problem. Biological Conservation **76**:105-112.

Cincotta, R. P., J. Wisnewski, and R. Engelman. 2000. Human population in the biodiversity hotspots. Nature **404**:990-992.

Cowling, R. M., and R. L. Pressey. 2001. Rapid plant diversification: Planning for an evolutionary future. Proceedings of the National Academy of Sciences, USA. **98**:5452-5457.

Cowling, R. M., R. L. Pressey, M. Rouget, and A. T. Lombard. 2003. A conservation plan for a global biodiversity hotspot--the Cape Floristic Region, South Africa. Biological Conservation **112**:191-216.

Ferrier, S. 2002. Mapping Spatial Pattern in Biodiversity for Regional Conservation Planning: Where to from Here? Systematic Biology **51**:331-363.

Folke, C., C. Perrings, J. A. McNeely, and N. Myers. 1993. Biodiversity conservation with a human face: Ecology, economics and policy. Ambio. Stockholm **22**:62-63.

Freitag, S., A. O. Nicholls, and A. S. Van Jaarsveld. 1998. Dealing with established reserve networks and incomplete distribution data sets in conservation planning. South African Journal of Science **94**:79-86.

Gaston, K. J., and A. S. Rodrigues. 2003. Reserve Selection in Regions with Poor Biological Data. Conservation Biology **17**:188-195.

Gladstone, W. 2002. The potential value of indicator groups in the selection of marine reserves. Biological Conservation **104**:211-220.

Goldsmith, F. B. 1987. Selection procedures for forest nature reserves in Nova Scotia. Biological Conservation **41**:185-201.

Grumbine, R. E. 1997. Reflections on "What is ecosystem management?" Conservation Biology **11**:41-47.

Gustafson, E. J., and G. R. Parker. 1994. Using an index of habitat patch proximity for landscape design. Landscape and Urban Planning **29**:117-130.

Hector, A., J. Joshi, S. P. Lawler, E. Spehn, and A. Wilby. 2001. Conservation implications of the link between biodiversity and ecosystem functioning. Oecologia **129**:624-628.

Heikkinen, R. K. 1939. Complementarity and other key criteria in the conservation of herb-rich forests in Finland. Biodiversity and Conservation **11**:1939-1958.

Howard, P., T. Davenport, and F. Kigenyi. 1997. Planning conservation areas in Uganda's natural forests. Oryx **31**:253-264.

Howard, P. C., P. Viskanic, T. R. B. Davenport, F. W. Kigenyi, M. Baltzer, C. J. Dickinson, J. S. Lwanga, R. A. Matthews, and A. Balmford. 1998. Complementarity and the use of indicator groups for reserve selection in Uganda. Nature **394**:472-475.

Karr, J. R. 1990. Biological integrity and the goal of environmental legislation: Lessons for conservation biology. Conservation Biology **4**:244-250.

Kremen, C., V. Razafimahatratra, R. P. Guillery, J. Rakotomalala, A. Weiss, and J. S. Ratsisompatrarivo. 1055. Designing the Masoala National Park in Madagascar Based on Biological and Socioeconomic Data. Conservation Biology **13**:1055-1068.

Lombard, A. T. 1995. The problems with multi-species conservation: Do hotspots, ideal and existing reserves coincide? S. Afr. J. Zool./S.-Afr. Tydskr. Dierkd. **30**:145-163

Lombard, A. T., R. M. Cowling, R. L. Pressey, and P. J. Mustart. 1997. Reserve selection in a species-rich and fragmented landscape on the Agulhas Plain, South Africa. Conservation Biology **11**:1101-1116.

Musters, C. J. M., H. J. de Graaf, and W. J. ter Keurs. 2000. Can protected areas be expanded in Africa? Science **5459**.

Myers, N. 1993. Biodiversity and the precautionary principle. Ambio. Stockholm **22**:74-79.

Myers, N. 1996. Two key challenges for biodiversity: Discontinuities and synergisms. Biodiversity and Conservation **5**:1025-1034.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature **403**:853-858.

Nepal, S. K., and K. E. Weber. 1994. A buffer zone for biodiversity conservation: Viability of the concept in Nepal's Royal Chitwan National Park. Environmental Conservation **21**:333-341.

Nicholls, A. O., and C. R. Margules. 1993. An upgraded reserve selection algorithm. Biological Conservation **64**:165-169.

Oenal, H., and R. A. Briers. 1508. Incorporating spatial criteria in optimum reserve network selection. Proceedings of the Royal Society of London, Series B: Biological Sciences **269**:2437-2441.

Pickett, S. T. A. a. T., J.N. 1978. patch dynamics and the design of nature reserves. Biological Conservation **13**:27-37.

Pimentel, D., C. Wilson, C. McCullum, R. Huang, P. Dwen, J. Flack, Q. Tran, T. Saltman, and B. Cliff. 1997. Economic and environmental benefits of biodiversity. Bioscience **47**:747-757.

Pimm, S. L., and J. H. Lawton. 1998. Planning for biodiversity. Science **279**:2068-2069.

Polasky, S., and A. R. Solow. 2001. The value of information in reserve site selection. Biodiversity and Conservation **10**:1051-1058.

Prendergast, J. R., R. M. Quinn, and J. H. Lawton. 1999. The Gaps between Theory and Practice in Selecting Nature Reserves. Conservation Biology **13**:484-492.

Pressey, R. L., C. J. Humphries, C. R. Margules, R. I. Van-Wright, and Williams. 1993. Beyond opportunism: Key principles for systematic reserve. Trends in Ecology & Evolution **8**:124-128.

Pressey, R. L. 1994. Ad hoc reservations: Forward or backward steps in developing reserve systems? Conservation Biology **8**:662-668.

Pressey, R. L., H. P. Possingham, V. S. Logan, J. R. Day, and P. H. Williams. 1999. Effects of data characteristics on the results of reserve selection algorithms. Journal of Biogeography **26**:179-191.

Pressey, R. L., H. P. Possingham, and J. R. Day. 2002. Effectiveness of alternative heuristic algorithms for identifying indicative minimum requirements for conservation reserves. Biological Conservation **80**:207-219.

Pressey, R. L., G. L. Whish, T. W. Barrett, and M. E. Watts. 2002. Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures. Biological Conservation **106**:57-69.

Purdie, R. W., R. Blick, and M. P. Bolton. 1986. Selection of a conservation reserve network in the Mulga Region of south-western Queensland, Australia. Biological Conservation **38**:369-384.

Randrianasolo, A., J. S. Miller, and T. K. Consiglio. 1289. Application of IUCN criteria and Red List categories to species of five Anacardiaceae genera in Madagascar. Biodiversity and Conservation **11**:1289-1300.

Rapoport, E. H., G. Borioli, J. A. Monjeau, J. E. Puntieri, and R. D. Oviedo. 1986. The design of nature reserves: A simulation trial for assessing conservation value. Biological Conservation **37**: 269-278.

Redford, K. H., and B. D. Richter. 1999. Conservation of Biodiversity in a World of Use. Conservation Biology **6**:1246-1256.

Reid, W. V. 1993. The economic realities of biodiversity. Issues in Science and Technology **10**:48-55.

Reyers, B. 2004. Incorporating anthropogenic threats into evaluations of regional biodiversity and prioritisation of conservation areas in the Limpopo Province, South Africa.

Rodrigues, A. S., and K. J. Gaston. 2001. How large do reserve networks need to be? Ecology Letters **4**:602-609.

Rodrigues, A. S. L., and K. J. Gaston. 2002. Optimisation in reserve selection procedures--why not? Biological Conservation **107**:123-129.

Rothley, K. D. 1999. Designing bioreserve networks to satisfy multiple, conflicting demands. Ecological Applications **9**:741-750.

Strittholt, J. R., and R. E. J. Boerner. 1995. Applying biodiversity gap analysis in a regional nature reserve the Edge of Appalachia, Ohio (U.S.A.). Conservation Biology **9**: 1492-1505.

UNEP 1995. global biodiversity assessment. Cambridge University Press. Cambridge.

Wilson, E. O. 1988. The current state of biological diversity. Pages 3-20. Biodiversity. National Academic Press, Washington, DC.

With, K. A. 2002. The Landscape Ecology of Invasive Spread. Conservation Biology **16**:1192-1203.

ANNEXE 1

Sujet	Études-références
Methodology for selection	(Araujo 1999; Araujo et al. 2002a; Arthur et al. 1997; Bedward et al. 1992; Belbin 1993, 1995; Briers 2002; Cabeza & Moilanen 2001; Church et al. 1996; Cowling & Heijnis 2001; Cowling & Pressey 2003; Cowling et al. 2003; Diamond 1986; Freitag et al. 1998; Gaston et al. 2001; Gaston & Rodrigues 2003; Gladstone 2002; Goldsmith 1987; Hansson & Angelstam 1991; Heijnis et al. 1999; Heikkinen 1939; Hoctor et al. 2000; Howard et al. 1997; Kremen et al. 1055; Lombard et al. 1997; Lomolino 1994; Nicholls & Margules 1993; Oenal & Briers 1508; Polasky & Solow 2001; Prendergast et al. 1999; Pressey 1994; Pressey & Cowling 2001; Pressey et al. 2003; Pressey et al. 2000; Pressey et al. 1993; Pressey et al. 1999; Purdie et al. 1986; Rapoport et al. 1986; Reyers et al. 2001; Reyers et al. 2002; Rodrigues & Gaston 2001; Rothley 1999; Rouget et al. 2003; Saetersdal 1994; Shafer 1999; Underhill 1994; Wessels et al. 2000)
Threat	(Araujo et al. 2002b; Ayyad 2003; Balmford et al. 2001; Brooks et al. 2002; Bruner et al. 2001; Ehrlich & Wilson 1991; Hansson & Angelstam 1991; Honnay et al. 2002; Miller & Hobbs 2002; Myers 1995; Peres & Terborgh 1995; Pimm & Lawton 1998; Randrianasolo et al. 1289; Reyers et al. 2002; Shafer 2001; With 2002),
Diversity and integrity	(Angermeier 2000; Angermeier & Karr 1994; Araujo 1999; Brooks et al. 2002; Cowling & Pressey 2001; Dumortier et al. 2002; Ehrlich & Wilson 1991; Ferrier 2002; Folke et al. 1993; Franklin 1993; Grumbine 1990; Grumbine 1997; Hector et al. 2001; Karr 1990; Lesica 1993; Lombard 1995; Lombard et al. 2003; Luoto et al. 2002; Miller 1991; Musters et al. 2000; Myers 1990, 1993, 1996; Myers et al. 2000; Noss 1983; Pimentel et al. 1997; Pimm & Lawton 1998; Redford & Richter 1999; Reid 1993, 1994; Rouget et al. 2003; Saetersdal et al. 1993; Strittholt & Boerner 1995; Williams et al. 1996; Wilson 1994)
Scale- Selection unit	(Franklin 1993; Grumbine 1990; Kunin 1997; Pressey

	& Logan 1998; Rouget 2003; Schwartz 1999)
Spatial design	(Andrén 1994; Cabeza & Moilanen 2001; Earn et al. 2000; Goetmark & Thorell 2003; Gustafson & Gardner 1996; Gustafson & Parker 1994; Hansson & Angelstam 1991; Harrison 1992; Hobbs 1993; Honnay et al. 2002; Kunin 1997; Margules et al. 1982; Moilanen & Hanski 1998; Naiman et al. 1993; Peres & Terborgh 1995; Pickett 1978; Rodrigues & Gaston 2001; Shafer 1999, 2001; Simberloff 1986; Simberloff & Cox 1987; Soule & Simberloff 1986; Turner 1989; Wiens et al. 1997; Wilcox & Murphy 1985; Zheng & Chen 2000), Mac Arthur & Wilson 1967
Remote sensing	(Ayyad 2003; Honnay et al. 2003; Luoto et al. 2002; Menon & Bawa 1997; Rouget 2003; Wessels et al. 2000) Amarnath and al., 2003
Representativeness	(Araujo 1999; Bedward et al. 1992; Belbin 1993; Freitag et al. 1998; Lesica 1993; Pressey & Taffs 2001; Pressey et al. 2002)
Complementary-	(Belbin 1995; Freitag et al. 1998; Gaston & Rodrigues 2003; Heikkinen 1939; Howard et al. 1998; Lombard 1995; Reyers et al. 2002; Reyers et al. 2000; Underhill 1994; Williams et al. 1996)
Rarity –vulnerability-Efficiency	(Bruner et al. 2001; Cowling et al. 2003; Lombard et al. 2003; Pressey & Taffs 2001)
Human importance	(Durbin & Ralambo 1994; Folke et al. 1993; Fox et al. 1996; Miller & Hobbs 2002; Myers 1995; Nepal & Weber 1994; Reyers 2004)