PRACTICAL APPROACHES FOR ASSESSING LOCAL LAND USE CHANGE AND CONSERVATION PRIORITIES IN THE TROPICS

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ABSTRACT

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Tropical areas typically support high biological diversity; however, many are experiencing rapid land-use change. The resulting loss, fragmentation, and degradation of habitats place biodiversity at risk. For these reasons, the tropics are frequently identified as global conservation hotspots. Safeguarding tropical biodiversity necessitates successful and efficient conservation planning and implementation at local scales, where land use decisions are made and enforced. Yet, despite considerable agreement on the need for improved practices, planning may be difficult due to limited resources, such as funding, data, and expertise, especially for small conservation organizations in tropical developing countries. My thesis aims to assist small, non-governmental organizations (NGOs), operating in tropical developing countries, in overcoming resource limitations by providing recommendations for improved conservation planning.

Following a brief introduction in Chapter 1, I present a literature review of systematic conservation planning (SCP) projects in the developing tropics. Although SCP is considered an efficient, effective approach, it requires substantial data and expertise to conduct the analysis and may present challenges for implementation. I reviewed and synthesized the methods and results of 14 case studies to identify practical ways to implement and overcome limitations for employing SCP. I found that SCP studies in the peer-reviewed literature were primarily implemented by researchers in large organizations or institutions, as opposed to on-the-ground conservation planners. A

variety of data types were used in the SCP analyses, many of which data are freely available. Few case studies involved stakeholders and intended to implement the assessment; instead, the case studies were carried out in the context of research and development, limiting local involvement and implementation. Nonetheless, the studies provided valuable strategies for employing each step of the SCP assessment and ways to overcome limitations. These included obtaining and using publicly available data resources, collaborating with institutions or organizations with resources, and using expertise to employ the analytical process. In conclusion, the local conservation organization should ultimately decide whether or not to use the SCP approach using reviews such as this one and the feasibility assessment model provided in this chapter.

In Chapter 3, to support locally based conservation planning efforts in southwestern Nicaragua, I collaborated with a small NGO and produced valuable data products for conservation planning. I produced a land-use and land cover change (LULC) classification and identified hot and cold spots (i.e., high and low concentration) of land cover change between the years of 2000 – 2009. I used SPOT satellite imagery from 2009, ground referenced data, and manual training points to classify 10 LULC types using a regression tree algorithm. I employed a post-classification change detection analysis to compare my classification to one from the year of 2000, applied a cluster analysis to delineate hot and cold spots of change, and used the resulting data products to identify preliminary conservation and restoration priorities. The LULC classification accuracy was 87.9% and deforestation rates were approximately 5.6% per year. I observed that pasture was the most converted-to class, plantation was a proliferating class, and some regrowth succeeded into secondary forest. Hotspots and cold spots of

change for conservation concern included areas converted from forest into pasture, which often occurred in areas of rugged terrain. Hotspots from forest to plantation occurred in the northern isthmus, while cold spots occurred in the south. These two trends revealed the vulnerability of remaining secondary forests, which are of primary importance to regional conservation efforts. Conservation priorities included remaining old secondary forest patches and succeeding forests occurring near them and should factor into future conservation planning.

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Table of Contents

List of Tables

CHAPTER 2: Systematic conservation planning: A guide for small conservation NGOs in tropical developing countries

CHAPTER 3: Land use and land cover change: Implications for conservation and restoration in southwestern Nicaragua

List of Figures

CHAPTER 2: Systematic conservation planning: A guide for small conservation NGOs in tropical developing countries

CHAPTER 3: Land use and land cover change: Implications for conservation and restoration in southwestern Nicaragua

Dedication

I dedicate my thesis work to my mother, Esther Cantu, and memory of my grandfather, Librado Olivarez, who both constantly pushed me to excel in my education and were strong advocates for my pursuit of a graduate degree. But most importantly, have always encouraged me to follow my dreams.

Preface

This master's thesis is presented in journal format. It includes a total of four chapters, of which the second and third have been prepared as manuscripts for submission in peer-reviewed journals. These two chapters are intended to stand alone with the first and last chapters aimed at tying them together; therefore, some redundancy in text is present in all chapters. Also, the pronouns "we" and "our" are used throughout.

Chapter 1: Overall thesis introduction and objectives

Tropical forests support considerable biodiversity and endemism (World Resources Institute, 2001) and also provide essential ecosystem services such as water filtration, food, and carbon storage (Bawa et al., 2004). Unfortunately, intensive land-use change in the tropics has accelerated over the last century and, consequently, threatening many of these places. Deforestation is the main driver of this change, occurring at alarming rates throughout the tropics (FAO, 2012; Saunders et al., 1991). The native land cover is often replaced with, primarily, agricultural land use types such as pasture, crop, and plantations (Sader and Joyce, 1988). These changes frequently result in fragmentation and degradation of the native forests, exemplifying the need for effective conservation.

Conservation efforts for tropical forests often face daunting resource challenges, including lack of data, expertise, and funding ─ especially for small, locally focused NGOs attempting to undertake the task. Compounded on these challenges is the fact that many tropical forests occur in developing countries. Many conservation efforts in tropical regions have been deemed unsuccessful, due to a lack of funds, limited governmental support, and reliance on ad hoc methods that are often inefficient and insufficient. Because ad hoc planning processes often overlook consideration of important biological and ecological features, lack well-defined goals, and lack a systematic decision-making process, the resulting reserve areas are often insufficient to conserve species and their habitats (Margules and Pressey, 2000).

Emerging approaches in systematic conservation planning (SCP) address the identified shortcomings of previous conservation planning through analysis and modeling. SCP systematically selects priority areas for conservation by considering many biological, ecological, and socio-economic variables, thus, targeting efficient conservation reserve design. Although literature on the SCP approach has increased in the past couple of decades (Kukkala and Moilanen, 2013), it may not be the panacea that some hoped for and expected. SCP often requires substantial resources, including data and expertise, which may not be available to many organizations, especially smaller NGOs that provide local grounding to broad conservation initiatives in the developing tropics.

Paso Pacífico, operating in southwestern Nicaragua, is an example of a small, local NGO attempting to conserve and restore native forests for species of concern, such as the black-handed spider monkey (*Ateles geoffroyi*). Nicaragua is a prime example of a country facing the many difficulties in achieving conservation objectives in the developing tropics. High level of forest fragmentation, rapid land use change, and the vulnerability of Nicaragua's remaining forest resources, endanger critical habitat for a wide variety of organisms, undermine its ecosystem services, and diminish ecological integrity. In attempt to decipher and minimize the effects of LULC change, we established a partnership between Northern Arizona University and Paso Pacífico and undertook a land use and land cover change analysis

The overarching goal of our study was to develop a set of recommendations to aid small NGOs in accomplishing effective and efficient conservation planning to safeguard the vital natural resources of the developing tropics. We developed a multi-pronged strategy to accomplish this goal:

(1) Conduct a SCP literature review.

- Objective 1: Identify the essential components and develop an overview of systematic conservation planning.
- Objective 2: Based on case studies described in the peer-reviewed literature, develop recommendations on how to implement an SCP assessment and ways to overcome limitations for doing so in developing countries.

(2) Assist in on-the-ground conservation work in southwestern Nicaragua.

- Objective 3: Produce a novel land use land cover classification for 2009, analyze changes between the years of 2009 and 2000, and determine the hotspots of land cover change.
- Objective 4: Provide recommendations for conservation and restoration planning based on these analyses.

(3) Provide overall conclusions and recommendations.

- Objective 4: Link the literature review and LULC analysis presented in Chapters 2 and 3 of this thesis, and provide conservation recommendations for small NGOs, including Paso Pacífico, in tropical developing countries.

Chapter 2: Systematic conservation planning: A guide for small conservation NGOs in tropical developing countries

Abstract

Tropical forests are abundant in biodiversity, face large scale land-use change, and most often occur in developing countries. These circumstances require augmented proficiency in conservation practices. However, numerous conservation efforts have been deemed inadequate due to ad hoc approaches used, which often lack clearly defined goals and are implemented without the consideration of important biological or ecological data. Stemming from these shortfalls, systematic conservation planning (SCP) is based on an explicit set of goals and targets, and efficiently uses available data to identify areas that can effectively represent biodiversity and other values. Nonetheless, this approach may not be a feasible option for small non-governmental organizations attempting to conserve in tropical developing countries due to resource limitations such as lack of data. The objective of this study is to create an overview of SCP, identify useful examples of the process, and develop recommendations to overcome limitations faced by small NGOs in tropical developing countries. To accomplish this task, we conducted a review of the peer-reviewed literature and selected case studies that carried out an SCP assessment in a tropical developing country. We organized and assessed the case studies based on eight specific components of the SCP assessment. In the overview, we described the basis of SCP, including its foundational concepts and principles, the eight components of focus, and the specific requirements needed for its implementation including data, expertise, software programs, and stakeholders. We found that a small number of SCP studies (n=14) have been carried out in tropical developing countries, primarily by researchers in large, international institutions or organizations. Furthermore, we observed that a variety of data, including biological and economic data, are often available for public use. Unfortunately, few of the studies involved stakeholders and few intended to implement the assessment. Based on the case study assessment, we provided suggestions for overcoming limitations, including using publicly available resources and collaborating with institutions and organizations, to aid the SCP assessment process. While we believe the SCP assessment is feasible for most organizations, the organization itself should determine the feasibility of the SCP approach using our and other SCP studies and guides, and the feasibility assessment we provided.

1. Introduction

Human exploitation of tropical forests has resulted in large-scale land use changes, significantly altering these ecosystems. Specifically, deforestation has decimated tropical forests across the globe over the past century, and continues at alarming rates—approximately 7.4 million hectares per year between 1990 and 2005—a rate higher than any other forest types (FAO, 2012; Saunders et al., 1991). Large-scale deforestation is largely a result of resource extraction (e.g., logging and mining), clearing for agriculture, and urban development. For example, 80% of Mesoamerican forest cover has been transformed into agricultural land (Harvey et al., 2008). This phenomenon has increased fragmentation, negatively affecting the ecosystems and the organisms that depend on them, including humans (Saunders et al., 1991). Moreover, land-use practices are impairing the valuable ecosystem services provided by forests including water filtration, carbon sequestration, and soil stability and fertility (Sunderlin et al., 2005; Kainer et al., 2009; FAO, 2012).

Due to their importance and vulnerability, many tropical forests are often considered as biological hotspots (i.e., high concentrations of both endemic species and habitat loss) or as high conservation priorities (Myers et al., 2000). Simultaneously, the largest tropical forests occur in developing countries (FAO, 2011) and implementing conservation in these countries may be difficult for a variety of reasons. Limited funding is a general barrier to conservation planning; however, this constraint is particularly acute in developing countries where monetary resources are especially scarce. Additionally, because people either live in or are indirectly dependent on tropical forests, implementing exclusionary conservation reserves may be a complicated and difficult task (Kainer et al., 2009). Despite these challenges, long-term benefits emerge from healthy ecosystems, and continued provision of the goods and services that underlie sustainable development require effective conservation strategies.

Conservation planning approaches, in general, primarily consist of two different frameworks — ad hoc approaches and systematic conservation planning (SCP, hereafter). Mills et al., (2012) defined the ad hoc approach as “conservation actions implemented without explicitly considering complementarity with existing action or contribution to achievement of broader goals such as species persistence.” The use of the ad hoc approach has resulted in protected areas being set aside for their aesthetic value, their minimum value to humans (e.g., unfertile or rugged topographic areas), or for opportunistic reasons (Groves et al., 2002; Pressey, 1994), as opposed to scientific assessments based on biodiversity value or other important factors (Watson et al., 2011). For example, Sanchez-Azofeifa et al. (2003) found that national parks in Costa Rica encompass the life zones that are least suitable for agriculture. Moreover, the ad hoc planning approach is considered to be cost ineffective (Sarkar et al., 2006). The urgent need to efficiently protect rapidly diminishing biodiversity with limited resources has influenced the development of systematic conservation planning (Margules and Pressey, 2000; Knight et al., 2006a).

SCP is a structured conservation approach intended to meet two key objectives: (1) representativeness—reserves designed to represent the full biodiversity of the region; and (2) persistence—reserves that support the long-term survival of biodiversity by retaining natural processes and excluding threats to biodiversity (Margules and Pressey, 2000). Additionally, SCP is based on critical concepts, such as complementarity (Kukkala and Moilanen, 2013; Watson et al., 2011; Sarkar et al., 2006). Complementarity is the measure of a specific areas' ability to represent previously unrepresented features (Margules and Pressey, 2000) and can be achieved by 1) defining current reserves and assessing their biological value, and 2) balancing existing or non-existing reserves with other conservation areas in order to maximize variety of species or biological features (Sarkar et al., 2006).

The overall SCP approach encourages and assists planners in (1) defining surrogates for biodiversity, (2) defining measurable goals and targets, (3) determining whether goals have been met in existing reserves, (4) locating and designing new reserves to complement existing reserves using specific methods, (5) applying specific criteria for prioritizing and implementing conservation actions, and (6) using monitoring and adaptive management to ensure persistence of key natural features (Margules and Pressey, 2000). This process aids in overcoming some of the common, reoccurring mistakes in conservation planning, including reducing arbitrariness and bias and increasing transparency, allowing for more effective conservation (Game et al., 2013). In addition to a more effective conservation planning strategy, SCP provides a framework detailing the critical components of the process, from guiding conservation planners through the assessment and identification of conservation priority areas, to monitoring the results (Margules and Pressey, 2000; Sarkar and Illoldi-Rangel, 2010). Knight et al., (2006a) provides a model example of this operational framework for conservation planning (Figure 2-1) which consists of three foundational elements: 1) empowering individuals and institutions, 2) conducting a systematic conservation assessment and 3) securing effective action. Although this study focuses on the conservation assessment part of the framework, it is important to acknowledge the entire process or operational model for effective conservation planning (Knight et al., 2006a; Figure 2-1).

The systematic conservation planning assessment (hereafter SCP assessment) consists of actions that identify the location and configuration of priority areas for conservation by employing technical approaches (Knight et al. 2008). SCP assessments are a key to conservation planning for a number of reasons. Because they are scientifically based, they provide a defendable platform to implement more efficient and less biased conservation actions (Knight et al., 2006b), lower the cost of conservation areas, in comparison with ad hoc planning-derived areas (O'Dea et al., 2006), and provide an approach for dealing with competing land uses (e.g., Marxan with Zones).

Most conservation work in the tropics is spearheaded by conservation-based non-governmental organizations (NGOs). Small, local conservation NGOs are widespread and active throughout the tropics and have generally employed the *ad hoc* approach, despite the increasing prominence of SCP research in peer-reviewed literature. However, the SCP peer-reviewed literature seldom use or promote the use of the SCP approach in tropical developing countries (Kukkula and Moilanen, 2013). Small local NGOs may not be using the SCP approach because of their lack of access to the peer-reviewed literature (Knight et al. 2008), and instead, are relying on improvised solutions that are unique to specific projects. Other reasons that small local NGOs may not employ SCP techniques include a deficiency in resources such as data, expertise, and computational capacity. SCP can be demanding of data quality and quantity, which are typically limited or lacking in tropical developing countries. Furthermore, SCP planning involves multiple steps and programs, such as data preprocessing and SCP software tools like Marxan (Margules and Pressey, 2000; Sarkar and Illoldi-Rangel, 2010) that require computer accessibility and expertise ─ critical elements that may be lacking in a small NGO.

SCP assessments are often employed without the cooperation of the local conservation practitioners (e.g., NGOs and government) themselves, resulting in a gap between assessment and implementation (Knight et al., 2008). For greatest effectiveness, SCPs should be demand led (i.e., requested by local conservation practitioners) versus supply driven (i.e., handed out to conservation practitioners by conservation scientists) (Knight et al., 2006b). Therefore, local conservation practitioners must understand the basis and requirements of the SCP approach in order to evaluate the benefits of an SCP assessment in their area of operation. A better understanding of the SCP process may lead to an increased use of the SCP planning process.

The purpose of this review is to provide information for understanding the essential elements of the SCP approach tailored to small NGO conservation planners in tropical developing countries. It includes:

- An overview of systematic conservation planning

- The essential components of systematic conservation planning, including data requirements, expertise, computational requirements, and stakeholder involvement
- An assessment of case studies in tropical developing countries that have used SCP, focusing on the following questions:
  - What approaches did the case studies take for each component in the SCP process?
  - What are the advantages and shortcomings of the approaches used in these case studies?
  - Which approach for each SCP component is best suited to the needs and limitations of small NGOs?
  - What solutions identified in these case studies can help to overcome limitations faced by small NGOs in developing countries?
- A model and guidelines for conservation practitioners to assess the feasibility of devising a SCP assessment in their region
- Suggestions and recommendations for future research in SCP tailored to conservation practitioners in tropical developing countries

2. Literature review methods

We conducted a search of the peer-reviewed literature in order to identify 1) relevant SCP literature reviews, and other publications that addressed the details and components of SCP, and 2) the systematic conservation planning projects that were carried out in tropical developing countries, several of which were subsequently selected as case studies illustrating specific approaches. These case studies were intended to provide instructive examples to guide future systematic conservation planning assessments carried out by small, local NGOs in the developing tropics.

We identified and collated articles published between 1995-2013 using Thomson Reuters' *Web of Knowledge* database and the keywords 'conservation planning', 'tropical', 'systematic conservation', and 'conservation prioritization'. This search resulted in thousands of publications that were further narrowed using the following criteria 1) articles relevant to the SCP overview portion of this paper, and 2) studies that employed a SCP approach in the developing tropics.

The specific case studies derived from this search were examined and coded, and basic information was extracted including the title, publication date, authors, and location of the study. We also identified and assessed the approaches used by the authors for each component of the SCP assessment process. These components include 1) identify and involve stakeholders, 2) identify the planning area and unit, 3) set goals and targets, 4) compile and assess data, 5) treat or process data, 6) identify and evaluate surrogates, 7) identify existing reserves, and 8) prioritize areas for conservation.

3. Systematic conservation planning: requirements for specific components

3.1 Components of SCP

The SCP process is comprised of distinctive components, otherwise known as stages, initially described by Margules and Pressey (2000) and later revised by Sarkar and Illoldi-Rangel (2010; Figure 2-2) and Pressey and Botrill (2008). Based on the components identified by Sarkar and Illoldi-Rangel (2010; Figure 2-2), we focused on the components of 1) identify and involve stakeholders, 2) identify the planning area and unit, 3) set goals and targets, 4) compile and assess data, 5) treat or process data, 6) identify and evaluate surrogates, 7) identify existing reserves, and 8) prioritize areas for conservation. These components constitute SCP assessment defined by Knight et al.

(2008) as employing technical activities for identifying the location and configuration of priority areas for conservation actions.

3.1.1 Focal SCP assessment components

1) Identify and involve stakeholders ─ Stakeholders have been defined as a key element in successful SCP projects (Watson et al., 2011; Sarkar and Illoldi-Rangel, 2010; Margules and Sarkar, 2007; Pierce et al., 2005). Stakeholders are those who may be affected by the plan, may influence the outcome or implementation of the plan, or can provide resources to the planning process (Margules and Sarkar, 2007).

2) Identify planning area and unit ─ With stakeholder input, the planning area and unit should be defined. The planning areas reflect the scale of data, ecological and political boundaries, available resources, land ownership patterns, and legal considerations. Planning units are the areas that may be selected to comprise the conservation area network (CAN) and can be defined as regular (squares, cells or hexagons) or irregular (land tenure or patches of habitat) shapes (Marglues and Sarkar, 2007).

3) Set goals and targets ─ While goals should represent the broader qualitative objectives of the project, targets should quantitatively represent these goals (i.e., the specific amount of a particular biodiversity feature to be represented in the priority areas defined by the algorithm or SCP program, such as occurrences or percentages). Setting clearly stated goals and targets aids in the defensibility of conservation decisions (Knight et al., 2006b; Margules and Pressey, 2000). Conversations for establishing goals and targets should be conducted with all stakeholders (Sarkar and Illoldi-Rangel, 2010). Unless using a planning program that does not require them (i.e., Zonation), targets must

be defined for all surrogates and other features of conservation interest (Margules and Pressey, 2000).

4) Compile and assess data ─ A variety of available data should be gathered including biological, spatial data, and social-economic data (Margules and Sarkar, 2007; Table 2-3). Data should be assessed in terms of their adequacy and surrogacy value (Margules and Pressey, 2000), as well as any special status they may hold (Margules and Sarkar, 2007). If there are enough time and resources to collect data to enhance or replace insufficient or poor data, the effort should be carried out efficiently, and tailored to meeting project goals and objectives (Sarkar and Illoldi-Rangel, 2010).

5) Treat or process data ─ Analyzing or treating data and creating models (if needed) are important steps for removing or refining inherent biases in many datasets (Sarkar and Margules, 2007; Margules and Pressey, 2000) or extrapolating species distribution data (Sarkar and Illoldi-Rangel, 2010, Cayuela et al., 2009).

6) Identify and evaluate surrogates ─ Surrogates are defined as biodiversity features (e.g., species, taxa, environmental variables or combinations of these) that can be used to represent all biodiversity, especially those elements that lack sufficient data for independent analysis (Moilanen et al., 2012; Margules and Sarkar, 2007).

7) Identify and assess existing reserves ─ Existing reserves should be assessed for their contributions to the targets of the plan (Sarkar and Illoldi-Rangel, 2010; Margules and Pressey, 2000). A gap analysis, which determines biological or ecological gaps in the existing conservation network, can aid this process (Groves et al., 2002).

8) Prioritize areas for conservation ─ This component attempts solve the optimization problem, which consists of maximizing representation of conservation features (i.e.,

having all surrogates meet the specified targets), while minimizing the area or cost (Sarkar and Illoldi-Rangel, 2010; Sarkar et al., 2006). This problem can be solved using specific algorithms or software programs with built-in algorithms (Moilanen et al., 2009; Sarkar et al., 2006).

3.2 Requirements of the SCP assessment

3.2.1 Surrogacy and data requirements

Limited existing biological data and constrained time and resources to collect it have influenced the use of surrogates in SCP assessments. A surrogate is defined by Rodrigues and Brooks (2007) as ‘any set of biodiversity features used to guide conservation planning with the expectation of conserving broader diversity’. Surrogates fall into two categories: 1) species-based surrogates, such as species with functional roles (e.g., keystone and focal species), umbrella species, and species with conservation status (e.g., endangered) and 2) surrogate sets, including sets of species of a taxa (e.g., birds), species assemblages (e.g., classification for community or habitat type), and environmental classes (e.g., classifications for vegetation types) (Margules and Sarkar, 2007).

While there is much debate on the type of surrogate to use (Sarkar and Illoldi-Rangel, 2010), no specific type of surrogate has been found best (Margules and Pressey, 2000). Determining the appropriate surrogate(s) depends on their effectiveness in representing biodiversity (Watson et al., 2011), which can be determined by analytical methods, such as species accumulation index and surrogacy graphs (Margules and Sarkar, 2007). Some suggest using species with special status or functional roles (Watson et al., 2011; Knight et al., 2006b; Groves et al., 2002). Conversely, environmental surrogates can be used as a coarse filter to capture biodiversity in data-poor regions (Watson et al., 2011), are often more powerful and useful than traditional species data (Knight et al., 2006b), and are relatively easier and cheaper to acquire. Many suggest using a combination of the two types to improve representation and adequacy (Margules and Sarkar, 2007; Sarkar et al., 2006; Margules and Pressey, 2000). Essentially, conservation features with clear and comprehensive distributions are preferable surrogates (Wang, 2014). Data availability and processing limitations will also narrow the choices.

In addition to surrogate data, a variety of other datasets for data preparation or for planning and decision making are used in SCP. Moilanen (2012) provide a comprehensive overview of data types that can be used in a SCP analysis, along with their specific uses (Table 2-3).

Biological data can include single species data (Diniz-Filho et al., 2012), multiple species data (Wilson et al., 2010; O'Dea et al., 2006), particular taxonomic groups (Urbina-Cardona & Flores-Villela, 2010), or multiple taxonomic groups (Kremen et al., 2008). Environmental data, including terrain (e.g., elevation and slope), climate (e.g., rainfall and temperature), and substrate data (e.g., soils), offer a broader scope, are useful in conjunction with biological data, or can be used for delineating species distributions (Margules and Sarkar, 2007; Groves et al., 2002; Margules and Pressey, 2000). Moreover, ecological and evolutionary processes data (e.g., waterways or drought refugia areas) are deemed important for maintaining persistence and allowing for adaptation processes to occur, especially under global climate change scenarios (Klein et al., 2009; Cowling and Pressey, 2003).

Other important data to include, when available, are cost and benefits, threats, feasibility and constraints, and human preferences data. Cost can be determined as the monetary value of the land or as indirect costs (e.g., the value of the land to stakeholders)

(Moilanen, 2012) and are important for making cost-effective decisions (Carwardine et al., 2008). Threat data can include processes that negatively affect conservation action or the biodiversity feature (Moilanen, 2012). Feasibility, opportunities, and constraints data can include a budget for implementing conservation action, land availability, and land tenure (Moilanen, 2012).

Having data in hand, however, does not justify their use as the data could be biased and skew the results (Watson et al., 2011). Reliable results for data processes (e.g., species distribution modeling) are highly dependent upon the availability and quality of well distributed occurrence data, which are often lacking in the tropics; therefore, all data should be analyzed for their qualitative and quantitative characteristics. For example, species-level point location data should have a minimum sample size of about 40-70 observations, otherwise may add little value, or compromise SDMs by introducing unnecessary uncertainty (Cayuela et al., 2009). Furthermore, the samples should be relatively evenly distributed across the species' ranges or within the area of interest (Cayuela et al., 2009). Assessing and preparing raw data for use often requires computational resources and programs.

3.2.3 Software program requirements

A growing library of software programs and tools are used in the SCP assessment. The selection of appropriate tools depends on the approach and needs of the project and may require considerable knowledge and expertise. Potential tools include those for data processing or analyzing, such as biogeographic or environmental modeling, in addition to conservation planning tools themselves.

A variety of software programs are used for data processing or analyses prior to spatial conservation prioritization. These may include, but are not limited to, tools for geospatial analyses (e.g., for producing environmental classifications or removing spatial bias of data), species distribution modeling (SDM) or habitat suitability prediction, population viability analysis, habitat connectivity or risk assessment, ecosystem service modeling, and statistical programs that generate input parameters for conservation prioritization (Margules and Sarkar, 2007; Sarkar et al., 2006). Employing these data processes can require considerable resources and expertise. For example, SDM identifies the potential geographic distribution of a species based on its occurrence data in relation to environmental variables that capture basic life history needs (Cayuela et al., 2009). This process requires occurrence data, appropriate climatic or environmental variables, an SDM software program, and appropriate expertise. Moreover, classifications, which are regularly used in SCP analyses and may need to be produced, require training data, remotely sensed imagery, employing corrections and processing the imagery, classifier software, geospatial programs, and appropriate expertise, among other things.

Conservation prioritization tools (i.e., software programs) are defined as those that 1) help generate priority areas for conservation of biodiversity and environmental features, and 2) incorporate the concept of complementarity in generating or assessing areas for conservation (Sarkar et al., 2006). These programs are meant to be used as a decision support tool, providing various options for stakeholders, as opposed to making the ultimate decision (Ardon et al., 2009; Moilanen et al., 2009). A majority of these tools either aim to minimize the number of sites or cost chosen for a conservation area network while representing all targets, or maximize representation of targets given maximum total area or cost (Margules and Sarkar, 2007; Sarkar et al., 2006). From these concepts arise distinctive objectives, including 1) those that employ a “set cover” approach, which aims to reduce the cost of the total site chosen for the reserve network while representing the minimum target for each biodiversity feature, and 2) those that target the “maximal coverage” approach, which maximizes the represented biological features given specific cost as the constraint (Moilanen et al., 2009; Sarkar et al., 2006). Understanding the inherent assumptions, mathematical basis, and limitations of these tools can help to ensure their effective application (Sarkar et al., 2006).

We collected and assessed information on the most commonly used and freely available conservation prioritization tools, including C-Plan, ConsNet, Marxan, Marxan with Zones, ResNet, and Zonation (Table 2-4). Previous research has reviewed these tools in terms of their realism (e.g., its ability to incorporate biodiversity features), relevance (i.e., its ability to account for practical planning), flexibility, treatment of uncertainty and variability, the degree of development and ease of use, and the ease of parameter estimation (Regan et al., 2009). These tools are based on simulated annealing and a few variations of heuristic algorithms. Inputs for each of these programs vary, but most call for biodiversity and environmental feature distribution data, setting targets (except for Zonation, which requires weights), and defined planning units. Marxan and Marxan with Zones require cost or a surrogate for cost, while cost is optional in Zonation and ConsNet. Outputs also vary, but typically include a list of optimal solutions, maps, and details for modeled outputs.

We also analyzed advantages and limitations of these programs (Table 2-4); however, we may not have encompassed all possibilities. C-Plan has the advantage over others in that it can facilitate real-time negotiations amongst stakeholders and results are easy to interpret. C-Plan, ConsNet, and Zonation have the ability to (or interface with programs that can) consider spatial criteria of the CAN including boundary characteristics, shape, or connectivity. Marxan with Zones is able to plan for multiple land use zones (e.g., conservation areas, agricultural lands), as opposed to strictly binary areas (i.e., inclusion of conservation sites or not) – a clear advantage over the other programs. However, it requires more inputs (i.e., data) than other tools, including a layer defining each zone, the cost for each planning unit within each zone, which may be interpreted as a limitation. Limitations for Marxan include not easily integrating stochastic or dynamic data and connectivity, being less transparent relative to other programs, and not beginner friendly. Furthermore, Zonation's results are dependent on the user specified starting point and its 'nesting approach' (i.e., chooses best 1% of land nested within the best 5%, and so on) may not be a suitable planning approach for all conservation features of interest. Overall these tools are beneficial for SCP; however, efficient and proper use of these programs requires appropriate expertise.

3.2.3 Expertise

Employing the SCP process requires expertise in several disciplines (Moilanen et al., 2009; Pressey and Botrill 2008; Knight et al., 2006b). Geospatial or software specialists familiar with data processing (i.e., those identified in section 3.2.2) are essential. For example, the collection and processing of spatial data for subsequent use in the SCP tools require geospatial expertise. This individual should, ideally, be familiar with the ecology and land uses of the focus area (Knight et al., 2006b) or able to incorporate local or expert knowledge to improve accuracy and reliability of the products. Most importantly, an analyst who can learn or has experience with the prioritization tool of choice (see section 3.2.2 for options), is required for ensuring the tools are properly used and their results are correctly interpreted (Ardron et al., 2010). The quality in the outputs of these processes is often dependent, not only on the data, but the individuals who perform them.

Expertise or familiarity with biological or ecological knowledge, conservation status of species (Cayuela et al. 2009), biogeography and natural history of the region of interest is important, including knowledge of the land uses, people, language and culture (Knight et al., 2006b). Local knowledge and language skills are imperative for conservation planning in the developing tropics where English literacy is limited, yet collaboration is essential. Community values often drive conservation priorities, thus incorporating them into conservation planning can increase the practicality of planning outcomes.

3.2.4 Stakeholder collaboration

Research has shown that stakeholder collaboration is critical to the success of conservation planning efforts (Knight et al., 2008; Pierce et al., 2005; Cowling and Pressey, 2003). Unfortunately, stakeholders are rarely included in the planning of SCP studies (Sarkar and Illoldi-Rangel, 2010; Sewall et al., 2011). This trend in SCP, in which the focus of most assessments is exclusively on natural resources, underestimates the conservation value that comes from understanding linked social-ecological systems that can influence conservation outcomes (Knight et al., 2006a) and ignores local knowledge that can inform conservation practice. Conservation plans, especially in the developing tropics, will only be realistic and effective if they involve a variety of stakeholders (Knight et al., 2006a).

Stakeholders are those who may be affected by the plan, can influence the outcome or implementation of the plan, or that can provide resources to the planning process (Margules and Sarkar, 2007). Examples include local peoples, community groups, experts, government officials, representatives of agricultural, forestry or tourism interests, and other conservation organizations (Knight et al., 2006b, Kainer et al., 2009, Cowling et al., 2003, Pierce et al., 2005). Stakeholder involvement consists of identifying their needs, interests, influences, and including their input throughout the SCP process (Knight et al., 2006b) in order to minimize conflict (Watson et al., 2011) and maximize their support of the plan. Involving local peoples in the conservation planning process yield benefits such as access to traditional ecological knowledge of the area and an increase in acceptance and ownership of the project, which can lead to improved conservation success (Ardron et al., 2010; Kainer et al., 2009). Stakeholders with expert knowledge and skills can help to fill gaps in existing data, and provide knowledge that can influence management and implementation of conservation plans (Cowling et al. 2003). Involving government officials (local, regional, and national) can influence the implementation of the conservation plan (Pierce et al. 2005). Moreover, defining sustainable land use cannot be accomplished without the input of the economic sectors of forestry, agriculture, tourism (Knight et al., 2006b), and other conservation organizations, particularly those within the planning region. Establishing these partnerships can lead to increased efficiency and efficacy of conservation planning.

4. Review of the systematic conservation planning case studies

We conducted a literature review and collated 14 case studies that employed an SCP assessment in tropical developing countries from 2001-2013 in order to answer our research questions based on the SCP assessment components (Table 2-2).

In addition to the questions we attempted to answer, we discovered some noteworthy overarching results. Among our most important findings was that SCP could be implemented in tropical developing countries despite limitations in data availability, funding, and expertise. We found the approaches or techniques used for each SCP component varied between each study and were dependent on aspects such as goals, targets, available data, and expertise. However, this variability only provided a glimpse of the considerable flexibility and variability found in SCP as these case studies are only a small subset of SCP assessments. Of the case studies we examined, many were carried out by conservation scientists, as opposed to conservation practitioners. This may be due to the tendency of scientists to publish, in comparison with practitioners, who tend to be consumers, rather than authors of the scientific literature. However, in only a few of the case studies were the SCP assessments conducted with the expectation that the results would be implemented (i.e., Sewall et al., 2011, Venter et al., 2013, and Wilson et al., 2010). This finding supported the notorious 'gap between research science and implementation' in conservation planning. Attempting to close the gap requires that scientists not only consider the SCP assessment itself, but the entire process, especially the on-the-ground implementation of conservation actions (Figure 2-1) (Knight et al., 2008). Nonetheless, although our literature review focused on a relatively small number of case studies (n=14), the results are insightful in that they, collectively, supported the feasibility of employing the SCP approach in tropical developing countries and provided a platform for identifying common challenges, recommendations, and examples from which to learn.

4.1 Component 1: Identifying and Involving Stakeholders

In SCP, stakeholders are important for successful planning and implementation processes, as they can provide input for the various components of SCP, and potentially provide resources, local or expert knowledge, and support the plan politically. However, only 4 of the 14 case studies (CS) involved stakeholders (Table 2-5). In those four studies, the stakeholders included government agencies, museums, universities (CS 3), non-governmental organizations (CS 10), local peoples (based on interviews; CS 7 & 10), experts (CS 7), and a multi-stakeholder partnership organization (CS 13).

Advantageous approaches and recommendations for engaging stakeholders identified in the case studies included using interviews or workshops as well as involving the local community, NGOs, and experts. For instance, the authors of CS 3 held workshops and training to facilitate a transfer of knowledge for future project implementation for stakeholders such as scientists, policy makers, and planners. In CS 7, the group held a workshop that leveraged knowledge from regional experts on flora and fauna, and local resource management, with the purpose of identifying conservation objectives and conservation feature data for its use in the assessment. We recommended small NGOs involving stakeholders who are subject matter experts on subjects, such as biology and ecology of the region, especially to fill data gaps (Cowling et al., 2003). Lastly, the authors in CS 10 involved local NGOs in the planning process by identifying their opinions on conservation opportunities, constraints and goals. They also incorporated community values and ecological knowledge through interviews aimed at identifying local attitudes and perspectives on the environment and conservation, and insights on biological and land use trends. This particular collaboration successfully led to an implementation strategy.

If workshops are implemented, they must be focused and facilitated in a manner that emphasizes efficiency and quality. Stakeholders have a variety of different backgrounds that influence their values and knowledge, which may lead to conflicting interests between parties (Wang, 2014). Thus, workshops should be facilitated by a neutral, non-stakeholder party who can effectively manage all parties and meet the objectives of the process. Workshops and interviews should be focused on engaging stakeholders in the planning process to provide input on subject matters specific to the needs of the SCP assessment such as identifying 1) goals and targets, 2) surrogates (i.e., which conservation features should be chosen and why?), 3) available data (e.g., do stakeholders harbor data, either physical or based on knowledge?), 4) values for specific areas (e.g., conservation, land-uses, or traditional uses), and 5) practicality of conservation in particular areas (e.g., opportunities and constraints).

The inadequate inclusion of government stakeholders in the SCP process was another limitation of the case studies. Without input from government or political leaders in the planning of a project, it is difficult, if not impossible to get their material or political support for the implementation of the plan. For example, the government of Madagascar determined that the country needed a 30% increase in protected areas, which the group in CS 5 based their priority areas on. These researchers should have obtained support for their assessment by involving the political leaders who determined the conservation objectives in order to facilitate the implementation of their results. Incorporating local and state government officials in the planning process increases the chances of implementation.

Additionally, we recommend that small NGOs applying SCP in the developing tropics should partner or collaborate with institutions, such as universities, research stations, museums or other conservation organizations. These collaborations may provide benefits including access to resources, such as data, funding, software programs, expertise, access to peer-reviewed literature and its interpretations, thus aiding in overcoming these potential limitations. For example, the authors of CS 3 partnered with a variety of stakeholders in order to leverage needed resources for their SCP assessment, which substantially affected the quality of their assessment. Including these types of stakeholders can provide means for project support and success.

4.2. Component 2: Identifying the planning area and unit type

When delineating a planning area, project objectives and feasibility ─ in terms of time and resources, data availability, scale and volume, and ecological and political considerations − should be considered. In the case studies we reviewed, the planning areas ranged in size from 374 km2 on the island of Mayotte, Union of the Comoros (CS 10), to 18.2 million km^2 in the neotropical region (cross-continental scale; CS 9) (Table 2-5). Our case studies used political boundaries (e.g., country boundaries) and ecological criteria, such as ecoregions, to define their planning area. For example, those that produced case studies 3 and 5 delineated the entire islands of Papua New Guinea and Madagascar, respectively, as their planning areas. On the other hand, the authors of CS 4 chose the Transvolcanic belt region of Mexico as their planning area because of its high endemism and high human population qualities. Moreover, a beneficial and practical approach was taken by the group in case study 13, which chose their study area based on the boundaries of the Berau regency of Borneo, Indonesia, where their collaborators, the Berau Forest Carbon Partnership, operate.

While the planning area may be predetermined by a focus area of the particular NGO, we advise that an overall manageable and feasible planning sized area or scale (i.e., small to medium scale area) is chosen for the analysis. Exceptionally large data sets derived from a large planning area may neither be practical nor manageable for a small conservation organization in a developing country. Alternatively, a fine-scale assessment (approx. 1:50,000) can target practical areas for reserve networks and land use planning (Knight et al., 2006b).

The planning unit chosen depends on the type of priority area intended for the analysis (e.g., cells or forest patches). Approximately 50% of the case studies used grids as their planning units, while the others used hexagons (CS 13), forest patches (CS 10), and land-use classes (CS 14). While grids or cells are common planning units and can be standardized across the study area, they may prove difficult to apply in highly fragmented areas ─ a prevalent trend in the tropics. Thus, defining and using habitat or forest patches is a more realistic option than cells as well as incorporate land cover types not clearly represented in cells (Grantham et al., 2008). In highly fragmented areas, which are often the case in tropical developing countries, a mix of the two types is recommended (Margules and Pressey, 2000). Another practical option is to use parcels or other governmental units commonly used by land use planners in the study area of interest. For example, in case study 3, Resource Management Units (RMU's) were used in Papua New Guinea because the final SCP assessment was going to be used by the government for land use planning.

4.3 Component 3: Setting goals and targets

While goals should represent the broader, qualitative objective of the project, targets should quantitatively specify how the goals will be reached. Although, 11 case studies defined their targets, only three case studies explicitly defined their goals, and one defined neither. This may have resulted from the similarity between goals and targets (i.e., the quantitative version of goals). Nonetheless, a lack of stated objectives, goals, and specific targets can lead to inefficiency in conservation planning (Margules and Pressey, 2000). Defining clear goals from the beginning provides transparency to the choices made (Sarkar and Illodi-Rangel, 2010), while defining specific quantifiable targets provides a roadmap for achieving goals, and aids in achieving representation and persistence (Margules and Pressey, 2000). Unfortunately, widely accepted framework and specifics for defining goals and targets have yet to be identified (Sarkar and Illoldi-Rangel, 2010; Margules and Sarkar, 2007); however, here, we have provided examples and suggestions for doing so.

Of the three case studies in which goals were explicitly stated, one (CS 2) defined 'alleles as their conservation goal'. The target derived from this goal was to 'find the smallest number of local populations in which all alleles are represented at least once'. This is a clear example of how goals can be translated into quantitative targets. In CS 10, stakeholder input was considered by identifying the goals of a local conservation group, which were 'to effectively conserve Livingstone's flying fox (a flagship species for protection of forests) and other elements of biological diversity on the Comorian islands of Anjouan and Moh´eli'. This is a clear example of using stakeholder input to define goals; however, they did not define targets, making it difficult to quantitatively determine whether goals were achieved. One innovative strategy employed in a few of the case studies was aligning SCP assessment goals with governmental conservation goals. In a few case studies, the SCP assessment leveraged government conservation goals and provided conservation-based, policy suggestions based on the outcomes from SCP analyses (Venter et al., 2013; Mills et al., 2012; Kremen et al., 2008). For example, in Madagascar the government proposed to increase their protected areas by 30%; thus, Kremen et al. (2008) used this opportunity to complement existing protected areas with reserves that systematically represented a variety of taxa in that 30% of the land.

Fundamentally, goals should broadly define ‘what constitutes adequate biodiversity protection’ and will most often be derived from expert knowledge (Sarkar and Illoldi-Rangel, 2010), but will benefit from the input of stakeholders (Watson et al., 2011). Moreover, as knowledge of various factors such as data and feasibility develop, goals may have to be revised accordingly (Margules and Pressey, 2000).

The most common approach for target setting was delineating certain percentages (of species distributions) or occurrences of selected species or species groups, or combinations of these. Unfortunately, the studies did not provide reasoning behind their choices for the target type (e.g., occurrences) or specific target. While some case studies (CS 4) chose the same percentage for each conservation feature, a few studies chose different percent targets and compared the outcomes. For instance, in CS 12, species representation values of 10% and 30% were compared and evaluated, and it was found that a target of 30% of species distributions would require 60-90% conservation of the planning area – a result monetarily unfeasible. On the other hand, a few studies aimed at representing species occurrences within each grid cell or the study area. For example, in CS 8, the aim was to represent each bird species once and five times in each grid, and then to compare and evaluate the outcomes. One novel approach was to (CS 1) compare two target scenarios and types: 1) one occurrence of each species and 10% for each habitat-based surrogate for the entire study area, and 2) three occurrences of all target species (each in a different grid), all occurrences of critical endangered species, and 25% for each habitat-based surrogate. Lastly, the authors of CS 14 used a different method for defining targets, which aimed at achieving equitable protection for all species by accounting for life history characteristics, home range size, and occupancy of each species. This may be a better option for target setting as it can account for adequate representation and persistence.

Targets should be based on biological principles and ecological theory, such as biogeography (Watson et al., 2011; Sarkar et al., 2006). Quantitative target setting has been a controversial issue, especially when based on rules of thumb with no biological basis, such as 10-12% (Sarkar and Illoldi-Rangel, 2010; Tear et al., 2005; Margules and Pressey, 2000). Targets must characterize the representation and persistence of individual conservation features, thus they will most likely vary (Margules and Sarkar, 2007). Comparing various targets and target types is one good option. Margules and Sarkar (2007) also provide methods for determining targets based on persistence, which include using heuristic rules and population viability analyses.

4.4 Components 4 & 6: Compiling and assessing data, and identifying and evaluating surrogates

We combined these two components because few case studies explicitly mentioned using surrogates in their analysis (CS 1, 3, 5, and 9); however, we presumed the conservation feature data mentioned in the other papers were surrogates. While data were generally used for species distribution analysis for surrogates, many also assisted in practical decision making.

A majority of the case studies used special status species and taxa for surrogates including those endangered, vulnerable, rare, and endemic, which are common surrogate types recommended by many (Watson et al., 2011; Knight et al., 2006b; Groves et al., 2002). For example, in CS 12 non-volant animals were chosen as surrogates because of their attributes including having high-regional extinction risk, high endemicity, and high species richness. However, not all special status species are valuable for conservation planning. For instance, the authors of CS 10 used a flagship species for conservation planning ─ a questionable surrogate type as they are charismatic species, yet not always ecologically significant; however, valuable flagship species are those who effectively represent a community or ecosystem (Caro and O'Doherty, 1999). Moreover, some case studies used environmental spatial data as surrogates, such as marine ecosystem distributions in CS 7. The use of widely available spatial data, such as climate, topography, vegetation cover, soil type, carbon, and remotely sensed imagery should be maximized in data-deficient tropical regions (Table 2-6). Still, due to general lack of data compounded by the necessity of determining conservation priorities in a short time frame, many recommend using a vast combination of available and reputable biodiversity features. This approach is preferred because it aims to encompass a breadth of biodiversity and essential components of ecosystems, in order to maximize the ability of reserve areas to adequately represent biodiversity features and to ensure their persistence (Moilenen et al., 2012; Margules et al., 2002; Faith et al., 2001b). One novel approach for maximizing representation was taken in CS 3, which used 1193 biodiversity surrogate attributes that consisted of a compilation of environmental domains, vegetation types, species clusters, and rare and endangered species data.

An assortment of data was used in these case studies to represent biodiversity features of interest and additional data that influenced the practicality of the planning process, including biological, environmental, climatic, social, and economic data. Biological data included single species data, such as plant, vertebrae, and non-vertebrae data (CS 1, 5, 9, and 10) and group of species, such as mammals (CS 4 and 14), carnivores (CS 6), birds (CS 8 and 11), and herpetofauna (CS 12). A variety of spatial data, including land use, vegetation or ecoregion cover types, protected areas, environmental domains and other environmental and climatic variables were used in 12 of 14 of the studies. Climatic and environmental variables (e.g., topography, soil types) were mainly used for determining species distributions and other data preprocessing, but also as surrogates. One group (CS 13), took a different approach to prioritize areas for reducing emissions from deforestation and forest degradation opportunity (REDD+), thus used more complex spatial data such as oil palm production potential and terrestrial carbon diversity. In addition to using biological and ecological data, we suggest utilizing cost or vulnerability data, if possible. These types of data can aid in determining the urgency of protection needed for particular area and the practicality of obtaining certain areas. For instance, a few studies used economic data, such as opportunity, start-up and ongoing management costs. Some of the studies incorporated data on threats represented by the special status of species (CS 6, 8, and 10), human population density (CS 8), and spatial data based on proximity to urban areas, slope, abundance of invasive species, and species richness (CS 10).

The data or surrogates chosen for an SCP assessment depend on many factors. Ultimately, because a lack of data is a common problem limiting conservation and research in tropical developing countries, data availability will play a major role in the feasibility of an analysis. Fortunately, a number of alternatives exist for acquiring data, which can minimize the use of critical funds and time required to collect data and help to overcome this limitation. In many of the case studies (CS 2, 3, 4, 6, 9, 11 and 12), researchers used a variety of data types including biological data, spatial data, and socio-economic data in their assessments (Table 2-3) that were acquired from a variety of publically available sources including museums, universities, and internet websites (Table 2-6). Another valuable information source for data used by our case studies was that of previous research. Researchers and organizations that collect biological and ecological data for specific projects may be willing to share their datasets for conservation efforts. For example, in CS 12, species data from 26 research projects, peer reviewed literature, manuals, and books were compiled and used in the analysis. In addition, some case studies (6, 9, 11, and 14) used point occurrence or distribution data found in publically available international or regional databases (Sarkar and Illoldi-Rangel, 2010). However, while leveraging these sources is essential for overcoming data limitations faced by conservationist in the tropics, these data could be biased in their spatial distribution (Knight et al., 2006b); thus, it is important to assess the adequacy of these sources, in terms of quality and quantity, before their use.

4.5 Component 5: Treating or processing data

The most common data processing steps used in these case studies, included species distribution modeling; environmental classifications (e.g., LULC); rescaling or resizing data; statistical analyses; and ranking, weighing and prioritizing layers or features. However, these processes may not fully represent the spectrum of data processes that can be used for SCP assessment.

Five of the 14 studies implemented a species distribution assessment using either MaxEnt or GARP software programs. Species distribution modeling extrapolates species occurrence data − a process that is most likely required for planning in the tropics due to limited datasets. This process, however, is sensitive to the quality and quantity of occurrence data, thus must be used appropriately (Cayuela et al., 2009). SDM modeling also requires the use of a variety of environmental and climatic variables, specific for defining the niche of the species of interest. For example, 22 freely available environmental and topographic variable data were used in the niche modeling of Mexican herpetofauna and resampled to a desired resolution. In addition to this study, the resampling or rescaling of spatial data was used in two other case studies. For example, in CS 8 human population data were rescaled to bird distribution data using the ArcGIS program. When data types are obtained at different scales, in order to reduce error, the alignment and rescaling of, for example, biological occurrence data with spatial environmental datasets (Table 2-6), is required (Wang, 2014).

In six case studies, classification analyses were either employed or used including vegetation (CS 1 and 4), land use (CS 2), and ecoregional classifications (CS 9). Classifications can be used in the analysis for different purposes including surrogacy. For example, in CS 1 researchers produced a vegetation classification and identified forest types; delineated forests with minimal edge for use as surrogates that represented relatively unfragmented forest areas; and demarcated cells containing at least 50% of forest within them for use in the prioritization analysis. Classifications are valuable to the SCP assessment because they provide insight to the present land use or the vulnerability of areas. However, the expertise required for a quality product may limit the use of these classifications. Nonetheless, they are useful data products especially in the developing tropics where limited biological data exists.

Many of the studies used a variety of statistical analyses and programs; however, many statistical analyses not described here may be used in SCP data processing. In CS 1, the authors used principle component analysis (PCA) to decipher the component useful for defining low edge forest types. A PCA is a well-known method that can be used for multivariate analyses requiring the delineation of the most important variables. They also employed a pair-wise Pearson’s correlation test using surrogate occurrence or distribution data to find related surrogates. The receiver operator characteristic (ROC) analysis was used in CS 9 to assess the niche modeling performance. Assessing the accuracy of SDM and niche modeling is an imperative step not used by any other case studies, but recommended, especially when models are based on bias or limited data. JMP and R statistical programs were used in CS 10 to prioritize conservation areas, as opposed to using existing SCP software programs, requiring numerous data processing steps and statistical analyses. This approach is not ideal, as we recommend that an existing SCP program is chosen for prioritization analyses due to their straightforward, pre-designed approach and freely available user resources.

These data processes will require technical expertise, thus, posing a limitation. If the expertise is not readily available, we recommend collaborating with an organization or institution with the means of providing the skills and computational capacity to run the necessary data processing analyses.

4.6 Component 7: Identifying existing conservation or reserve areas

The identification and use of existing conservation areas were only found in 5 of the 14 case studies. This is an important step and should be integrated in the analysis, if possible, in order to 1) assess the degree to which existing conservation areas meet defined goals and targets (Margules and Sarkar, 2007; Groves et al., 2002), and 2) determine the placement of new reserves to form an efficient (e.g., connected) CAN (Wang, 2014).

A few case studies assessed the integrity of existing conservation areas. For example, the authors in CS 8 assessed the performance of important bird areas (IBAs) delineated by experts, and compared them to the results of an SCP assessment. They found that the SCP assessment contained higher species richness than the IBA areas, revealing the benefits of the SCP approach. The authors of CS 9 also analyzed the performance of protected areas representing Red List species in comparison to an SCP analysis targeting 10% representation for each species, and found that protected areas in Mesoamerica, Choco and the Tropical Andes did better in representing Red List species in contrast to other protected areas of the world. These findings suggest that the level of performance of protected areas in representing biodiversity features vary depending on the goals and targets defined by the SCP project and where they occur. While these analyses are worthy, the information derived from them should go beyond these comparisons to determine the underrepresented conservation features of interest, and aid in planning for complementarity or adequate representation of these features.

4.7 Component 8: Prioritizing areas for conservation

Prioritizing conservation areas can be employed using either a stand-alone reserve defining algorithm or a general SCP software program (see section 3.2.3 for details). Most studies (11 of 14) used a generic SCP software program, including Marxan with Zones (3 studies), ResNet (2 studies), C-Plan, Zonation, ConsNet, TARGET, and Sites. Unfortunately, the studies did not report specific reasons for choosing a particular algorithm or SCP software program.

Determining which algorithm or SCP program to use depends on many factors including goals of the project, data availability, and expertise; however, we have provided recommendations based on the consideration of real-world circumstances, and our analysis of the SCP tools (Section 3.2.3 and Table 2-4) and case studies. First, when choosing whether to use an algorithm or program for the analysis, we recommend that a ready-built program be used. These programs have been tested and used in a variety of SCP research and thus, provide the user with information and support for understanding the tools' capabilities and details, such as inputs and outputs, not found with stand-alone algorithms. Specifically, we propose the following considerations for the selection of a specific SCP tool: 1) If an analysis calls for a multi-zoning, multi-stakeholder approach and all data required are available, Marxan with Zones is the appropriate choice. This program can consider a variety of land uses when planning for conservation – in essence a more pragmatic approach and especially useful in sustainable land use planning. However, if data is a limiting factor, C-Plan is a helpful tool that can facilitate real-time negotiations amongst stakeholders and assess context-specific configuration decisions for specific parts of the planning region; 2) If specific targets cannot adequately be determined, Zonation requires user-specified weights instead; 3) If cost data (or a surrogate for cost) cannot be acquired, cost is optional in both ConsNet and Zonation; 4) In highly fragmented environments, programs that account for spatial criteria such as shape of reserves, boundary and connectivity characteristics should be considered including C-Plan, ConsNet, and Zonation; and 5) If expertise on SCP processes are unavailable or minimal, user-friendly programs such as C-Plan and ResNet can be used. We recommend these considerations if attempting an SCP approach in a tropical developing country; however, assessing the feasibility of the SCP approach should first be considered.

5. Assessing the feasibility of systematic conservation planning

Our review of the SCP assessment revealed that, realistically, many limitations exist for small NGOs attempting to employ the SCP approach in tropical developing countries. While the benefits of the SCP approach are manifold, the approach may not be feasible in all situations, specifically due to limited resource requirements. Based on our review of the SCP literature, specifically from the SCP requirements, we provide a conceptual model (Figure 2-3) with details (in text below) for each step to guide conservation practitioners in assessing the feasibility of implementing an SCP assessment in their respective region. Determining the feasibility of SCP using this model, however, requires careful consideration of the SCP details found in this and other SCP reviews, the case study examples, and recommendations.

(1) The feasibility assessment begins with defining the spatial extent and scale of the project. This decision requires consideration of preliminary conservation goals and is influenced by factors including the focus area of the organization, ecological and political boundaries, and practical, site specific influences that may affect implementation. When choosing a planning area a couple considerations are: 1) do current maps or boundaries exist for a particular area of interest? 2) does the organization have the capacity (i.e., funding, timeframe) for conservation at this scale? If not, can collaboration with other institutions or organizations assist in this regard? It is important to keep in mind that elements of the process (e.g., data availability, goals and targets, or availability of other resources) will also influence the selection of the appropriate spatial scale, and vise-versa. Refer back to section 4.2 for examples and suggestions.

(2) Define preliminary goals that are clear and translatable into quantifiable targets (or weights if using Zonation) in order to fit the SCP framework (Margules and Pressey, 2000). The overarching goals of an organization and potential stakeholders, and examples of goals from the case studies should inform goal identification. For example, goals should encompass aspects of representation and quality for specific conservation features

of interest within the planning area (e.g., ecosystems, specific species or taxa) (Groves et al., 2002). Some notable considerations when determining this include: 1) Does the organization have mission and visionary goals to inform goals? 2) Does the organization have the time or human capacity to involve stakeholders in the goals setting process? 3) Does the organization have the technical expertise for setting appropriate targets based on goals? 4) Are their specific conservation features of interest in the region in which the goals can be based upon? Refer back to section 4.3 for examples and suggestions on goal and target setting.

(3) Compile and assess data and surrogate resources, including those already acquired, those needed, and may potentially be acquired. A list of required data, based on preliminary goals and focus area, should be compiled and, in most cases, will include surrogacy, biological, environmental, climatic, and socio-economic data in addition to existing reserve areas. Determine the availability or cost of acquisition for these data (Table 2-3, Table 2-5, Table 2-6); if data are not available, can they be acquired? All available data should be assessed for adequacy in terms of the quantity and quality and scale. Steps to assess surrogates, data scale-mismatch should also be assessed here. Refer to sections 3.2.1, 4.4, and 4.6 for examples of these processes. If the available data are not adequate to achieve goals, and if the cost of acquiring new data is too high, the project should be scaled back. This process can include setting more realistic goals and modifying targets based on available data, reducing the study area, using alternative data, or revising the project objectives.

(4) Next, determine the necessary analyses and modeling procedures to process and perform prioritization work. This step may require appropriate expertise, and thus should

be sought if needed. For this step consider: 1) what is the current state of the data? 2) do the data need to be extrapolated to the study area? 3) do the data need to be rescaled or resampled to fit other data or the study area? 4) What specific SCP tool will be used to prioritize conservation areas? Data processes may include surrogacy analyses, SDM, spatial analyses and mapping, and implementation of SCP algorithms. Reference sections 3.2.3, 4.5, and 4.7, and SCP software user manuals (Table 2-4) for examples of the data processes and recommendations for which SCP tool to use. SCP software manuals often provide users with information on the data processes (or inputs) required for the analyses.

(5) Determine what types of computational resources are needed to execute the analytical approaches identified in step 4. This step may require appropriate expertise, and thus should be sought if needed. Using the resources, examples, and recommendations from sections 3.2.3 and 4.5, consider the analyses required for pre-data processing and prioritization (step 4) and determine the computational resources (e.g., software and hardware, speed, memory) needed for employing the analyses. Many software programs are freely available, including most of the widely used SCP tools (Table 2-4), and often come with user manuals that describe their computational and data requirements. Moreover, computational capacity will entail managing and storing data. If these, resources are limited, options such as cloud storage and collaborating with partners with available computational memory resources exist. A few considerations include: 1) Does the organization have access to these resources and expertise to run multiple analyses? If not, can resources be acquired through consulting or collaboration with experts or other organizations? If these resources cannot be acquired, another conservation approach, such as an expert-based planning design, may be required.

(6) Determine the expertise required to obtain and manage needed data resources, and to implement the analytical approaches identified above. In section 3.2.2, we have listed these areas of expertise and their specific roles, including SCP expertise, statistical capacity, and geospatial skill sets. Determine whether the expertise is available in-house or can be obtained through contracting or collaboration. If not, another conservation approach may be preferable.

(7) Assess the funding requirements and prepare a project budget based on available data, computational demands, and expertise required, including the costs, if any, of data acquisition, expertise, computational resources, project implementation, and support for volunteers and employees. Determine the adequacy of existing funds and feasibility of acquiring additional funds through grants, donations, or cooperative agreements. Considerations for this step include: 1) determining whether collaborating with other NGOs or institutions with resources can alleviate costs by providing necessary resources for the assessment, 2) determine other cost-alleviating approaches to employing an SCP assessment. For instance, employing a multi-objective and multi-zoning approach in planning can also provide the benefit of minimizing cost, especially when incorporating areas of variable conservation status and land use, such as sustainable forestry or agriculture. However, if the SCP approach is not feasible given extremely limited resources, we recommend scaling back the effort and capitalizing on existing funding resources for a more manageable conservation approach, which may be an ad hoc, expert based, or a hybrid combination of SCP and ad hoc methods (see Pressey and Botrill, 2009).

Determine the time frame required to carry out the assessment by considering the steps listed above, including the time required to acquire funding and other needed resources. It may be time consuming to identify appropriate stakeholders; set conservation goals and targets; obtain funding; process data; perform data analyses and conservation prioritization; and carry out post-prioritization implementation assessment. A timeframe may be difficult to predict and is highly dependent upon the given situation, however, failure to plan realistically often leads to cost overruns and incomplete efforts. The realistic timeframe should be compatible with budgets and the availability of the necessary expertise needed to execute the SCP assessment.

(8) Additional considerations for facilitating the employment of SCP include: 1) Do potential stakeholders or existing collaborators have resources to share? 2) Do current networks for conservation exist in the study area (e.g., local community groups, other conservation organizations) for support and involvement in the SCP process? 3) Are their existing or proposed policies or regulations (either locally or regionally) in the area of interest to use as a leverage for conservation planning? 4) Do mechanisms exist to execute SCP more effectively, such as existing interviews, surveys, or spatial decision support system? Determining if this information exists can help facilitate the SCP implementation process.

(9) If it is determined that SCP is feasible, we suggest the following general steps for moving forward with the SCP assessment. 1) Access, review and become familiar with key SCP literature that describe the entire SCP process in more depth, including journal articles (Knight et al., 2006b; Cowling and Pressey, 2003; Groves et al., 2002; Margules and Pressey, 2000), chapters (Watson et al., 2011), and books (Moilanen et al., 2009;

Margules and Sarkar, 2007). 2) Involve all appropriate stakeholders and expertise identified above to define goals and targets, to delimit the planning area, and to determine appropriate surrogates, available data, data processes and the SCP tool. This process can be implemented through a variety of focused workshops (Refer to section 4.1). 3) Run data processing, prioritization, and multi-criteria analyses using appropriate expertise. 4) Assess results with all stakeholders and experts, and, if needed, revise and analyze. If priorities are not practical or stakeholders do not generally agree, the plan may need revising. 5) Implement the assessment (Refer to recommended resources above for details).

6. Conclusions and Recommendations

SCP in, theory is an efficient and scientifically robust approach for conducting conservation planning. However, for small NGOs in tropical developing countries, conducting SCP may be challenging due to limitations, such as the lack of data and limited expertise. In this review, we examined 14 case studies describing SCP assessments in tropical developing countries that, together, provided 1) critical insight into the challenges faced by small, local NGOs, 2) details of the SCP assessment requirements, 3) examples and recommendations on approaches for SCP assessment components, 4) ways to overcome limitations for employing the SCP assessment components, and 5) guidelines for assessing the feasibility of SCP in the developing tropics.

While the implementation and monitoring components of SCP are beyond the scope of our review, we acknowledge the importance of the entire SCP process and recommend the review of specific implementation guidelines found in other important research articles (see Knight et al. 2006a, b). We believe that providing detailed information and examples on the components of the assessment process and its resource requirements, specifically intended for resource-poor conservation practitioners, can promote the use of the SCP approach by small conservation NGOs in tropical developing countries.

Given the unique circumstances attending small, local NGOs in the developing tropics, whether or not the SCP approach is appropriate can only be determined by each organization, through the examination of individual cases and reviews, such as this one, and the SCP feasibility assessment model provided in this study. In many cases, however, limited resources and scientific capacity will likely constrain efforts to implement SCP, leaving conservation planners to make do with sub-optimal planning approaches (Sewall et al., 2011). In these situations, careful examination of planning practicalities might result in the pursuit of a hybrid approach (Pressey and Botrill, 2009) or downscaled SCP assessment used to complement an expert-driven approach.

Nevertheless, information outlined above may help in overcoming barriers to SCP implementation by small NGOs in tropical developing countries and encourage creativity in applying quantitative approaches to what otherwise would be a purely subjective set of planning decisions. If SCP is not feasible at present, the information provided here could be useful in preparing for potential SCP analyses in the future. Even where possibilities are limited, a deeper understanding of SCP may help conservation managers think differently, adopt a more science-based approach, and overcome some of the limitations that constrain conservation efforts, in general.

Based on this review, we offer several suggestions to conservation planners regarding future research in SCP in tropical developing countries:

- Work with researchers to develop new SCP tools with lighter data demands, to suit the data-deficient situations and diverse land use objectives encountered in tropical developing countries. While the utility of such a tool may be more limited, there are many areas rich in biodiversity that would benefit from a simpler tool that could run despite current limitations of data availability. Although certain tools (e.g., Marxan with Zones) attempt to address the multi-objective multi-zoning scenarios typically found in the tropics, they are more demanding in model parameterization than other existing tools (e.g., Marxan or Zonation). A program or an explicit approach robust to situations where data are limited and land use planning conditions are diverse could encourage the broader implementation of the systematic approach.
- Greater collaboration is needed between SCP scientists and conservation practitioners to help develop practical and realistic conservation plans and close the gap between science and implementation (Sewall et al., 2011; Knight et al, 2008; Margules and Pressey, 2000). These relationships must be fostered from the beginning through the end, to create the motivation, understanding, and support for science-based, stakeholder-influenced SCP approaches by all participants. Only then, can resources on both ends of the science-practice spectrum be fully and effectively used to benefit conservation action (Redford et al, 2003).
- The creation of an organization that provides a conduit for connecting small NGOs with resources, researchers, and data for SCP could expedite both innovation and collaboration. Such a bridge organization could develop partnerships among the appropriate institutions and organizations in order to promote the SCP approaches in tropical developing countries. It could also assist organizations in locating and

acquiring the appropriate expertise, data, computational, and monetary resources required, thereby enhancing conservation outcomes.

- And although it may appear impractical or overly academic, both conservation scientists and practitioners should publish the outcomes of their conservation planning efforts, preferably in the peer-reviewed literature, regardless of the project outcome. Whether a project is successful or not, the publication will be of value by providing guidance for future projects (Redford & Taber, 2000) and shared information essential for the development of operational models (Knight et al., 2006b). This is yet another area where partnerships with larger institutions, such as universities and international conservation NGOs, would be mutually beneficial.

In the end, conservation efforts often rely on small, local organizations, especially in the tropics. Successful outcomes depend on innovative planning approaches, and in cases where actions require careful prioritization of management and land acquisition decisions, SCP may provide the most effective approaches for maximizing conservation value. However, SCP tools can be complicated and require data and experience that may be in short supply in many tropical regions. Thus, there is a need for clear guidelines for the selection of an appropriate approach, as well as a bridge to partnering organizations that can help implement models and computational approaches in a manner that addresses real-world challenges, while providing training and support to local conservation practitioners. We hope that conservation efforts in the developing tropics become more efficient and effective in the future, based in part on the review and suggestions provided here.

Tables and Figures:

Table 2-1: Case studies used for this analysis including their case study number, planning area, and description.

Case Study #	Location, Size of Planning Area (Reference)	Case Study Description
1	Western Ghats, India - 160,000km^2 (Das et al., 2006)	Prioritized areas based on irreplaceability using surrogates (i.e., threatened and endemic plant and vertebrae, unfragmented forest areas, dry forests, sub-regionally rare vegetation types and a remotely sensed surrogate for unique evergreen ecosystems)
2	Brazilian Cerrado - approx. 2 million km^2 (Diniz-Filho et al., 2012)	Attempted to demonstrate the use of SCP in prioritizing areas for in situ and *ex situ* conservation of *Dipteryx alata* (endemic tree species)
3	Papua New Guinea (PNG) - 462,840 km^2 (Faith et al., 2001a,b,c)	Prioritized areas in PNG using 87 plant and animal taxa as biodiversity surrogates with minimum cost and considered other socio-economic data (i.e., land use history, human population density, and previous conservation assessments) to minimize potential conflict with forestry production opportunities
4	Trans Volcanic Belt, Mexico - 123,355km^2 (Fuller et al., 2006)	Attempted to develop a framework for prioritizing areas in primary vegetation using SCP, connectivity areas, and multi-criteria analysis using the distributions of 99 endemic, non-volant mammal species
5	Madagascar - 587,040km^2 (Kremen et al., 2008)	Prioritized areas for conservation based on six major taxonomic groups (i.e., ants, butterflies, frogs, geckos, lemurs, and plants) and assessed the surrogacy capability of these groups
6	Neotropical Ecoregions – approx. 18.2 million km^2 (Loyola et al., 2008)	Prioritized areas (combinations of neo tropical ecoregions) for three scenarios (i.e., high vulnerability, species persistence, and low human impact) for carnivores and their species traits (i.e., phylogenetic diversity, body size, rarity, and extinction risk)
7	Fiji - In shore marine waters - 30,000km^2 (Mills et al., 2012 & 2011)	Attempted to develop a method to predict the benefits of SCP over ad hoc approaches. Prioritized areas based on marine ecosystems and a suitability layer for different forms of marine resource management and other data gathered by interview of regional experts
8	Tropical Andes - Venezuela,Colombia, Ecuador, Peru, Bolivia - 4,722,965 km^2 (O'Dea et al., 2006)	Attempted to assess the performance of expert driven Important Bird Areas (IBAs) with SCP prioritized areas and also determined the degree of concurrence of at-risk bird species richness with human population
9	Mesoamerica, Choco, and Tropical Andes - 1,654,419 km^2 (Sarkar et al., 2009a)	Prioritized areas for 78 IUCN Red List species used as surrogates supplemented with additional analyses based on ecoregional diversity
10	Mayotte, Union of the Comoros - 374 km^2 (Sewall et al., 2011)	Prioritized areas for forest reserves given 30 indicator variables measured in forests and villages based on 3 conservation criteria including conservation value, threat to loss of biological diversity, and feasibility.
11	Southern Mexico - N/A (Toribio & Peterson, 2008)	Prioritized areas based on maximizing species richness for 89 endemic bird species

Case Study #	**Location, Size of Planning Area (Reference)**	**Case Study Description**
12	Southern Mexico - 396,311km^2 (Urbina-Cardona & Flores-Villela, 2010)	Prioritized areas for 222 amphibian and 371 reptile species
13	Borneo, Indonesia - 22,000km^2 (Venter et al., 2013)	Attempted to prioritize areas for REDD+ strategies and agricultural expansion using land use data, cost data
14	East Kalamantin, Indonesia - approx. 200,000 km^2 (Wilson et al., 2010)	Prioritized areas that account for diverse land uses that can achieve conservation goals using land use data (and their contribution to conservation), 1086 mammal species data, and cost data

Table 2-2: Components of the systematic conservation planning assessment and their descriptions. These components are not executed in a linear sequence and they interact with each other in great complexity. See Figure 2-2 for specific interactions and components of the entire SCP process. This table was adapted from a number of sources (Sarkar and Illoldi-Rangel., 2010; Watson et al., 2011; Pressey and Botrill, 2008; Cowling and Pressey, 2003; Margules and Pressey, 2000).

Component	***Details***
1. Identify and involve stakeholders	• Determine key stakeholders • Identify their needs and inputs • Attempt to involve them in the entire process
2. Identify planning area and unit	• Define the planning area for project • Select the units that will be used in the prioritization analysis
3. Set goals and targets	• Identify broad stakeholder values and qualitative goals • Based on these goals, identify specific, quantitative targets for specific biodiversity features and other ecological features of interest
4. Compile and assess data	• Collect data for the study area and assess its quality • Include species data and spatial data and if possible, socio-economic data
5. Treat or process data	• Refine collected data by removing biases or interpolating data • Model species distributions or niches if needed
6. Identify and evaluate surrogates	• Choose species or biodiversity features that represent or merit conservation consideration and represent overall biodiversity
7. Identify existing reserves	• Identify existing reserves • Determine to which extent conservation targets have been met in these reserves
8. Prioritize areas for conservation	• Based on goals and targets, use refined data and prioritization algorithms to determine areas for conservation priority

Table 2-3: List of data that may be used in spatial conservation planning. Note: this table is not comprehensive (Source: Moilanen et al., 2012).

Major category	Type	Component	Usage
Biodiversity distribution data	Species	Present distribution	Most common quantity of spatial planning.
		Future predicted distribution	Predicted assuming climate change; used for identifying future core areas of biodiversity.
		Historical distribution	Sets baseline; degree of decline to present time may influence weight given for feature.
		Connectivity responses	Relevant for understanding the importance of habitat pattern for the species.
		Persistence	Is required for favourable conservation outcome. Based on habitat area, quality and connectivity, but difficult to estimate.
		Genetic diversity	May influence health of populations. Large-scale data for many species hard to come by.
		Vulnerability to threats	What kinds of human-caused pressures is the feature sensitive to?
		Environmental niche	Identified via species distribution modelling; basis of statistical distribution modelling.
	Habitat types, ecosystems	Present, historical, & future predicted distribution	As for species, but feature is a habitat type or ecosystem with specific characteristics. A commonly used feature type.
		Vegetation condition; vulnerability	Habitat condition is reduced by human impacts; highly important quantity but not necessarily easy to estimate.
		Similarity to other habitat types	Two nominally different habitat types (say spruce forest and pine forest) may share a significant fraction of species, which should be accounted for in connectivity calculation.
	Ecosystem services	Distributions	Where are they generated?
		Underlying ecosystem processes	What ecosystem processes produce the ecosystem service?
		Value to society	Value given to specific ESS.
Costs & benefits	Direct costs	Land acquisition	Cost of buying land for conservation.
		Maintenance	Cost of maintaining conservation areas in good condition.
	Indirect, opportunity costs	Costs to different stakeholders	Conservation may cause different opportunity costs to different stakeholders.
	Benefits	Ecosystem services	Value of benefits provided by ESS that are maintained by conservation action.
		Direct benefits and income from nature	Different material and immaterial benefits to local communities from habitats and species maintained by conservation.
Threats	Type; effects of conservation action	Stoppable	The threat can be removed by conservation.
		Unstoppable	Conservation action will not remove the negative effects of the threat. Like, climate change is not stopped by local action.
		Transferrable	The threat (e.g., forest clearing) can be stopped in one area but it will relocate nearby.
	Effect on features		Sensitivity of features to threats.
	Intensity distribution		Spatial distribution of the intensity of the threat.
Feasibility, constraints and opportunities	Budget		Amount of resources available for conservation. Could also be specified as yearly allocations.
	Land availability		Availability of land parcels for conservation; conservation opportunities.
	Governance		Influences likelihood of successful implementation of conservation
	Planning units	Property and administrative borders	Division of landscape into units that should be uniformly treated in planning. Preferences may differ between administrative areas.
		Hydrological catchment structure	Threats may be correlated within hydrological catchments making them natural planning units at least for riverine analyses.
Human preferences	Preferences of people and institutions will influence analysis structure and the relative weights or targets assigned to different features.		
Environmental variables	While conservation decisions rarely are directly based on environmental factors, data about environmental variables underlies statistical distribution modelling.		

Table 2-4: Specific aim, algorithm, inputs, outputs, advantages, limitations, and program resources of common conservation prioritization tools (formulated using Moilanen et al., 2009 and tool sources and manuals. (*) Denotes optional data.

Tool Source	**C-Plan** (Pressey et al. 2009)	**ConsNet** (Ciarleglio et al., 2009, 2008)	**Marxan** (Ardron et al., 2010)	**Marxan with Zones** (Watts et al., 2009)	**ResNet** (Sarkar et al., 2009b)	**Zonation** (Moilanen et al., 2009)
Specific Aim	To select sites that will satisfy targets for features	To select sites that will minimize number of selected sites and maximize the coverage of defined surrogates, optimize cost and spatial criteria	To minimize summed cost and connectivity cost while achieving target representation	To minimize summed cost and connectivity cost of the zone configuration while achieving target representation and zone targets	To minimize set of areas while representing all surrogates by meeting their targets	To account for representation and persistence given cost or area constraints
Algorithm	Stepwise Heuristic	Metaheuristic	Simulated annealing	Simulated annealing	Heuristic (two-pass)	Metaheuristic (accelerated reverse stepwise heuristic)
Inputs	- conservation features or areas (biological, physical, cultural, or visual; land or water) - planning units - targets for conservation features - species distribution data or occurrence of feature with in planning sites	- conservation feature distribution data - targets for biodiversity features - planning unit - cost or benefit data* - constraint goals/ spatial qualities	- conservation feature data (including biological data, socio-economic data, ecological data) - targets for conservation features - define cost (or surrogate for cost)	- conservation feature data - define zones - targets (for each zone) - planning units - cost for each planning unit within each zone (or surrogate for cost) - define preferred relationships between zones*	- biological or ecological data or surrogates - targets for biodiversity features - define planning units - select initial cell or set of cells (based on rarity or richness of surrogates)	- distribution maps of conservation features - weights not hard targets for each conservation feature - connectivity responses - point distributions of species* - uncertainty layers* - cost layer* - planning unit layer* - mask layer* - species interactions*

CONT’	C-Plan	ConsNet	Marxan	Marxan with Zones	ResNet	Zonation
Outputs	- maps of results w/ categories of conservation status - information about sites and the planning area - reports	- list of optimal solutions - maps with optimal solutions	- list of optimal solutions - maps with optimal solutions	- solutions, best solutions, and missing values for each run - summary information - scenario details - summed solution and solutions matrix	- log output files (i.e., record of most relevant information for each run) - GIS files	- zoned map w/priority ranks for each cell - performance curves graphs for each species - species habitat quality info - model outputs
Advantages	- can facilitate real-time negotiations amongst stakeholders; easy interpretation - efficiently processes large data sets - GIS capabilities - interfaces with other programs that consider boundary characteristics, cost, and socio-political factors, GIS - assesses context-specific configuration decisions for specific parts of the planning region - user-friendly, manual helpful	- considers spatial criteria including shape, connectivity, replication, and alignment - analyzes costs or benefits (optional) - can easily process exceptionally large data sets - friendly user-interface	- can process large data sets in a timely manner - allows for trade offs - flexible (in biological organization, data types, participatory processes, modifying existing results, and algorithms) - considers socioeconomic objectives - good user manual - interfaces with other programs (file formatting, GIS, executing)	- considers different objectives, land use types or zones, and costs - can define preferred relationships between zones - analyses cost	- provides user w/ multiple conservation alternatives - can process exceptionally large data sets with speed - interfaces with Multisync (for including other data, biotic and abiotic criteria, and socio-political data) - results are easily interpretable - no programming or mathematical skills required to use - good resources	- functions on large raster grid maps - assesses trade-offs given weights not targets, and others - direct workflow w/GIS and spatial modeling programs - can set connectivity constraints based on specific species - contains uncertainty analysis - can limit output to percent of area or percent of species distributions - interpretable results - after setting parameters, user friendly

CONT'	C-Plan	ConsNet	Marxan	Marxan with Zones	ResNet	Zonation
Limitations	- does not consider different objectives (e.g., land use types) - does not address connectivity - does not address cost - no best map - current manual incomplete - an optimal solution cannot be guaranteed	- does not consider different objectives (e.g., land use types) - an optimal solution cannot be guaranteed	- cannot easily integrate stochastic or dynamic data - does not consider different objectives (e.g., land use types) - cannot consider species specific connectivity - not as transparent relative to other programs - not beginner friendly (no graphic user interface; must calibrate frequently; interface with multiple programs to prep data)	- requires more data than original Marxan - data input is limited by memory space - increasing number of zones requires more iterations, processing time, and computational capabilities	- does not consider different objectives (e.g., land use types) - spatial configuration is limited - not suitable for habitat cells determined by stochastic processes - difficult to represent population or feature viability - an optimal solution cannot be guaranteed	- does not consider different objectives (e.g., land use types) - the output is highly dependent on the user-specified starting point of the analysis - an optimal solution cannot be guaranteed - nested format cannot be used for all species
Program Resources	User manual, program, and other resources available at: http://www.edg.org.au/free-tools/cplan.html	User manual, program, and other resources available at: http://uts.cc.utexas.edu/~consbio/Cons/consnet_home.html	User manual, program, and other resources available at: http://www.uq.edu.au/marxan	User manual, program, and other resources available at: http://www.uq.edu.au/marxan/docs/Marxan_with_Zones_User_Manual_v101.pdf	User manual available at : http://uts.cc.utexas.edu/~consbio/Cons/ResNet-1.2.pdf Program and other sources available at: http://uts.cc.utexas.edu/~consbio/Cons/Labframeset.html	User manual, program, and other resources available at: http://cbig.it.helsinki.fi/software/zonation

Table 2-5: Case studies organized by the components of systematic conservation planning assessment and other data. Each case study is numbered and location and reference are included. Components of systematic conservation planning include (1) stakeholder involvement (Y/N), (2) Planning area and unit type, (3 & 5) data and/or surrogates used (*)Denotes more specific data used, see paper for details [Abbreviations: BSA-biodiversity surrogate attribute data; CLIM- climatic layers; COST-cost data (start up, management and/or opportunity); DIST –distance measure; ECCL-ecoregion classification; EcD-ecosystem distribution data; ENV- environmental layers; GEN-genetic data; INT- data from interview with stakeholders or locals; LULC-land use land cover classification/data; LULCpr-used existing land use land cover classification to delineate specific areas (e.g., anthropogenic areas); MASK-data to exempt from analysis; MOR-species morphology characteristics; PA-Protected areas; POP-human population data; POS-Point Occurrence Species data; PREF-preference areas defined by experts; SpD-Species distribution data; SSSp-Special status species data (vulnerable/endangered/endemic/rare/threatened)] , (4) data processing [Abbreviations: CC- cost of each strategy calculated; COR- correlated data; DIST- a distance measure (Mahalanobis distance) of every pixel to a reference forest class; DOM- identified environmental domain using PATN software; HS-identified habitat suitability based on the synthetic suitability index; IND-calculated and index for timber volume and agricultural potential; INT- preference of stakeholders, local people, or experts identified in interviews; LULC- land use, land cover classification; MASK-mask calculation; OCC-mapping of occurrence point within each grid; RES- rescaled data to other data (ex. Human population data to bird data); ROC –(Receiving Operator Characteristic (ROC) analysis for niche modeling or species distribution assessment; SDM- species distribution modeling; SGS- used FSTAT program to calculate standard genetics statistics; SNM-species niche modeling; STAT-statistical analysis including JMP, R, PCA-Principle component analysis (statistical analysis), and PEAR-pair wise Pearson's correlation test; WEIGHT-determined conservation status based on weights of numerical value; ZON-identified zones based on land use land cover and concession status; (*) denotes that more data processing occurred, see paper for details, (6) goals and targets [categories include percent (P); representation (R)], (7) inclusion of existing conservation areas, (8) SCP algorithm (A) or program (P) used for prioritization of conservation areas.

Case Study #	**Location/Reference**	**Component 1: Stakeholder Involvement (Y/N)**	**Component 2: Planning Area/Unit Type**	**Component 3: Goals (Y/N)/ Targets (category)**	**Component 4&6: Data/ Surrogates Used (Y/N)**	**Component 5: Data Processing**	**Component 7: Inclusion of existing Conservation Areas (Y/N)**	**Component 8: SCP Algorithm (A) or Program (P) Used**
1	Western Ghats, India/ Das et al., 2006	N	160,000km^2/ grid cells	N/ PER & REP	SSSp LULC DIST/ Y	OCC LULC DIST STAT (PCA, PEAR)	N	C-Plan (P)
2	Brazilian Cerrado/ Diniz-Filho et al., 2012	N	approx. 2 million km^2/ N/A	N/ REP	LULC GEN/ N	SGS LULC	N	Simulated annealing (A)

Case Study #	Location/Reference	Component 1: Stakeholder Involvement (Y/N)	Component 2: Planning Area/Unit Type	Component 3: Goals (Y/N)/ Targets (category)	Component 4&6: Data/ Surrogates Used (Y/N)	Component 5: Data Processing	Component 7: Inclusion of existing Conservation Areas (Y/N)	Component 8: SCP Algorithm (A) or Program (P) Used
3	Papua New Guinea (PNG)/ Faith et al., 2001a,b,c	Y	462,840 km^2/ Resource Management Units of PNG	N/ PER	BSA COST PA MASK PREF/ Y	DOM IND MASK INT *	N	TARGET (P)
4	Mexico (Trans Volcanic Belt)/ Fuller et al., 2006	N	123,355km^2/ grid Cells	N/ PER	POSp ENV CLIM/ N	LULC SDM	Y	ResNet (P)
5	Madagascar/ Kremen et al., 2008	N	587,040km^2/ N/A	Y/ N/A	SSSp/ Y	SDM	N	Zonation (P)
6	Neotropical Ecoregions/ Loyola et al., 2008	N	Approx. 18.2 million km^2/ N/A	N/ REP	SpD MOR SSSp/ N	WEIGHT	N	SITES (P)
7	Fiji (in shore marine waters)/ Mills et al., 2012 & 2011	Y	30,000km^2/ grid cells	N/ PER	EcD CLIM ENV INT/ N	INT *	N	Marxan with Zones (P)
8	Tropical Andes (Venezuela,Colombia, Ecuador, Peru, Bolivia)/ O'Dea et al., 2006	N	4,722,965 km^2/ World Map grid cells	N/ REP	SSSp POP/ N	RES COR	N	Maximum coverage (A)
9	Mesoamerica, Choco, and Tropical Andes/ Sarkar et al., 2009a	N	1,654,419 km^2/ grid cells	N/ PER	SSSp PA ECCL/ Y	SNM ROC	Y	ResNet (P)

Case Study #	Location/Reference	Component 1: Stakeholder Involvement (Y/N)	Component 2: Planning Area/Unit Type	Component 3: Goals (Y/N)/ Targets (category)	Component 4&6: Data/ Surrogates Used (Y/N)	Component 5: Data Processing	Component 7: Inclusion of existing Conservation Areas (Y/N)	Component 8: SCP Algorithm (A) or Program (P) Used
10	Mayotte , Union of the Comoros/ Sewall et al., 2011	Y	374 km^2/ forest patches	Y/ N/A	INT SSSp */ N	WEIGHT STAT (JMP, R)	N	N/A
11	Southern Mexico/ Toribio & Peterson, 2008	N	N/A	N/ N/A	POS CLIM LULC/ N	SDM	N	Heuristic complementarity (A)
12	Southern Mexico, Urbina-Cardona & Flores-Villela, 2010	N	396,311km^2/ grid cells	N/ PER	POS CLIM ENV LULC/ N	RES SDM LULCpr	Y	ConsNet (P)
13	Borneo, Indonesia/ Venter et al., 2013	Y	22,000km^2/ hexagons	N/ PER	COST */N	CC	Y	Marxan with Zones (P)
14	East Kalamantin, Indonesia/ Wilson et al., 2010	N	Approx. 200,000 km^2/ units based on national land use classification system	N/ NEW METHOD for targets (see paper for details)	SpD COST LULC/ N	ZON HS	Y	Marxan with Zones (P)

Table 2-6: Data category, type, description, and source for overcoming limitations.

Data Category	Data Type	Data Description	Data Source
Biological	General Point Occurrence	Mammal data collections	Mammal Network Information System (MaNIS) (http://manisnet.org)
		Amphibian and reptile data collections	HerpNET (http://www.herpnet.org/)
		Biodiversity data collections	VertNet (http://portal.vertnet.org)
		Bird specimen data collections	ORNIS (http://www.ornisnet.org)
		Fish data collections	FishNet2 (http://www.fishnet2.net)
		Biodiversity data collections	Red Mundial de Informacion sobre Biodiversidad (REMIB) (http://www.conabio.gob.mx/remib/doctos/remib_esp.html)
		Plant data collections	University of Missouri Botanical Garden, Tropicos (http://www.tropicos.org)
		Biodiversity data collections	Global Biodiversity Information Facility (http://www.gbif.org)
		Biodiversity data collections	Smithsonian National Museum of Natural History (http://www.mnh.si.edu/rc/)
		Biodiversity and ecosystem data for the western hemisphere	(http://www.natureserve.org)
	Species Distribution	Database of species distributions (mammals, amphibians, reptiles, and birds)	WWF Wild Finder (http://worldwildlife.org/pages/wildfinder)
		Species distributions of terrestrial mammals	Global Mammal Assessment Program (http://globalmammal.org)
	Special Status Information	Conservation status of species, subspecies, and varieties	(http://www.iucnredlist.org)

Data Category	Data Type	Data Description	Data Source
Spatial/ Environmental	Ecoregions	Links to various ecoregion datasets (terrestrial, marine, freshwater & others)	(http://worldwildlife.org/pages/conservation-science-data-and-tools)
	Biodiversity priority ecoregions	Global 200 priority regions	(http://worldwildlife.org/publications/global-200)
	Land cover and other datasets	Global land cover datasets and others	(http://www.landcover.org/data/)
		Global vegetation cover	Modis vegetation continuous fields (http://glcf.umd.edu/data/vcf/)
		Global tree cover	Landsat Tree Cover Continuous Fields (http://glcf.umd.edu/data/landsatTreecover/)
		U.S. Geological Survey datasets	(http://earthexplorer.usgs.gov/)
	Land cover change	Land cover change for countries	(www.terra-i.org)
		Deforestation Scenarios for the Amazon Basin and adjacent countries	(http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1153)
		Global forest change (2000-2012)	(http://earthenginepartners.appspot.com/science-2013-global-forest) By: Hansen et al.
	Protected areas	World database on protected areas	(http://www.unep-wcmc.org/world-database-on-protected-areas_164.html)
	Satellite imagery	Remotely sensed imagery for land	Landsat (http://landsat.gsfc.nasa.gov/)
		Remotely sensed imagery for land, ocean, and atmosphere	Modis (http://modis.gsfc.nasa.gov/data/)
	Climatic variables	Global climate layers	(http://www.worldclim.org)
		Climate variables data sets (e.g., precipitation, temperature, sea surface temp, etc.)	NOAA’s Earth System Research Laboratory (http://www.esrl.noaa.gov/psd/data/gridded/)

Data Category	Data Type	Data Description	Data Source
	Environmental variables	NASA’s global elevation data	DL from USGS website (http://srtm.usgs.gov/)
		Soil datasets	World Soil Information (http://www.isric.org/data/data-download)
		Data layers for topographic and watershed analyses	(http://worldwildlife.org/pages/hydrosheds)
	Hydroshed information	Global carbon emissions and other related datasets	Carbon Dioxide Information Analysis Center (http://cdiac.ornl.gov/)
	Carbon emissions	Pan-tropical Carbon Stock	Woods Hole Research Center (http://www.whrc.org/mapping/pantropical/carbon_dataset.html)
	Carbon or biomass data	Publically available consensus data and other related datasets	(http://sedac.ciesin.columbia.edu/data/collection/gpw-v3/sets/browse)
Socio-Economic	Human population & others	Information on existing and planned development activity	Moabi (http://worldwildlife.org/pages/moabi)

Figure 2-1: An example of an operational model for implementing conservation action. (Source: Knight et al., 2006a).

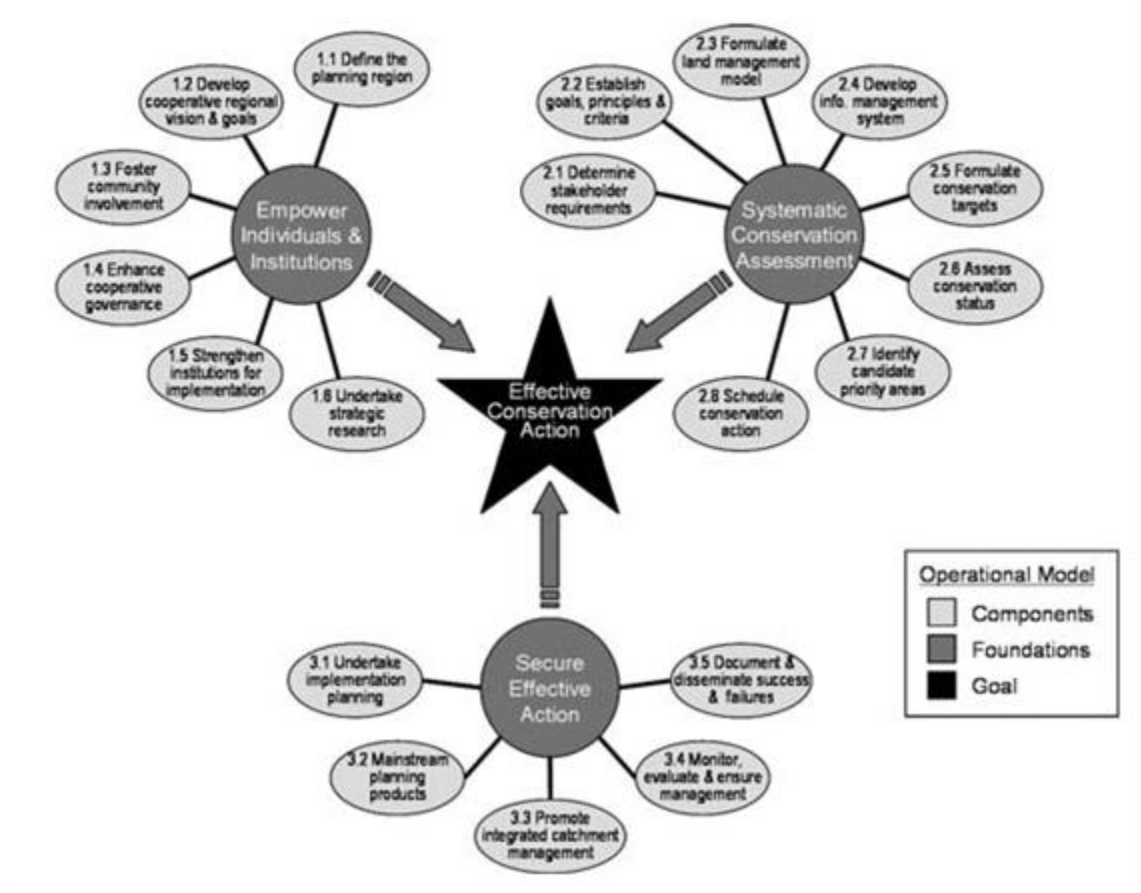


Figure 2-2: Components of systematic conservation planning and the direction of their influences on one another shown in arrows (Sarkar and Illoldi- Rangel 2010). Note that potential interactions between any two components exists. Large black box denotes the assessment components discussed in this chapter.

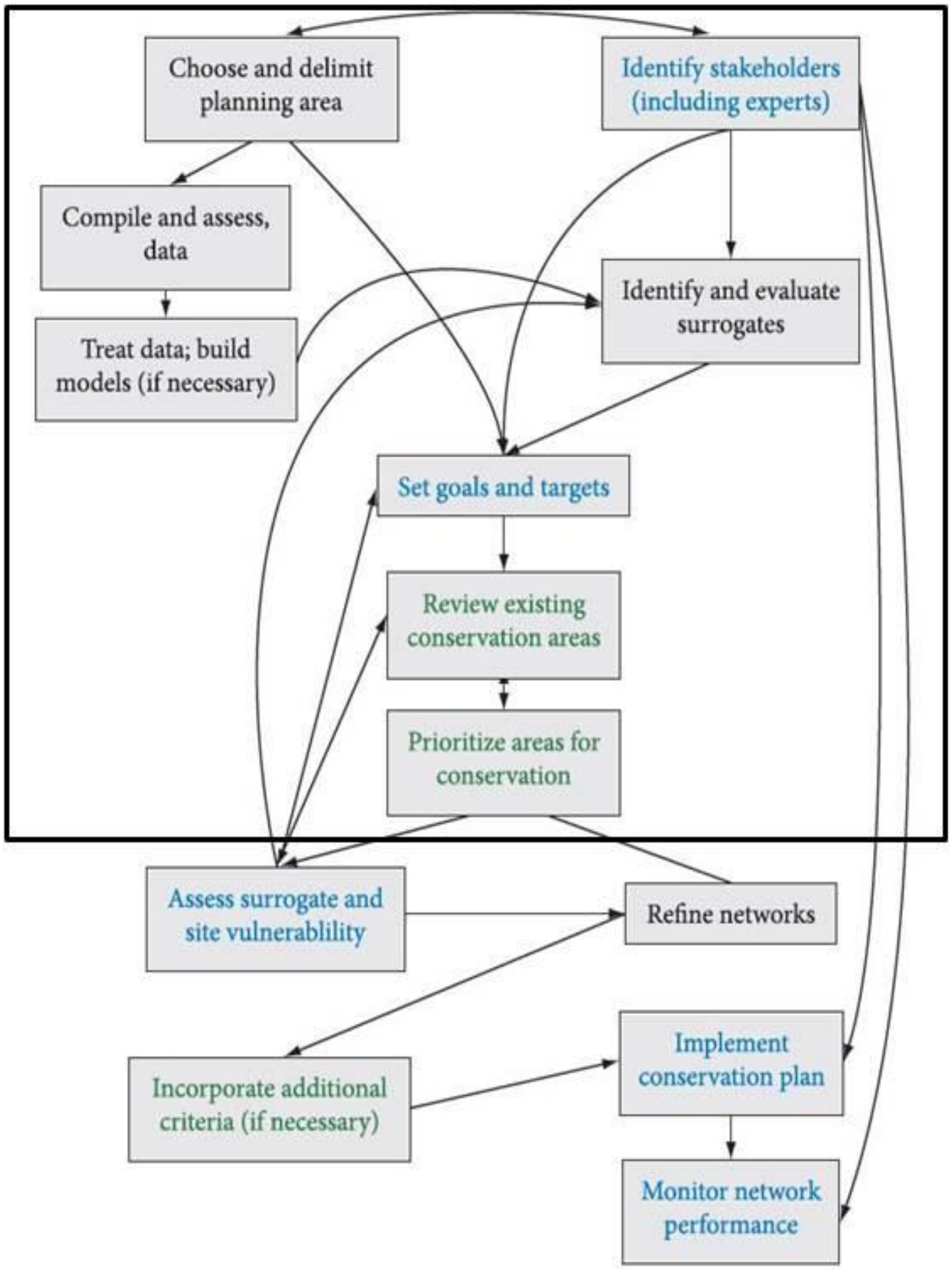
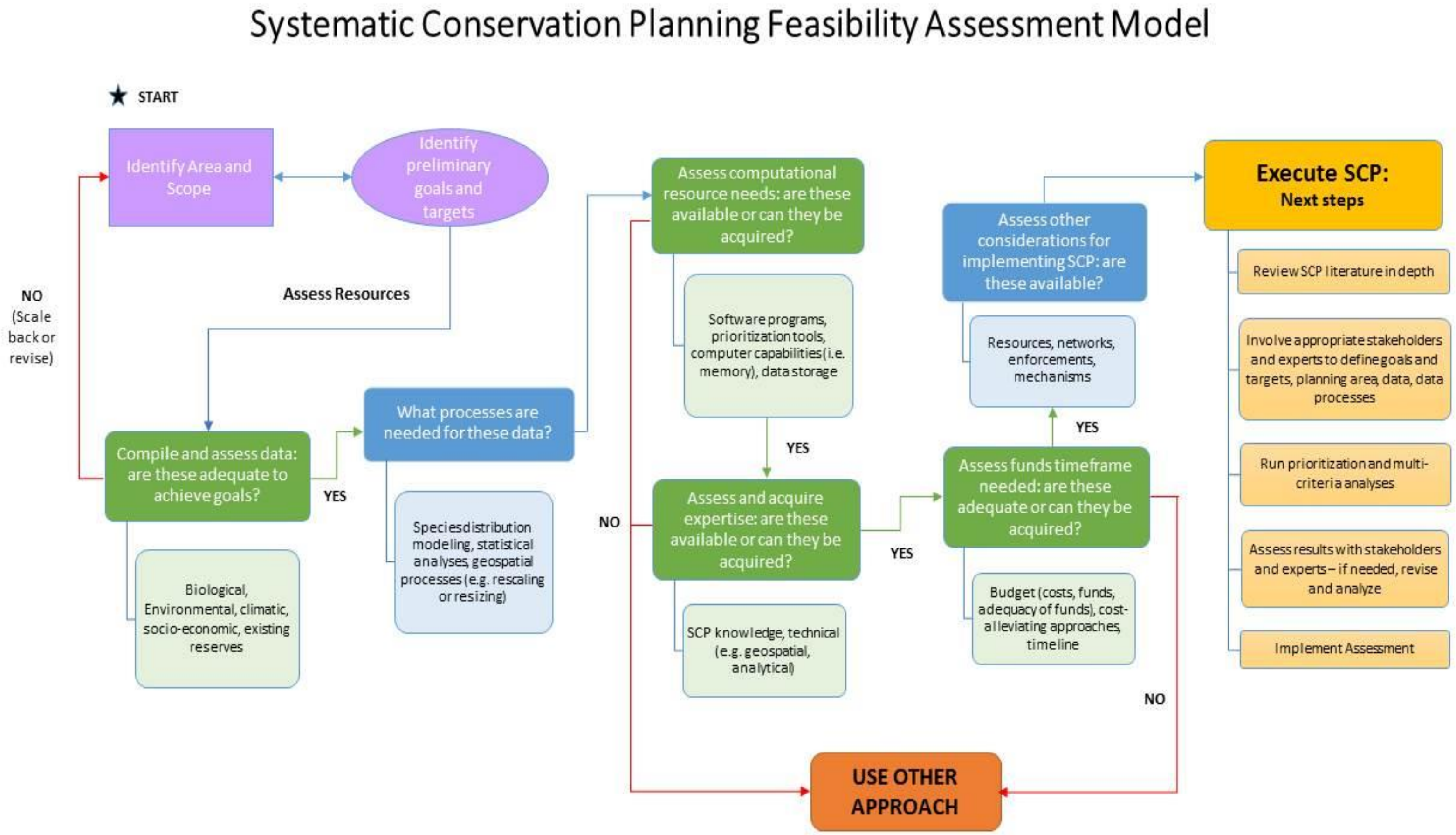


Figure 2-3: Systematic conservation planning feasibility assessment. Start at upper left hand corner and follow the arrows to determine if SCP is feasible in any given region. Blue dotted bi-directional arrow denotes interactions. See section 5 for details of each component.



Chapter 3: Land use and land cover change: Implications for conservation and restoration in southwestern Nicaragua

Abstract

The Rivas isthmus in southwestern Nicaragua has experienced, and continues to experience, large-scale deforestation and land use change. This change often results in fragmented native forests surrounded by a mosaic of land cover types, such as pasture and croplands. Due to the vast and fluctuating change in this region, hotspots and cold spots of change (i.e., areas where land conversion occurs in very high and very low density, respectively) are often lost in the array of change across the landscape, yet are important for observing distinct land use trends, thereby facilitating more efficient conservation planning. The objective of this study is to provide conservation and restoration recommendations by classifying land use and land cover types in southwestern Nicaragua in 2009 and to characterize changes, particularly deforestation patterns, hotspots, and cold spots of land use change, between the years of 2000 and 2009. We collected SPOT satellite scenes from 2009, collected ground referenced data in 2012, delineated manual training points, and used a machine-learning classification and regression tree algorithm to classify 10 land use and land cover types. We compared our results to a previous classification from the year 2000 using post-classification change detection techniques and applied a cluster analysis to delineate hotspots and cold spots of change. Hotspots of change are defined as, polygons with statistically significant, high neighborhood clustering scores surrounded by neighbors with similar high values, and cold spots of change are, polygons with statistically significant, low neighborhood clustering scores surrounded by neighbors with similar low values of change. Classification accuracy was within range of acceptable results at 87.7%. Deforestation rates on the Rivas isthmus were approximately 5.6% per year. Pasture changed the least, plantation is a rapidly emerging class, and regrowth is occurring across the landscape with a modest portion succeeding into secondary forest. Hotspots of change from forest into pasture occurred in areas despite rugged terrain, revealing the pervasiveness of pasture in the region. Hotspots and cold spots of change from forest to plantation occurred in the northern and southern parts of the isthmus, respectively, and reveal the vulnerability of remaining secondary forests important for conservation. These remaining secondary forests and hotspots of succession from regrowth into secondary forest that occurred near secondary forests should be considered priorities for conservation.

1. Introduction

The rapid conversion of tropical forests into other land cover types, such as pastures or crop land, has been particularly prominent in tropical developing countries (Sader and Joyce, 1988). This change begins with deforestation and is often driven by agriculture, timber harvest, and urban development.

In the past century, deforestation has expanded across the globe at alarming rates with many negative consequences. For example, between the years of 1990 and 2005 the overall net reduction of forests was approximately 1.7% (FAO, 2012). Worldwide deforestation and change in land use and land cover (hereafter LULC) perpetuate the global biodiversity crisis through fragmentation of native land cover types, often resulting in habitat loss and ecological degradation (Sanchez-Azofeifa et al., 2001). Fragmentation creates isolated forest patches, increases edge areas and negative edge effects, and reduces or eliminates connectivity for wildlife movement across the landscape, all of which can lead to population declines or extinction of the species affected (Terrason et al., 2010). Moreover, deforestation leads, and climatological changes (Mas, 1999). These adverse effects are also inextricably tied to the loss of ecosystem services such as nutrient cycling or water filtration, which are naturally provided in an intact ecosystem (FAO, 2012; Kainer et al., 2009; Sunderlin et al., 2005).

The Central American tropics support high amounts of biodiversity and endemism; however, they are also experiencing rapid land use change (World Resources Institute, 2001). Although Central America spans only 0.5% of the world's land mass, it contains 7% of the world's ecological diversity, which includes 22 different ecoregions (World Resources Institute, 2001). Nevertheless, 80% of Mesoamerican forest cover has been transformed into agricultural land (Harvey et al., 2008). For example, tropical dry forests (TDF), a highly threatened and vulnerable ecosystem, are characterized by fertile soils and are associated with optimal climates ideal for agricultural use (Calvo-Alvarado et al., 2009; Bawa and Seidler, 1998). The extensive loss of TDF has resulted in less than 0.1% remaining along the Pacific coasts of Central America (Gillespie et al, 2000).

The Rivas Isthmus in southwestern Nicaragua exemplifies the ecological diversity and LULC trend of the world's tropics. The region contains a variety of ecosystems characteristic of the biologically diverse tropics including tropical dry forests, tropical moist forests, and coastal mangrove forests (Otterstrom et al, 2007). Unfortunately, Nicaragua in general, has lost more than 50% of its forest cover over the last 60 years and, if current trends continue, could lose the rest in the next few decades – primarily in southwestern Nicaragua (Zeledon, 2009; Weaver et al., 2003). Deforestation and land conversion practices have fragmented the southwestern landscape and have created a disconnected mosaic of land cover types (Hagell, 2010), including secondary forest fragments. The remaining secondary forest fragments provide habitat for species of conservation concern, such as the black-handed spider monkey (*Ateles geoffroyi*) − an endangered species reliant on secondary forests in the southwestern region (Hagell 2010, Sesnie et al. 2008). With TDF severely reduced, these patches of secondary forests, and places like the La Flor Nature Reserve, located on the Pacific coast of Nicaragua, become important areas for conservation (Gillispie, 2000). Given the complexity of the situation, sustainable conservation planning and forest restoration are vital elements in preserving biological and ecological integrity.

As rapid LULC change continues, identifying land use trends and forested fragments are important first steps for conservation. However, characterizing a fragmented and highly dynamic landscape can be challenging when conservation efforts are limited due to lack of resources such as expertise and funds. Hence, distinguishing valuable conservation areas most and least vulnerable to change and identifying the type of changes that threaten them become important secondary tasks.

Detecting areas of concentrated change provides a reference for the most vulnerable areas to change. For example, deforestation hotspots have been defined as concentrated areas of human-induced change, as opposed to diffuse, undefinable patches across the landscape (Van Laake and Sanchez-Azofeifa, 2004; Veldkamp et al., 1992). This approach highlights patterns of clustered LULC conversion by identifying ‘hotspots (i.e., highly clustered) and cold spots (i.e., less clustered)’ of change – a difficult task in a dynamic and fragmented landscape. An effective spatially explicit ‘deforestation hotspot’ characterization approach employed by Van Laake and Sanchez-Azofeifa (2004), was more objective and flexible compared to previously used hotspot approaches based on expert opinion and thus, susceptible to subjective bias.

The objective of our study was to identify areas in the Rivas Isthmus that have faced deforestation, shown vulnerability to land use conversion, and experienced natural forest regeneration to better inform future conservation and restoration priority. More, specifically, we examined:

- What are the patterns of LULC in year 2009 and how have they changed since year 2000?
- Where are the areas that are the most and least vulnerable to LULC or have the greatest potential for conservation and restoration?
- What conservation and restoration prioritization opportunities exist according to the examination of LULC change?

This study took place by collaborating with Paso Pacífico, a non-profit conservation organization in Nicaragua. One of Paso Pacífico's conservation objectives encompasses forest restoration and examination of the effect of LULC change on species of concern such as the critically endangered black-handed spider monkey. Remaining secondary forest fragments are critical habitat for this endangered species (Hagell, 2010; Sesnie et al. 2008) and other forest-dependent species. Our study identified fragments of remaining secondary forests and areas that are the most vulnerable to LULC change. This information is vital for future research and prioritizing conservation and restoration efforts.

2. Study Area

Our 3233 km^2 study area was in the Rivas Isthmus in southwestern Nicaragua between the Lake of Nicaragua and the Pacific Ocean, bordering with northwestern Costa Rica (Figure 3-1). The elevation of the study area ranges from sea level to 1400 m. The Pacific coastal mountain range extends from the north to the south of our study area with the Zapateras and Mombacho volcanoes in the northeast. The climate consists of a rainy season (winter) from May - December and a dry season (summer) from January - April. Mean annual precipitation ranges from 1000 mm to more than 1700 mm (Hijmans et al., 2005) and the annual average temperature is 26.7^{o} C. The natural vegetation primarily consists of tropical dry forests, tropical moist lowland forests, and mangrove forests. Anthropogenic influences since the 1940's have influenced the present landscape, which comprises a mosaic of natural vegetation, pastures, agricultural lands, plantations, and urban areas (Sesnie et al., 2008). Crops that are cultivated in the region include rice, beans, and sugar cane, and plantations consist of bananas, teak, coffee, and coconut trees.

Conservation actions in the Rivas Isthmus are limited. While 23% of the Atlantic and 12% of the Central regions of Nicaragua are protected, only 5% of the Pacific region is protected (Weaver et al., 2003). The Pacific region encompasses a small number of protected areas such as Volcan Mombacho, Volcan Zapateras, Playa La Flor and other private reserves; however, studies have shown that these reserves are inadequately protected from deforestation (Weaver et al., 2003) perhaps due to the insufficient enforcement of the laws that protect them. Conservation efforts in the study area have been initiated and implemented by Paso Pacífico and other organizations (Hagell, 2010; Sesnie et al. 2008). Paso Pacífico focuses on reforestation to restore the connectivity of the Paso del Istmo corridor found on the Rivas Isthmus for the protection of biodiversity and wildlife migration (Figure 3-2). A few of their specific projects and objectives include the Return to Forest reforestation project, the neotropical migratory bird initiative, jaguar conservation, and assessing the effects of fragmented habitat on bats and their contributions to ecosystem services – all of which involve the local Nicaraguan community in education and conservation leadership (Paso Pacífico, 2006).

3. Methods

3.1 Ground referenced data

We collected ground reference data for training and testing the classifier used for our LULC classification. Ground reference data is a key component in the analysis of remotely sensed data and strengthens the use of remote sensing tools (Newton et al., 2009; Congalton and Green 2009). Due to time limitations, weather conditions, site accessibility, terrain, and movement through dense vegetation, we employed a hybrid sampling design that entailed stratified random and haphazard sampling approaches. We also developed a flexible data collection approach to allow the ground reference data to be suitable across multiple classifiers.

3.1.1 Preparation for ground reference data collection

We compiled existing spatial data of roads, terrain accessibility, and orthorectified aerial photographs from year 2004 (spatial resolution = 80 cm) to facilitate the identification of potential sampling locations. We also delineated potential roads based on the aerial photographs and merged them with the existing road data (Figure 3-3). We then digitized access points using the merged road data, aerial imagery, and Google Earth and Bing Maps satellite imagery to visually identify locations that would yield sampling efficiency. Access points were digitized in areas that 1) contained more than one land use type within 1 km and 2) were within 1 km from a road and then further prioritized.

Based on the digitized access points, we located and ranked sampling priority for 617 access points that could be used to determine the ground data collection locations (Figure 3-3). The assignment of sampling priority aimed to maximize sample size in locations where the greatest LULC heterogeneity was detected. Each potential access point was given a sampling priority (ranked in the scale of 1-4) based on its distance from the road and the heterogeneity of surrounding LULC. First, in order to sample away from the roadside and move efficiently through dense vegetation, an access priority number was assigned to each digitized access point based on its distance from roads. Access priority =1 for a point that was ≤ 50 m from the road, access priority = 2 when an access point was 50-200 m from the road, access priority = 3 for an access point that was 200-500 m from the road, and access priority = 4 when an access point was ≥ 500 m from the road. To minimize distance and time traveling from one sample location to the next without clustering the sample locations, we constrained candidate points within 300-800 m of one another. The number of neighboring points within an 800 m radius of each candidate point (i.e., frequency) was calculated. A sampling priority, which combined access priority and frequency of LULC types, was then assigned to each digitized access point. A sampling priority = 1 when access priority ≤ 2 and frequency ≥ 2, sampling priority = 2 when access priority = 3 and frequency ≥ 2, sampling priority = 3 when access priority = 2 or 3 and frequency = 1, and sampling priority = 4 for the rest of access points. This resulted in approximately 617 prioritized access points.

Three buffer ranges were then created around each access point. From the center of the access point, the zone 1 buffer was 25-75 m, the zone 2 buffer from 75-125 m, and the zone 3 buffer from 125-175 m. Using a random point generator, 9 potential ground reference points were generated in the buffer zones of each access point. Four points were created in zone 1, 3 points in zone 2, and 2 points in zone 3 (Figure 3-3). The zoning system intended to capture heterogeneous LULC types across the specified distances from the roads so as to minimize time navigating through dense vegetation and allow for a greater probability of selecting access points closer to the road.

3.1.2 Ground referenced data collection

Due to our limited time frame and assistance capacity of our collaborators in the region (i.e., knowledgeable field guides in the given area), our collection of ground referenced data were confined to the southern third of the Rivas isthmus. Approximately two crews, each comprising of one to two field assistants and a Nicaraguan field guide, collected the data from mid-June to mid-August of 2012. Of the finalized 617 access points, those that occurred in the most difficult access areas (i.e., mountainous, rugged, or limited access roads) were given collection priority due to the projected precipitation increase towards the end of the season. To efficiently train the chosen classifier, our goal was to collect an equal number of ground referenced points for each LULC type that were evenly distributed across the data collection area.

Upon arrival at each access point, we chose one to two of the nine ground referenced points based on the LULC types they represented, specifically aiming to represent two different LULC types. At each ground reference point, we collected waypoint data using a Global Positioning System (GPS) along with site condition information (Figure 3-4). From each reference point, we delineated a circular plot with four subplots by running a 50 m tape in each cardinal direction and estimated the percentage cover (i.e., 0%, <25%, 25-50%, 50-75%, and >75%) of each LULC type within each subplot. Potential LULC types included old secondary forest, young secondary forest, old regrowth, young regrowth, wetland, crop, pasture, old monoculture plantation, young monoculture plantation, old multispecies plantation, young multispecies plantation, urban, and reforested (Table 3-1). We collected total of 398 ground referenced point data (Figure 3-1), many that were subsequently used in the classification analysis.

3.2 Classification

3.2.1 SPOT imagery and classification preparation

3.2.1.1 Imagery details and preprocessing

Four Satellite Pour l'Observation de la Terre (SPOT) images with a 20 m resolution were preprocessed in preparation for the LULC classification. Two (SPOT2) images from Jan 26, 2009 contained red (R), green (G), and near infrared (NIR) spectral bands, whereas the other two (SPOT4) from February 5, 2009 contained the above three bands and a shortwave infrared band.

We mosaicked the 2004 orthorectified aerial photographs that covered the entire Rivas Isthmus using a cubic convolution resampling method using the software ENVI 4.7 (Exelis Visual Information Solutions, Inc.) and subset the mosaic by removing large lakes and the Pacific Ocean. We then performed geometric corrections for each SPOT image using the subset mosaic as reference and the Autosync function in the software ERDAS Imagine 2010 (Intergraph Corporation). Approximately 25 ground control points were created for each SPOT image, all with an individual root-mean-square deviation (RMSE) ≤ 0.05 pixels or 1 m. Total RMSE for each image was also ≤1 m.

We created two mosaicked images from the SPOT imagery, one comprised of the two SPOT2 satellite images and the other of the two SPOT4 images and subsequently removed the fourth band (shortwave infrared) of the SPOT4 mosaic to match the spectral composition of the SPOT2 mosaic (i.e., green, red, and near infrared bands). To create images with matching radiometric information, radiometric normalization between the two mosaicked SPOT images was performed using the ENVI extension Iteratively

Reweighted Multivariate Alteration Detection (IR-MAD) and image normalization tools (Canty and Nielsen, 2008). IR-MAD searches and identifies ‘no change’ pixels in a way that removes observer bias and ensures invariant pixels that span the full spectrum are found (Canty and Nielsen 2008). Once ‘no change’ pixels have been identified, a model recalibrates target image pixels to the reference image to reduce the effect of atmospheric differences between two images. The target image was then normalized to the reference image (Dickson et al., 2011) and the corrected SPOT 2 and SPOT 4 mosaic images were mosaicked together to create a final image with 3 spectral bands spanning the entire study area.

3.2.1.2 Classification variable preparation

We prepared a suite of spectral and topographic environmental variables identified in previous studies as important for characterizing vegetation types (Poulin et al., 2010; Sesnie et al., 2008; Eckert, 2012). To create additional spectral variables, we derived the first two axes of principal components of the spectral bands (i.e., green, red, and near infrared of the final SPOT mosaic). Principal Components Analysis (PCA) is a process in which SPOT bands are recombined to form a new set of bands that are each a weighted sum of band values. PCA creates an orthogonal transformation of the input data such that each PCA output band is linearly independent from other PCA bands. PCA bands are ordered such that the first PCA describes the greatest amount of variance, followed by the second, third, and so on (Dickson et al. 2011). For this study, we used the first and second PCA bands, as these two axes explained 98% of spectral variance among the three bands. We also created vegetation indices including Normalized Differential Vegetation Index (NDVI), Difference Vegetation Index (DVI), Green-Red Vegetation Index (GRVI), Infrared Percentage Vegetation Index (IPVI), Normalized Difference Water Index of

McFeeters (NDWIF), Near Infrared over Green (NIR-G), Optimized SAVI (OSAVI), Soil Adjusted Vegetation Index (SAVI), Simple Ratio (SR), and Vegetation Index (VI) (Table 3-2, layers 10-19). We also used topographic variables including elevation, slope, cosine-transformed aspect, and Topographic Wetness Index (TWI) (Table 3-2; bands 6-9) that were derived from the Shuttle Radar Topography Mission digital elevation model and obtained from previous work (Sesnie et al., 2008). These topographic variables were resampled to match the SPOT pixel size of 20 m.

3.2.1.3 Training and testing data

Field data were sorted based on the dominant vegetation type and percentage cover for each LULC type to enhance data quality and capacity to augment classification training sample development using ArcMap 10.0 Visual Basic script (Esri, Inc.). Due to the absence or rarity of, and variation within certain classes, we eliminated the selective logging and reforested classes; combined the multiple plantation classes into a single plantation class (PL); and created wetland- mixed-forest and urban-mixed-agriculture classes (Table 3-2). Moreover, clouds, shadow, and water were delineated and removed from the imagery. Our final classification scheme encompassed nine vegetation classes including urban-mixed-agriculture, wetland-mixed-forest, young regrowth, old regrowth, young secondary forest, old secondary forest, pasture, crop, and plantation (Table 3-2).

A visual inspection and low accuracies of the preliminary classification revealed considerable misclassification in the northern portion of the isthmus, likely due to a lack of ground referenced data in that area; therefore, we digitized manual training points evenly across the isthmus to provide sufficient classification training samples. We generated a 6 x 6 km grid over the study area, and delineated at least one training point for each LULC class in each grid cell using the processed SPOT imagery, Google Earth imagery, and field knowledge. To increase validity of the manually created training points, points that passed the quality assessment were selected for further analysis.

To facilitate capturing the variation within each class, polygons were derived (Congalton and Green, 2009) and verified at our ground reference plots, subplots, and locations of our imagery training points. It has been suggested that approximately 50 polygons should be used in classifier training for study areas that are approximately 400,000 ha and contain 12 LULC classes. This number represents a balance between statistical validity and practicality (Congalton and Green, 2009). We created approximately 30-90 polygons for specific LULC classes (Table 3-3) at approximately 100-200 m in width based on the location of ground reference subplots and final training points with the highest confidence of representation. Additionally, in order to compensate for the temporal differences of the ground referenced data (2012) and the SPOT images (2009), all polygons covering the ground plots were visually inspected for validity by comparing the LULC types discernible from the SPOT mosaic with Google Earth's multi-temporal imagery.

3.2.2 Classification implementation

3.2.2.1 Classifier

We used the RuleGen 1.02 extension for ENVI 4.7 (Exelis, Inc.) utilizing the ten-fold univariate Quick Unbiased Efficient Statistical Tree (QUEST) algorithm (Jengo, 2004) as the final classifier for this study. RuleGen uses the machine-learning classification and regression trees (CART) algorithms to determine statistical relationships between predictor variables in order to produce a decision tree (Jengo, 2004). The QUEST algorithm produces binary trees where each node is split into two subnodes. For the final classification, we chose and used nine LULC classes (Table 3-1) based on the availability of quality ground referenced and manual training data, and the accuracy assessments derived from multiple classification iterations.

3.2.2.2 Accuracy assessment

We used an error matrix to assess the accuracy of our LULC classification (Congalton and Green, 2009). Given a percentage of training data, the error matrix compares information from training data to information on the map, and calculates producer's and user's accuracies, as well as kappa and KHAT statistics (Congalton and Green, 2009). Producer's accuracy measures errors of omission and determines the probability that a reference sample is mapped correctly. User's accuracy measures errors of commission and determines the probability that a sample from the LULC classification matches its actual LULC class. A kappa analysis is a derivative of the error matrix and is defined as "a discrete multivariate technique used in an accuracy assessment to statistically determine if one error matrix is significantly different from another" (Congalton and Green, 2009). The KHAT statistic provides a measure of how well the classification agrees with the reference data. KHAT statistics that are greater than zero signify better than random and ranges for KHAT include strong agreement (i.e., >0.8 or 80%), moderate agreement (i.e., 0.4 -0.8 or 40-80%), and poor agreement (i.e., <0.4 or 40%) (Congalton and Green, 2009).

3.3 Change detection and cluster analyses

Change detection analyses have proven imperative in defining LULC changes in the past century (Turner et al., 2003). We compared the changes over a nine year period for the Rivas Isthmus using post-classification change detection methods. We then determined the most vulnerable areas of change using an objective approach similar to the deforestation hotspot analysis of Van Laake and Sanchez-Azofeifa (2004) to identify hotspots of LULC conversion. Our approach differed from Van Laake and Sanchez-Azofeifa (2004) by characterizing areas that experienced the most and the least spatially intensive LULC conversion to identify areas that have been deforested, are most and least impacted by conversion (Van Laake and Sanchez-Azofeifa, 2004), and are naturally regenerating.

3.3.1 Change detection preprocessing

Prior to the implementation of the change detection analysis, we preprocessed and prepared the two LULC classifications being compared, which included our 2009 classified image and the 2000 classified image from Sesnie et al. (2008) (Figure 3-5). The two classifications were different in several ways and thus, required standardization in their spatial resolution and their LULC classes to enable direct comparison. The 2000 LULC classification used Landsat images at a 28.5 m resolution, characterized 10 LULC types, and used the Random Forest classifier. We resampled the 2009 classification to a cell size of 28.5 m to match the 2000 classification. In addition, we standardized LULC classes across both classifications by removing incomparable classes and reclassifying both images. Classes removed from the 2000 classification included urban, wetland, water, bare soil, rock, and clouds, and those removed from the 2009 classification included urban-mixed-agriculture and wetland-mixed-forest. Based on agreement between Sesnie et al., (2008) and ourselves, we reclassified and merged a few classes from the 2009 classification. Young secondary forest and old secondary forest were reclassified as forest, old regrowth was reclassified as regrowth, and pasture and young regrowth were reclassified as pasture. The voided areas from each image were then equally removed from the other image. The final comparable LULC classifications (Figure 3-6) were used in the change detection analysis.

3.3.2 Change detection

A post-classification change detection method was employed in ENVI in order to identify the changes in the study area over the nine year period. This method was chosen because vital information such as change from one class to another can be detected. Mas (1999) compared change detection techniques and found that the post-classification method was the most accurate procedure and had the advantage of indicating specific change (i.e., from one class to another).

3.3.3 Change cluster analysis

We performed a cluster analysis to identify the hotspots and cold spots of change in order to highlight areas that are the most and least vulnerable to LULC conversion, as well as areas that are naturally regenerating from deforested lands.

To minimize noise in each change class (e.g. forest to pasture), small areas of change (i.e., polygons of 1800-8100 m^2, produced from a change detection output raster layer) were removed from the analysis. We determined the threshold minimum size of remaining change polygons by implementing visual inspections.

We calculated Ripley's K function, a multi-distance spatial cluster analysis tool, to explore spatial patterns of significant clustering or dispersion of each change over a range of distances using the software ArcGIS 10 (ESRI, 2013 a). We determined the size of neighborhood clustering search window for each change class by identifying the particular distance that showed the most prominent spatial clustering (i.e., when the deviation of observed K from expected K within a high value of confidence envelope of random distribution was the greatest). We then calculated a neighborhood clustering score for each change polygon. This score was based on three criteria within each neighborhood clustering search window, including 1) distance to the nearest polygon, 2) number of polygons within the neighborhood, and 3) total area of polygons within the neighborhood. Distance from each change polygon to the nearest neighbor was calculated using the Near tool in ArcGIS 10 and ranked from 5 (the closest) to 1 (the farthest). Number of neighboring polygons was calculated using the Generate Near Table and Frequency tools in ArcGIS 10 and ranked from 5 (the most neighbors) to 1 (the fewest neighbors). Total area of neighboring polygons was calculated and ranked from 5 (the largest area) to 1 (the smallest area).The sum of three ranks was the final neighborhood clustering score with 3 being the lowest and 15 the highest.

In order to determine the hotspots and cold spots of change, we calculated an Anselin Local Moran's I index for each change class to identify significant hotspots, cold spots, and spatial outliers based on weight given to each change polygon (i.e., the neighborhood clustering score) and the deviation of Local Moran's I index from complete spatial randomness (ESRI, 2013b). Hotspots (i.e., high-high clusters) indicated change polygons with high neighborhood clustering scores surrounded by neighbors with similar high scores. Cold spots (i.e., low-low clusters) indicated change polygons with low neighborhood clustering scores surrounded by neighbors with similar low scores. Spatial outliers (i.e., low-high clusters) were change polygons with low neighboring clustering scores surrounded by neighbors with high scores (ESRI, 2013b).

4. Results

4.1 Land use and land cover classification

The final inputs used for LULC classification contained variables of PCA 1, PCA2, elevation, slope, TRASP, TWI, NDVI, and SAVI (Table 3-2), with a high overall accuracy of 87.7% (Table 3-4), meeting the minimum level of interpretation accuracy for LULC classification (Anderson et. al, 1976). Accuracies for both the user's and producer's accuracies of all classes were above 75%. Producer's accuracies ranged from 76.7-95.6% (wetland-mixed-forest to crop) with the highest being crop, old secondary forest, and pasture and the lowest being wetland-mixed-forest, young secondary forest, and old regrowth (Table 3-4). User's accuracies ranged from 76.3-95.5% (wetland-mixed forest to crop) with the highest being crop, urban-mixed-agriculture, and old secondary forest and the lowest being wetland-mixed-forest, old regrowth and young regrowth (Table 3-4). The overall kappa score was 0.86 and KHAT scores for all classes were in strong agreement (i.e., >.8) with the reference data, except for wetland-mixed and old regrowth, which were in moderate agreement with the reference data.

The LULC classification error matrix provided insights to frequent misclassification amongst classes (Table 3-5), many of which were likely a result of spectral similarities and spectral heterogeneity. Crop and pasture were often misclassified as each other. Plantation was often misclassified as old and young regrowth. Wetland-mixed-forest was misclassified as young regrowth, plantation, and old regrowth. Young regrowth was naturally misclassified as old regrowth and wetland-mixed-forest. Old regrowth was primarily misclassified as young regrowth followed by young secondary forest. Young secondary forest was repeatedly misclassified with old secondary forest and vise-versa.

Percent area for LULC classes in the 2009 classification ranged from 6.1% (urban) to 23.1% (young regrowth). Secondary forest totaled 13.7%, which included young secondary forest (7.5%) and old secondary forest (6.2%). Total regrowth across the study area was approximately 34%, young regrowth being the highest (23.1%) followed by old regrowth (10.1%). Agricultural classes including pasture (19.6%), crop (9.2%), and plantation (8.9%) accounted for a total of 37.7% of the landscape.

A visual interpretation of the final LULC classification (Figure 3-7 a-c) revealed that topography strongly influenced the occurrence of LULC classes. The most steep and rugged areas, including the Pacific coastal mountains, the southern sliver of land between the lake and Costa Rica, and the volcanic areas to the north, encompassed most of the secondary forest. Old secondary forest occurred in small patches on the most remote and difficult-to-access terrain. Regrowth primarily occurred in the rugged areas of the Pacific mountain side. Conversely, the mostly flat lake side of the isthmus was chiefly comprised of agricultural practices including pasture, cropland, and plantation. While pastures mainly occurred on the mildly-sloped lake side, they were also scattered across the isthmus despite steep terrain. Some occurrences of plantation were also found in more rugged terrain.

4.2 Change detection

A visual comparison of the two classification images revealed the following important trends (Figure 3-6). Forest and regrowth have largely decreased throughout the isthmus. However, some secondary forest has increased in areas previously defined as regrowth, specifically in areas with rugged terrain, such as the volcanic areas and the southern Pacific mountains. Additionally, plantation has substantially increased; however, it was not classified in the 2000 LULC classification due to its insignificance as a separate class (S. Sesnie, personal communications). Pasture has increased in the northern half of the isthmus scattered between regrowth and forested areas.

The change detection results revealed the percent change for each LULC class into another (Figure 3-8 a-d). Forest has changed by more than 50% rendering the deforestation rate for the nine year period at approximately 5.6% per year. Approximately 20% of forest was converted into pasture, 16.1% into regrowth, and 10.7% into plantation

(Figure 3-8b). Regrowth experienced the most change at about 78%, of which 47% was converted into pasture, 8.2% into plantation, and 2.3% into crop; however, 20.3% of regrowth succeeded into secondary forest (Figure 3-8d). Conversely, agricultural classes either changed the least or were converted into other agricultural classes. Pasture changed the least at 28% and was converted into crop at 13.7%, followed by regrowth at 5.9%, and plantation at 5.3% (Figure 3-8c). Crop either stayed as crop (35.3%) or was transformed into other agricultural classes, such as pasture (44.6 %) and plantation (16.5%) (Figure 3-8a).

4.3 Ripley's K

The Ripley's K analysis disclosed that clustering of the change classes (e.g., crop to pasture) ranged from 1.5 to 8 km (Table 3-7). The average clustered distance for all change classes was approximately 5 km. The clustered distance for crop change tended to be either very high or very low. Crop to plantation and forest to crop had the highest clustered distance values at 8 km each, while the lowest clustered distance values were from crop to regrowth at 1.5 km.

4.4 Change cluster analysis (hotspot and cold spot analysis)

The type of clustered change that occurred on the landscape strongly depended on the type of change.

The clustered changes from forest to other classes were spread out across the isthmus (Figure 3-9 a-d). Hotspots of change (i.e., high-high clusters) from forest to pasture (Figure 3-9b) were observed in the north central part of the isthmus as well as in the south central part, despite the rugged terrain in these areas. This unanticipated trend reveals the prevalence of pasture in the region. Hotspots of change from forest to plantation (Figure 3-9c) occurred in the north and central lake-side of the isthmus. Cold spots of change (i.e., low-low clusters) from forest to plantation were found throughout the south central mountainous areas near the Costa Rican border. Hotspots of change from forest to regrowth (Figure 3-9d) occurred in large pockets throughout the Pacific mountains and the volcanic areas to the north.

Hotspots and cold spots of change from regrowth to forest (Figure 3-10b) were mainly concentrated in the southwestern rugged areas of the isthmus where access is often limited and revealed the restricted areas for forest succession in the region. Cold spots of regrowth into plantation (Figure 3-10d) were lightly spotted throughout the isthmus and hotspots of this change were observed in the southeastern sliver of the study area. Cold spots of regrowth into pasture (Figure 3-10c) were highly scattered throughout the isthmus, but hotspots of this change were concentrated in the north central portion ─ a trend exceptionally similar to the forest to pasture change.

Hotspots of change from crop into plantation (Figure 3-11b) and crop into pasture (Figure 3-11a) were concentrated on the lake side where agricultural practices are prominent. Cold spots of these specific crop changes were scattered across the isthmus, primarily in the mild-sloped lake side areas. Change from crop to regrowth was negligible (Figure 3-11c).

Pasture was the class that changed the least. Hotspots of change from pasture to crop (Figure 3-12a) occurred in the predominantly agricultural lakeside. Hotspots of change from pasture to plantation (Figure 3-12b) took place in the southeastern portion of the isthmus near the Costa Rican border. Hotspots of change from pasture to regrowth (Figure 3-12c) were situated along the western Pacific coastal mountains. Cold spots of change from pasture to plantation, regrowth, and crop were spotted throughout the isthmus.

5. Discussion

5.1 Land use and land cover classification

Our LULC classification had satisfactory overall accuracy, with specific accuracies varying among individual LULC types (Table 3-4). The use of terrain variables has been shown to increase classification accuracy (Sesnie et al., 2008) and also positively influenced ours. A few classes, however, contained lower accuracies (approximately 76-80%). For example, both the user's and producer's accuracies for the wetland-mixed-forest class were less than 80%; young secondary forest also had a low producer's accuracy (78.2%); and old regrowth had a low user's accuracy (76.3%). These outcomes could have been due to confusion amongst related classes (e.g., misclassification of wetland-mixed-forest with regrowth and forested classes), resulting in the misclassification of many samples and thus, low accuracies (Table 3-5).

Our main challenges for producing more accurate results stemmed mainly from limited spectral bands; the lack of useful indices that could have been derived from additional bands; the spectral heterogeneity within certain classes; and spectral homogeneity between certain classes. Our SPOT imagery was limited to the green, red, and NIR bands as opposed to Landsat ETM+ imagery, which contains up to eight different bands including blue, green, red, two NIR bands, a thermal band, a mid-infrared, and a panchromatic band (United States Geological Survey, 2013). The green and NIR bands help in identifying vegetation (Liew, 2001), while the red band helps to determine vegetation slopes (United States Geological Survey, 2013). However, because we had various types of classes, especially those hard to distinguish from each other (e.g., young regrowth and old regrowth), additional bands and their derived indices could have been useful in distinguishing similar classes and thus, improved their accuracies.

Our forested classes were difficult to differentiate and our technique could have been improved by using specific bands with valuable spectral information, such as the mid-infrared band (Landsat ETM+), and variables such as NDVIc (Sesnie et al., 2008). The mid-infrared and thermal bands have been found to increase the capacity of discriminating tropical forest regeneration components from one another (Boyd et al., 1996). Moreover, NDVIc is an index built using various specific bands and a key in accurately classifying regrowth and wetland classes and distinguishing forest from other LULC types (Sesnie et al., 2008). The absence of these key variables may have limited the ability of our classifier to differentiate these classes. However, our analysis contained the NIR band, which is known to differentiate forest regeneration in tropical regions, as well as secondary forest from non-forested categories during the dry season when foliage is minimal (Stevens et al., 2011; Steininger 1996); thus, aiding in the discrimination of our multiple forested classes and their acceptable accuracies.

Differentiating our agricultural classes was also a difficult task to due to their inherent spectral heterogeneity and mixed spectral characteristics. A previous study by Hayes and Cohen (2007), found that regrowth and agricultural classes have greater within-class variability in comparison to secondary forest. Having the blue band, which helps to discriminate soil from vegetation (United States Geological Survey, 2013), could have facilitated in separating pastures and deforested areas with regrowth, crop, or urban areas.

5.2 Change detection

Our change detection analysis revealed the following important trends: 1) fragmentation is occurring in various sizes, 2) deforestation is occurring at a high rate and forest is being converted mainly into pasture and plantation, 3) regrowth is a capricious class but a portion succeeded into secondary forest, 4) agricultural classes tend to reside on the flat lake side of the isthmus, and 5) pasture has a strong influence in the region.

5.2.1 Fragmentation

Fragments of change occurred in various sizes throughout the landscape. Small fragments of change supports an analysis by Rudel et al. (2009), who described impoverished, small farmers who convert the land for sustenance and livelihood as the primary drivers of deforestation from 1985-present day in Central America. Some have proposed that this phenomenon is a result of land allocation to multiple farmers across these regions and a key cause of forest degradation (Pedroni et al., 2008). Larger fragments, however, may be a result of large-scale, enterprise-driven deforestation – an increasing trend more recently observed in Latin America (Rudel et al., 2009). Many socioeconomic factors are considerably changing this dynamic and fragmented landscape.

LULC change cannot be fully understood without the understanding of both social and natural sciences (Rindfuss et al., 2004); thus, future studies in this region should analyze the socioeconomic trends in light of LULC to better understand the drivers of change, such as policy changes, and how these factors might impact or better inform future conservation and restoration efforts. For example, Calvo-Alvarado et al. (2009) examined the social implications, such as structural drivers and conservation policies, on deforestation and natural forest regeneration for the Guanacaste region of Costa Rica. They found that one of the main drivers of deforestation was pasture expansion attributed to an increase in the beef industry; however, the subsequent fall of the industry and the shift into a service-oriented economy resulted in forest regeneration.

5.2.2 Deforestation trends and forest changes

A vast amount of forest has been lost (50%) – essentially converted into other LULC classes, revealing a high deforestation rate of 5.6% per year. Similar high deforestation rates (4.2% per year) were observed in eastern Costa Rica between the years of 1986-1991 (Sanchez-Azofeifa et al., 2001). In contrast, deforestation rates between the years of 1978-1993 in the Atlantic region of Nicaragua were at an average of -0.5%, which is fundamentally forest regrowth (Stevens et al., 2011). These differences suggest that analyzing deforestation rates of broad areas or large regions, such as Nicaragua or Central America, can often conceal or undermine trends in smaller, specific areas within them. For this reason, it is recommended that these processes are examined at multiple scales (Bray, 2010).

We found that remaining forest was aggregated in areas with steeper slopes, higher elevations, and limited access, which mirror the findings of a similar study carried out in Costa Rica (Sanchez-Azofeifa et al., 2001). Research has shown that variables such as terrain, roads, and population density, influence forest vulnerability (Pedroni et al., 2008). While these tendencies are apparent in our study, they were not explicitly analyzed. A follow up study analyzing these trends would be beneficial.

Conversion of remaining tropical dry forests into agricultural classes remains a critical concern for conservation efforts in the region. Pasture is the main culprit of this change ─ approximately 20% of remaining forest was converted into pasture. This trend is of conservation concern as pasture is a dominant land use in the region and has already contributed to severe fragmentation and degradation. Moreover, approximately 10.7% of forest was converted into plantation. Plantations may seem a better land use option relative to pasture. For example, coffee plantations in the Mombacho region have been found to serve as a refuge for howler monkeys (McCann et al., 2003). Nonetheless, a forest transformation into a non-native monoculture, such as a teak plantation, cannot provide the structural and functional complexity for biodiversity of a native forest (Barlow et al., 2007). A preliminary assessment of landscape connectivity on the Rivas isthmus found that proposed plantations in the south would severely impact forest connectivity for the Central American spider monkey (Hagell, 2010). Unfortunately, many of these plantations have appeared in our analysis.

5.2.3 Regrowth changes

Regrowth is a noteworthy class because of its high percentage of change at 78% – most of it being converted into pasture (47%) (Figure 3-8d). This result reveals two important characteristics of this class including 1) its close ties with pasture and 2) its high variability or susceptibility to change. The first characteristic suggests that fallowing pastoral practices may be occurring, which consists of resting a pasture for a period of time allowing for substantial vegetation regrowth and then converting it back into pastoral land (Hartter et al., 2008). This perpetual disturbance and land use conversion into agriculture is a problem that can negatively influence ecological integrity. Conversely, a substantial percent of regrowth (20%) has succeeded into secondary forest, a trend primarily observed in rugged areas with limited access. Similar trends were observed in various parts of Latin America (Asner et al., 2009). Our research suggests that relatively less human influence is found in these areas and thus, their preservation can benefit connectivity efforts due to their occurrences near old secondary forests. However, the two characteristics expose the probable difficulty of implementing conservation or restoration practices in this class. Compounded on this are the nature of these changes including being very fragmented, having pronounced size variation, and occurring scattered across the study area. These results support our implementation of the cluster analysis, which focused on the most and least concentrated areas of change.

5.2.4 Crop and pasture changes

Agricultural classes, specifically crop, either stayed as crop or were converted into other agricultural classes, such as plantation and pasture (Figure 3-8a & 3-8c). Both our results and previous research (Pederoni et al., 2008) revealed that agricultural classes were aggregated on flatter slopes and areas at lower elevations. Due to their easy accessibility, these areas generally tend to be dominated by a variety of agricultural land use classes (Pederoni et al., 2008). Thus, we presume that these areas are likely to remain as agricultural classes and as a result, generally lack conservation or restoration potential.

Pasture changed the least (28%), in addition to being the most 'converted to' class (Figure 3-8 a-d) and the second largest class in the 2009 classification (19.6%). As seen here, pastoral practices are a driving force of large-scale LULC change and dominance throughout Latin America (Zeledon, 2009; Meyer and Turner, 1992). These results also suggest that forests converted to pasture have a lesser chance of returning to forest. However, this conclusion should be further investigated in order to reveal the long-term trends of these changes by employing a temporal change detection analysis over a period greater than 10 years.

5.3 Hotspots and cold spots of change

The results of the cluster analysis of change depicted these LULC change patterns in further detail and provided insight for conservation and restoration priorities. Specific hotspots and cold spots for each change class occurred in different parts of the isthmus (Figures 3-9 – 3-12). Our conservation and restoration recommendations were dependent upon the type of change (i.e. class to class), the degree of change (i.e. hotspot or cold spot), and the location of change. For example, while some hotspot changes may imply urgent conservation actions (e.g., forest to pasture in the southern isthmus), hotspots from forest to pasture in the central isthmus is likely a location where the change is beyond the efforts for conservation, especially because regrowth to pasture also occurs here.

5.3.1 Forest changes

Cold spots of change from forest to pasture (Figure 3-9b) occurred in various sized patches throughout the isthmus. Based on our field knowledge and previous research (Rudel et al., 2009), this trend is a most likely a result of small farmer subsistence. These areas may present themselves as an ideal target for restoration because their low clustering thus, low conversion intensity, but only if the area is no longer being used for pasture or other land uses. Specifically, areas surrounded with important habitat, such as secondary forests, should be considered for restoration.

Hotspots of change from forest to pasture (Figure 3-9b) occurred in the north central and south central parts of the isthmus. The hotspots in the north central region revealed an unanticipated trend and although its root cause is unknown, it may reveal large-scale pastoral development. More notable, are the hotspots of change that occurred in the less accessible south central part of the isthmus where larger, more connected tracks of secondary forest remain. This finding is of conservation concern, especially if these areas are considered to be ‘safer’ from change due to their limited accessibility. The southern hotspots should be targeted for conservation action because of their direct occurrence near critical patches of remaining forest as opposed to the northern hotspots.

Hotspots of change from forest to regrowth (Figure 3-9d) occurred in large pockets throughout the Pacific mountains and the volcanic areas to the north. Cold spots of this change were also found throughout the more rugged, western half of the isthmus. Both of these changes may call forth one of two interpretations 1) the area was used at some point and may still be in use, potentially for pasture, which may be in fallow and thus emanating a spectral signal of regrowth, or 2) the area is now abandoned and undergoing succession. The implication for conservation of this class is also two-fold. If the first interpretation is true, then conservation or restoration may not be feasible given that the land may be used for other purposes. However, if the latter interpretation is true, then there may be good opportunities for conservation planning. For example, many of these hotspots occurred in areas where remaining tracks of secondary forest occur. Therefore, restoration or conservation of these areas, especially those to in the far south, could aid in expanding these forests or the connectivity of them. However, predicting the trajectory of these areas is somewhat difficult and will require a more in depth analysis.

Plantation is an expanding land use class in the region and perhaps a strong culprit of deforestation; thus, it requires considerable conservation attention. The hotspots of change from forest to plantation (Figure 3-10c) that appeared to the northeast are likely a product of shade coffee plantations, as seen in Google imagery and in other research (McCann et al., 2003). They are of concern for conservation planning efforts because one hotspot occurred next to the Mombacho volcanic region where remaining secondary forest patches reside. Conversely, cold spots of this change occurred throughout the south central rugged areas near the Costa Rican border and are most likely due to the development of hard wood monoculture plantations, such as teak. These areas are of concern because they resided near some of the larger remaining tracks of secondary forest in the region (Hagell, 2010; Sesnie et al. 2008). We suggest that the southern cold spots of change are targeted for conservation as opposed to the hotspots to the north because 1) it may be more difficult to plan for conservation in areas with heavy change (i.e., hotspots), as opposed to those under less intense change (i.e., cold spots), and 2) coffee shade plantations have been found to have a lesser impact on forest dependent species than monoculture teak plantations that severely compromise the native forest (Hagell, 2010; McCann et al., 2003).

5.3.3 Regrowth changes

Regrowth change was notable for its considerable transformation and because a portion of it succeeded into secondary forest. Hotspots of regrowth to forest (Figure 3-10b) were concentrated in areas where secondary forest was also occurring, such as the rugged areas of the Pacific mountains and the volcanic regions of the study area. These areas should be of conservation or restoration priority because 1) they are less likely to face LULC conversions relative to the flat areas on the lake side and other dynamically changing areas identified in this analysis, and 2) it can help facilitate connectivity or expansion of the remaining secondary forests given their proximity to them. Cold spots occurred in the western rugged areas and the southern sliver of the isthmus. The occurrences of the regrowth in these areas are probably due to limited accessibility. Similar forest regenerating trends have been seen throughout different countries in Latin America and may be a result of various factors, including urbanization and environmental policies (Calvo-Alvarado et al., 2009). Conversely, they could also be fallowing areas that may be used in the near future (Hartter et al., 2008). For example, these cold spots of this change occurred in areas where hotspots of forest to pasture (Figure 3-10b) occurred, indicating dynamic land use in this particular area and making them less ideal as conservation priorities.

Regrowth into pasture (Figure 3-10c) and pasture to regrowth (Figure 3-12c) are important trends because of the strong association between these classes. Approximately half of regrowth was converted into pasture. A large patch of hotspots in the north central part of the study area closely mirrors the forest to pasture change. These trends point out the extensive change into pasture occurring in this area, potentially from the establishment of large-scale agricultural farms, as opposed to the small farmer subsistence usage that has typically dominated the landscape change. Additionally, hotspots from pasture to regrowth (Figure 3-12c) occurred in the southwest and northwest and in cold spots lightly scattered throughout. Cold spots from regrowth to pasture also prominently occurred throughout the isthmus. These trends are likely a result of the generally dynamic nature of pastoral lands (i.e., periods of rest or fallow). Regrowth is notably being converted to, or back into, pasture making these two classes difficult to prioritize for conservation. Moreover, it is likely that in the future these types of changes will affect different areas of the region ─ fluctuating with economic and political situations and site specific land use decisions. We recommend that highly dynamic classes and areas should not be considered for conservation priority because they are likely to continue being used and are highly fragmented resulting in lower habitat quality.

5.3.3 Crop and pasture changes

Agricultural practices, such as plantation, crop and pasture dominated the flat lake side part of the isthmus (Figure 3-7 a-c). The prevalent change in this area was from one agricultural class to another, specifically hotspots of change from crop to pasture (Figure 3-11a), crop to plantation (Figure 3-11b), pasture to crop (Figure 3-12a), and pasture to plantation (Figure 3-12b). Due to existing heavy agricultural uses, population density, terrain slope, and road density (Pedroni et al. 2008) these hotspots of change should be considered as low conservation priority because they are likely to continue as agricultural classes.

These change categories also appeared in cold spots across the study area and may also support the claim that pastures and cropland are often rotated depending on the year or season (personal communications) suggesting that these areas are also likely to remain as agriculture. The cold spots may signify small land owner subsistence use and may be restored by working with specific land owners that allow reforestation on their property. However, because of the many instances spread across the landscape, they may prove difficult to work with. Further analysis would be needed to determine which cold spots should be prioritized.

6. Conclusions and management implications

Land use and land cover change analyses will continue to be important in future ecological studies and conservation efforts. Identifying change over a decade is valuable information because it can be used to highlight areas that are most and least vulnerable to change and thus, provide insights for conservation priorities. In addition to our LULC classification being used for conservation planning efforts, it will be used for other ecological analyses carried out by our collaborators. For instance, our LULC map will be used as a layer for comparing mature forest patches with bat species diversity and the effects of landscape fragmentation on bats (C. Chambers, personal communications).

Our method in identifying clusters of conservation vulnerability is one way to prioritize areas for conservation and restoration and it reveals the leveraging of limited resources and time to create a useful product for conservation efforts. However, we suggest that further research, such as systematic conservation planning, be used on the Rivas isthmus to identify a comprehensive conservation reserve network. Systematic conservation planning is recommended because it is a scientifically grounded approach that systematically leverages data (e.g., spatial and species occurrences) as inputs to identify the most efficient reserves in a given area (Margules and Pressey, 2000). In regions where data are limited, such as southwestern Nicaragua, classifications and vulnerability information are valuable data inputs for SCP prioritization, especially useful for maximizing efficiency and effectiveness of time and resources (Margules and Pressey, 2000).

Managers implementing conservation in this region should acknowledge two important factors determined in this analysis when considering conservation objectives: 1) conversion of remaining secondary forest patches is still occurring and will negatively affect biodiversity and connectivity, 2) however, because livelihoods are closely tied with land use, collaborating with local stakeholders should be considered a priority for implementing sustainable conservation and restoration.

Remaining secondary forest fragments appear to be vulnerable to pasture and plantation – cover types that can be difficult to reverse once converted. Hence, we stress that remaining tracks of secondary forest are considered as priorities for conservation, especially those in the southern isthmus. Areas where regrowth has succeeded into secondary forest should also be a conservation priority. In order to maximize the connectivity of secondary forests, priority areas for restoration should include areas that lie in or around the remaining southern tracks of forest. Because of their limited accessibility, people tend to use these areas less. Inevitably, this may promote upland conservation reserves due to the unfavorable characteristics in the lowland areas, such as intense deforestation and use (Rudel et al., 2009) as seen in our analysis. Although this is not the most ideal option, it is more attainable in a landscape where limited forested area remains, and high fragmentation and intense land use occur.

Overall trends in forest changes present conservation concerns as forest remnants are vital to the recovery of endangered tropical dry forests (Tarrason et al., 2010) and their forest-dependent organisms, such as the black handed spider monkey (Sesnie et al., 2008). Nevertheless, these results may also represent an opportunity for an integrated landscape that includes a combination of sustainably managed conservation areas and other land use types (Harvey et al., 2008). For example, some land uses have conservation potential, such as plantations (Chazdon et al., 2009), which can provide a source of canopy for dispersal or carbon sequestration. Remote areas that contain scattered cold spots of agricultural change are good candidates for sustainable use and conservation through the collaboration of conservation organizations, farmers, and land owners. Integrated management, however, would require the consideration of conservation value for all types and subtypes of land use cover (e.g., crop and the specific type of crop), a task that can be difficult in practice. If conservation managers can at least identify the culprits of land use change and their stakeholders, a collaborative approach may increase conservation sustainability. For instance, an agreement could be made in which agricultural land uses are established in areas with lower conservation value (e.g., abandoned pastures) versus those with high conservation value. Ideally, this collaboration would reduce the amount of future deforestation and ecological degradation. Previous research has provided guidelines for an integrated landscape inclusive of conservation and agricultural production for sustainable use (Harvey et al. 2008).

Conservation and restoration efforts are challenging in the developing tropics especially when dealing with limited resources such as funds, data, and scientific expertise. Nevertheless, this study is a unique example of leveraging limited resources and collaboration to provide valuable data products, and to assess LULC change and its conservation implications for on the ground conservation work. This collaboration between a small NGO in the tropics (Paso Pacífico) and an educational institution (Northern Arizona University) reveals the ability to overcome resource limitations. We hope to continue this partnership and encourage other institutions and organizations to increase these types of collaboration efforts for more efficient conservation planning.

Tables and Figures:

Table 3-1: Land use and land cover classes used in the classification analysis, their abbreviations, and definitions. (*) Denotes classes included in the final classification.

Land Use or Land Cover Class	**Abbreviation**	**Definition**
Crop*	CR	all annual crops (e.g., rice, corn, beans, wheat, sugar cane, etc.)
Pasture*	PA	all pastured areas grazed by cattle or horses
Plantation*	PL	all orchards and native or non-native trees grown for harvest
Young monoculture plantation	YMP	young singular species of plantation (age dependent on harvest time)
Old monoculture plantation	OMP	old singular species of plantation (age dependent on harvest time)
Young multi-species plantation	YMSP	young multi-species plantation (age dependent on harvest time)
Old multi-species plantation	OMSP	old multi-species plantation (age dependent on harvest time)
Young Regrowth*	YR	dense vegetation in age 0-10 with pioneer species and no canopies
Old Regrowth*	OR	dense vegetation in age 11-25 with some trees reaching maturity and providing minimal canopy coverage
Young Secondary Forest*	YSF	vegetation in age 26-40 with most trees providing mostly closed canopies; some large diameter trees; no pioneer species found
Old Secondary Forest*	OSF	vegetation in age > 40 with fully closed canopies; most trees large in diameter and tall; no pioneer species found
Wetland	W	areas that along rivers or stream corridors, or near large lakes
Wetland-mixed-forest*	WMF	areas along rivers or stream corridors, areas near large lakes, and some forested vegetation usually along the stream corridors
Urban	UR	cities, roads, houses, other human infrastructure
Urban-mixed-agriculture*	UMA	cities, roads, houses, other human infrastructure, and some agricultural lands such as crop and pasture

Table 3-2: Image information for training layers used in the 2009 LULC classification. (*) Denotes the layers used for the final classification.

Layer	Acronym	Name	Description/Algorithm
1	B1	SPOT Band 1	Green (0.50 - 0.59 µm)
2	B2	SPOT Band 2	Red (0.61 - 0.68 µm)
3	B3	SPOT Band 3	Near Infrared (0.79 - 0.89 µm)
4*	PCA 1	Principle Component Analysis	(SPOT Bands 1-3) axis 1
5*	PCA 2	Principle Component Analysis	(SPOT Bands 1-3) axis 2
6*	N/A	Elevation	Elevation
7*	N/A	Slope	Slope
8*	TRASP	Transformed Aspect of the Slope	Transformed Aspect of the Slope (Sesnie et al. 2008)
9*	TWI	Terrain Wetness Index	Terrain Wetness Index (Sesnie et al. 2008)
10*	NDVI	Normalized Difference Vegetation Index	(B3 – B2)/(B3 + B2)
11	DVI	Difference Vegetation Index	B3-B2
12	GRVI	Green-Red Vegetation Index	B1/B2
13	IPVI	Infrared Percentage Vegetation Index	B3/(B3 + B2)
14	NDWIF	Normalized Difference Water Index of McFeeters	(B1-B3)/(B1+B3)
15	NIR-G	Near Infrared over Green	B3/B1
16	OSAVI	Optimized Soil Adjusted Vegetation Index	(B3-B2)/(B3+B2+0.16)
17*	SAVI	Soil Adjusted Vegetation Index	1.5*(B3-B2)/(B3+B2+0.5)
18	SR	Simple Ratio	B2/B3
19	VI	Vegetation Index	B3/B2

Table 3-3: A list of land use types and the number of training points and polygons created for each type.

Land Use Type	Field Points	Manual Points	Final training Points	Final Polygons Created
Cloud	N/A	87	N/A	N/A
Shadow	N/A	66	N/A	N/A
Water	N/A	42	N/A	N/A
Wetland-mixed-forest	N/A	N/A	N/A	75
Urban-mixed-agriculture	N/A	54	N/A	32
Crop	163	144	123	70
Pasture	219	197	119	82
Plantation	153	180	139	91
Young Regrowth	119	82	57	78
Old Regrowth	148	73	20	66
Young Secondary Forest	109	63	7	64
Old Secondary Forest	103	99	88	51

Table 3-4: Classification accuracies based on an error matrix (Table 3-5) output from a cross-validation assessment in Rule Gen.

Class	Producer's accuracy (%)	User's accuracy (%)	Overall accuracy (%)	Conditional K_{hat}	Z-score	Kappa
Urban-mixed-agriculture	87.02	90.57		0.90		
Crop	95.63	95.52		0.95		
Pasture	90.28	87.99		0.87		
Plantation	87.47	88.28		0.87		
Young regrowth	83.09	82.95		0.81		
Old regrowth	80.63	79.45		0.78		
Young secondary forest	78.16	84.08		0.82		
Old secondary forest	93.10	89.63		0.87		
Wetland-mixed-forest	76.16	76.34		0.75		
			87.68		**426.93**	**0.86**

Table 3-5: Final land use classification error matrix derived from Rule Gen's cross validation output. Columns and rows represent reference data and classified data, respectively. Highlighted numbers represent the total number of correctly classified samples.

LULC class	Crop	Old Regrowth	Old Secondary Forest	Pasture	Plantation	Urban-mixed-agriculture	Wetland-mixed-forest	Young Regrowth	Young Secondary Forest	Row total
Crop	5846	0	2	99	47	94	5	25	2	6120
Old Regrowth	3	2289	94	4	88	0	84	224	95	2881
Old Secondary Forest	3	73	6084	0	72	0	32	23	501	6788
Pasture	125	2	0	3305	11	229	13	71	0	3756
Plantation	37	70	53	9	2982	3	87	82	55	3378
Urban-mixed-agriculture	61	0	0	169	3	2448	16	6	0	2703
Wetland-mixed-forest	6	91	31	1	62	23	1294	111	76	1695
Young Regrowth	31	216	18	74	76	16	108	2972	72	3583
Young Secondary Forest	1	98	253	0	68	0	60	63	2867	3410
Column Total	6113	2839	6535	3661	3409	2813	1699	3577	3668	34314

Table 3-6: Area and percent area of each classified vegetation type in the 2009 LULC classification.

Vegetation type	**Area (km ^{2})**	**Percent area (%)**
Urban-mixed-agriculture	188.1	6.10486
Crop	273.1	8.86421
Pasture	603.9	19.601
Plantation	285.8	9.27755
Young regrowth	712.0	23.1094
Old regrowth	336.5	10.9227
Young secondary forest	231.8	7.52228
Old secondary forest	190.4	6.18039
Wetland-mixed-forest	259.4	8.41767
TOTAL	3081.0	100

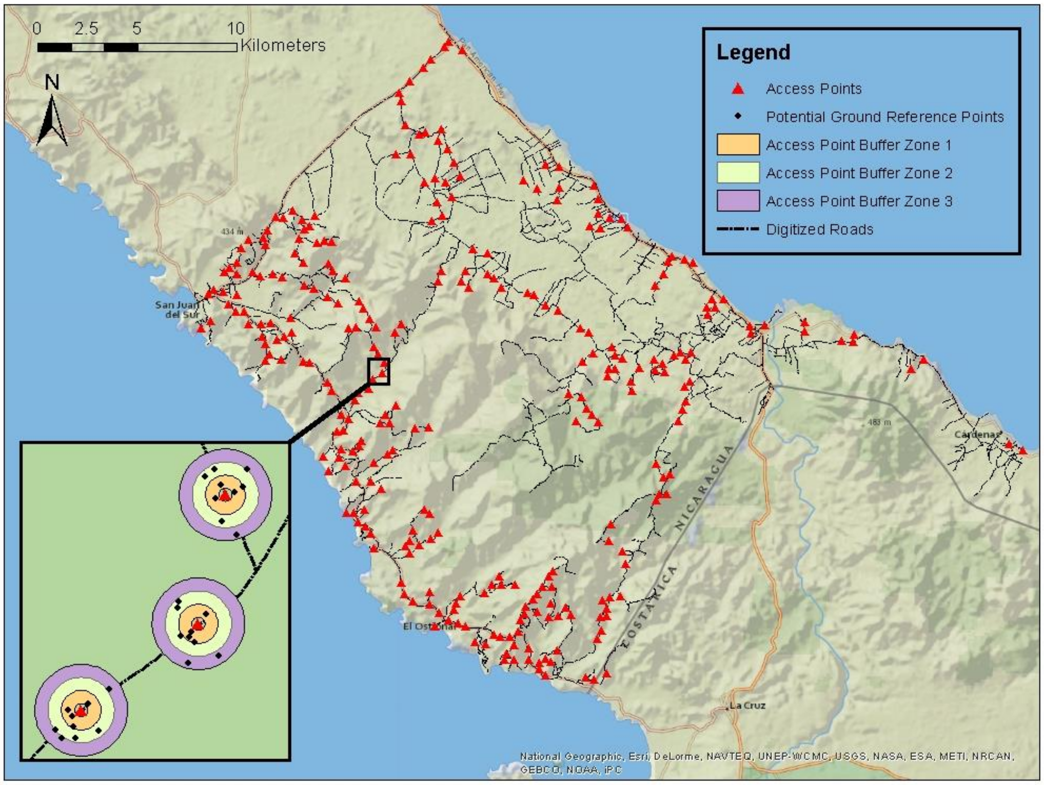
Table 3-7: Distances for each change type based on the Ripley's K analyses.

From	**To**	**Ripley's K Distance (km)**
Crop	Pasture	7
	Plantation	8
	Regrowth	1.5
Forest	Crop	8
	Pasture	6
	Plantation	6
	Regrowth	5
Pasture	Crop	4
	Plantation	4.5
	Regrowth	5
Regrowth	Crop	3
	Forest	5
	Pasture	5
	Plantation	4

Figure 3-1: The study area and final ground referenced points in southwestern Nicaragua.

Figure 3-2: The Paso del Istmo corridor in southwestern Nicaragua.

Figure 3-3: Access points with access point buffers, potential ground reference points, and digitized roads.



National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC

Figure 3-4: Ground reference point field data sheet.

Ground-Reference Protocol

Crew Initials:	**Date:**______-______/2012	**Point ID:**_____	**UTM** : **E:** **N:**
Weather Conditions:		**Site Picture Numbers:**	

Est. GPS Error:

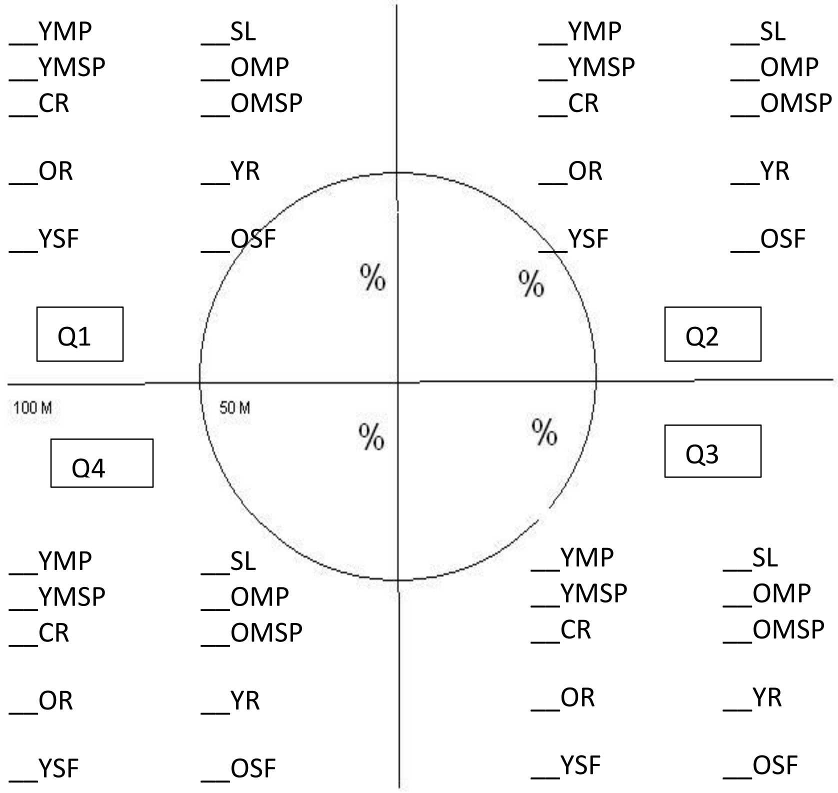
%Slope (Circle One):
Flat 0-10% 10-35% 35-45% 45-Vertical

Aspect (Circle One):
N NE E SE
S SW W NW

Elevation:

Additional Site Comments:

YMP and YMSP→YP
OMP and OMSP→OP
No SL from field
Add RE = reforested
Add UR = urban



Percent Coverage Ranges (for Plot Diagram Above)
0% <25% 25-50% 50-75% >75%

Mapping Protocol

Crew initials:__________ **Date:**___ _-_____/2012_	**Property Name/Owner:** **Land use history:**
UTM (Beginning Corner of Property Line) **E:** **N:** **Site Picture Numbers:**	

Property Type (Circle One):

Community YMP YMSP CR OR YSF W SL OMP OMSP YR OSF PA RE

Land Use Type (for Plot Diagram Above)**:**

- **YMP**- Young Monoculture Plantation
- **YMSP**- Young Multi Species Plantation
- **CR**- Crops
- **UR**-Urban
- **OR**- Old Regrowth
- **YSF**- Young secondary forest
- **W**- Riparian
- **SL-** Selective Logging
- **OMP**- Old Mono Culture Plantation
- **OMSP**- Old Multi Species Plantation
- **YR**- Young Regrowth (Abandoned Pasture, Crops, or Plantation)
- **OSF**- Old Secondary Forest
- **PA**- Pasture
- **RE**- Reforested

Figure 3-5: The 2000 land use classification used in the change detection analysis (Source: Sesnie et al. 2008).

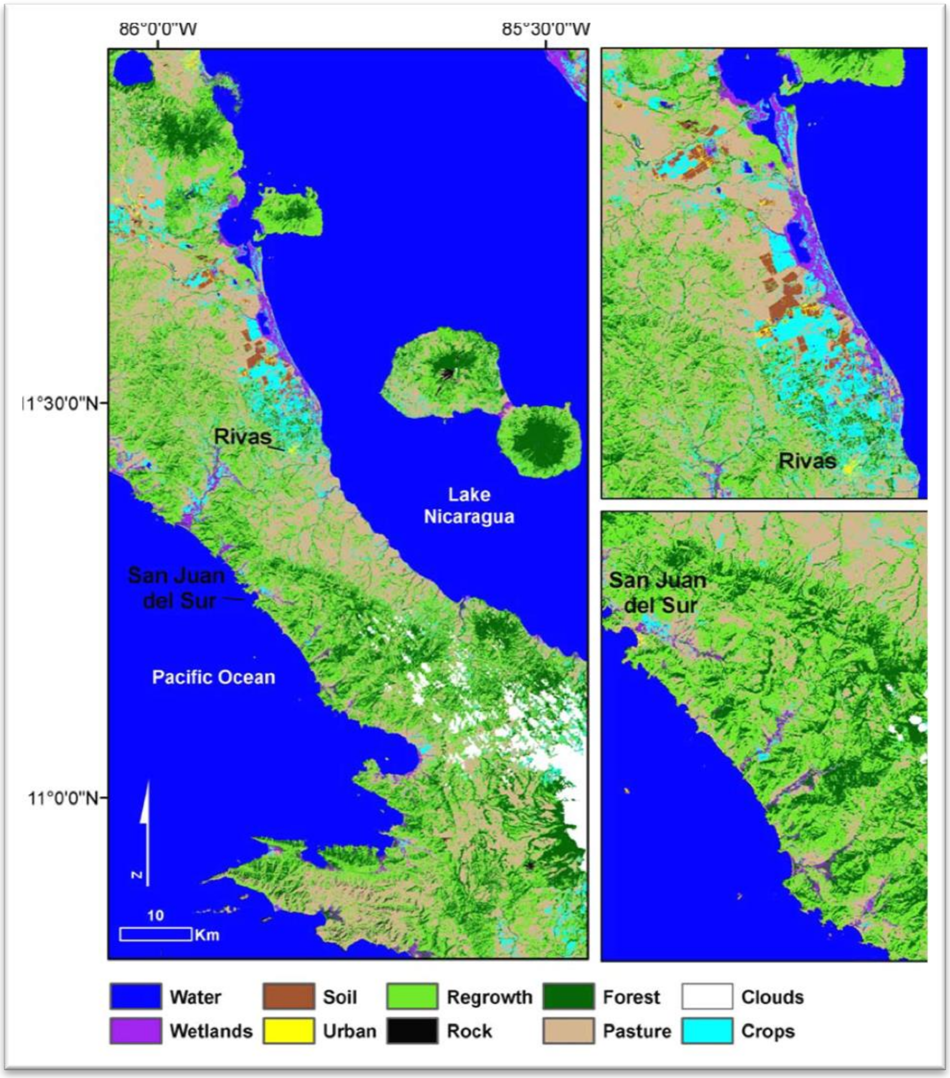


Figure 3-6: The modified LULC classifications 2000 (left) and 2009 (right) used in the change detection analysis.

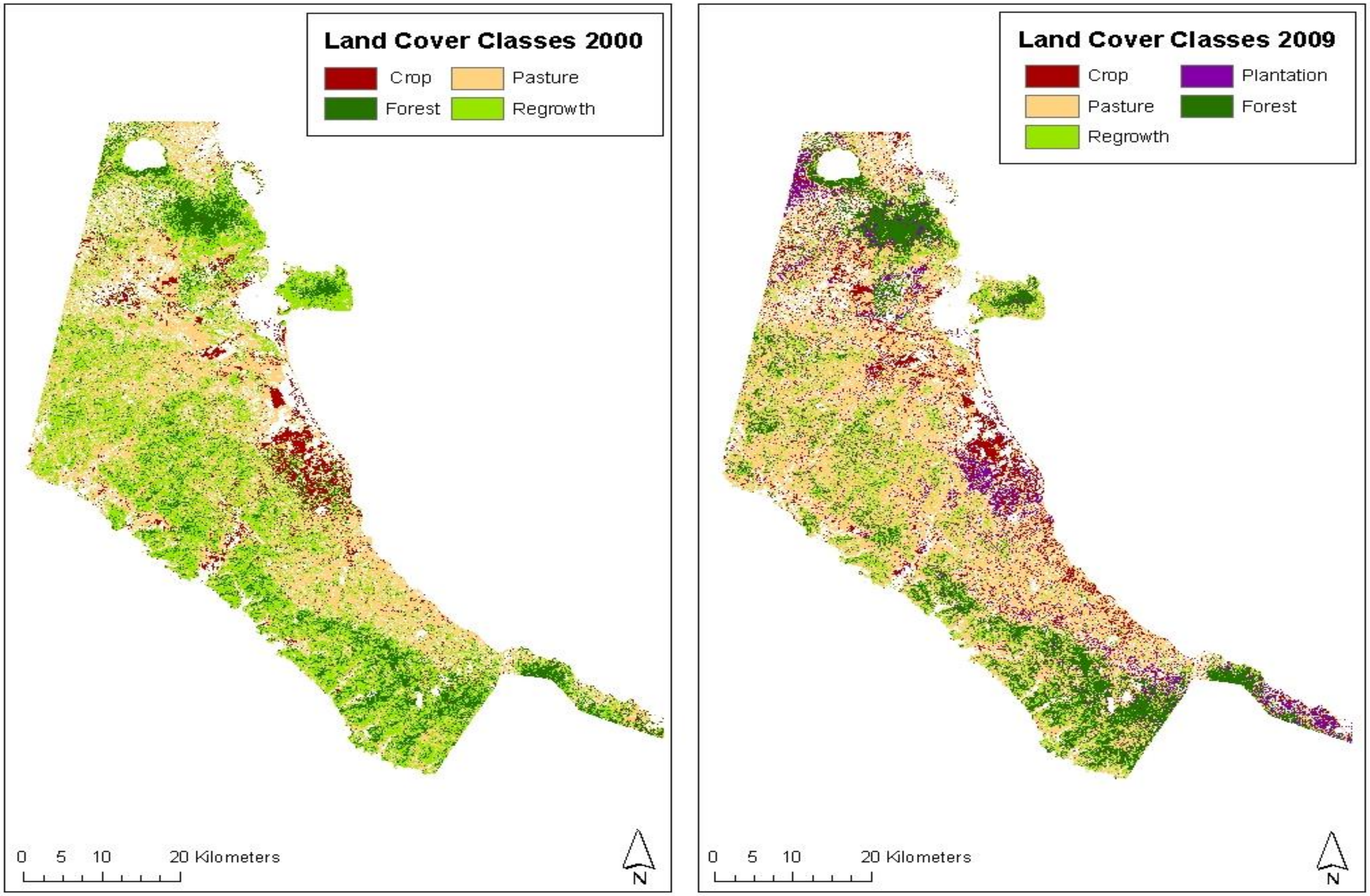
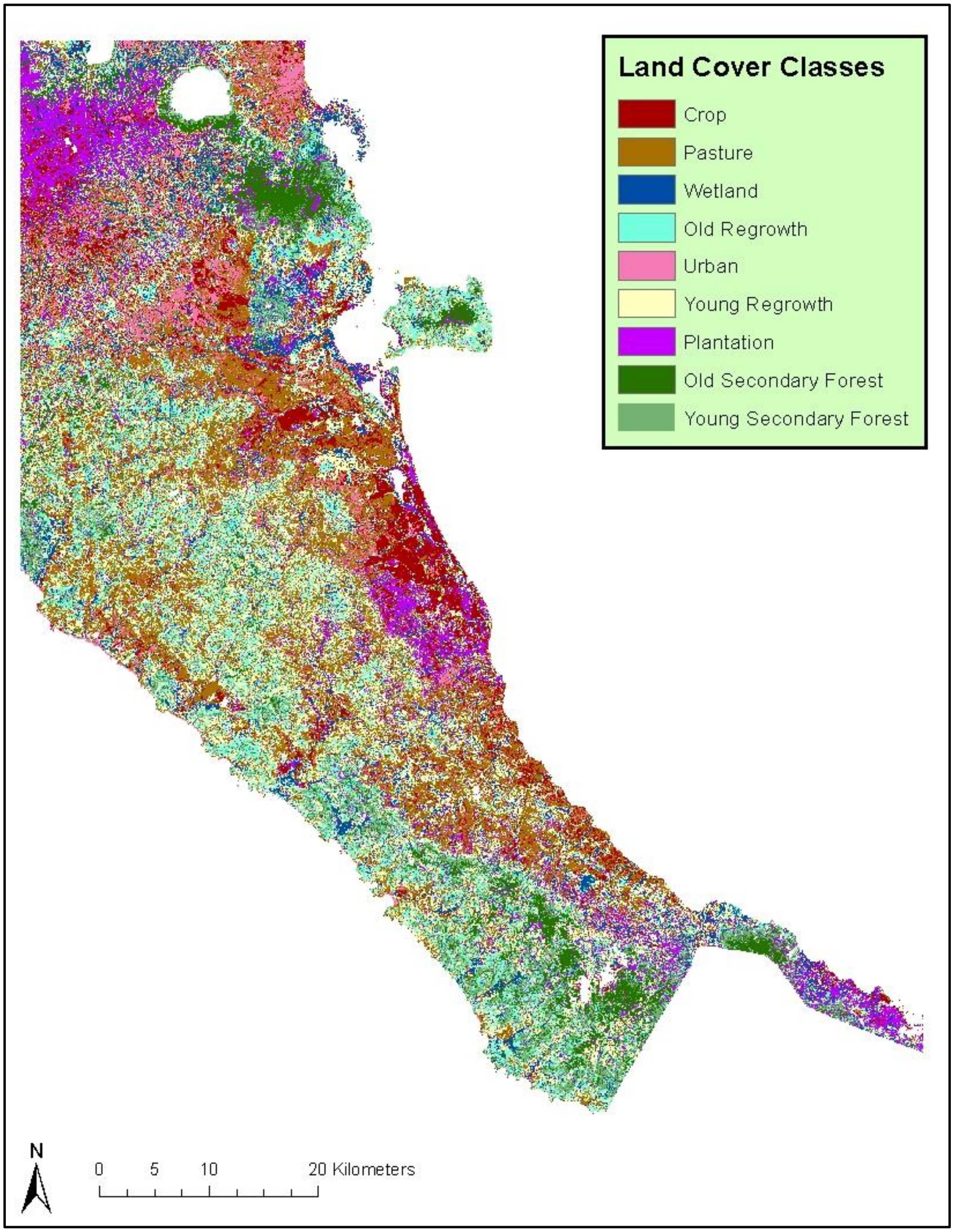


Figure 3-7 (a-c): Final 2009 land use classification for SW Nicaragua (a), northern zoom (b), and southern zoom (c).



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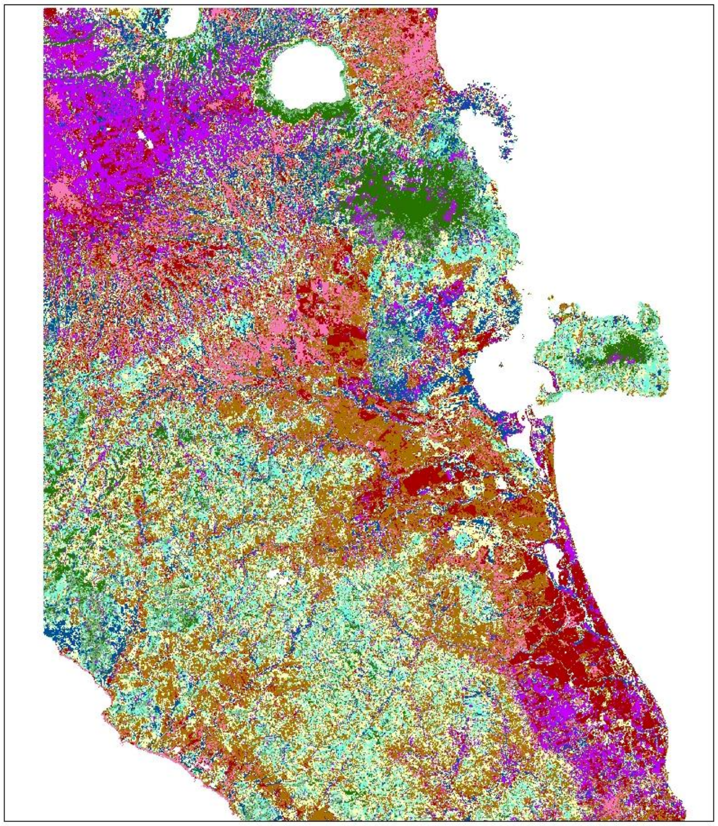

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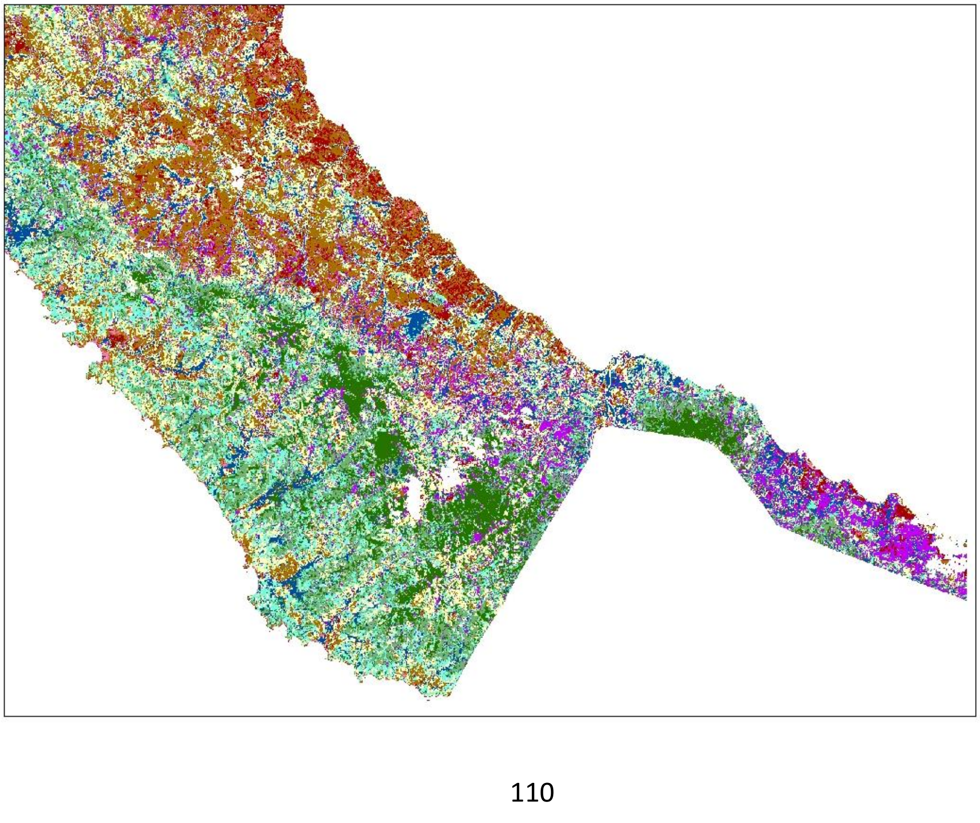
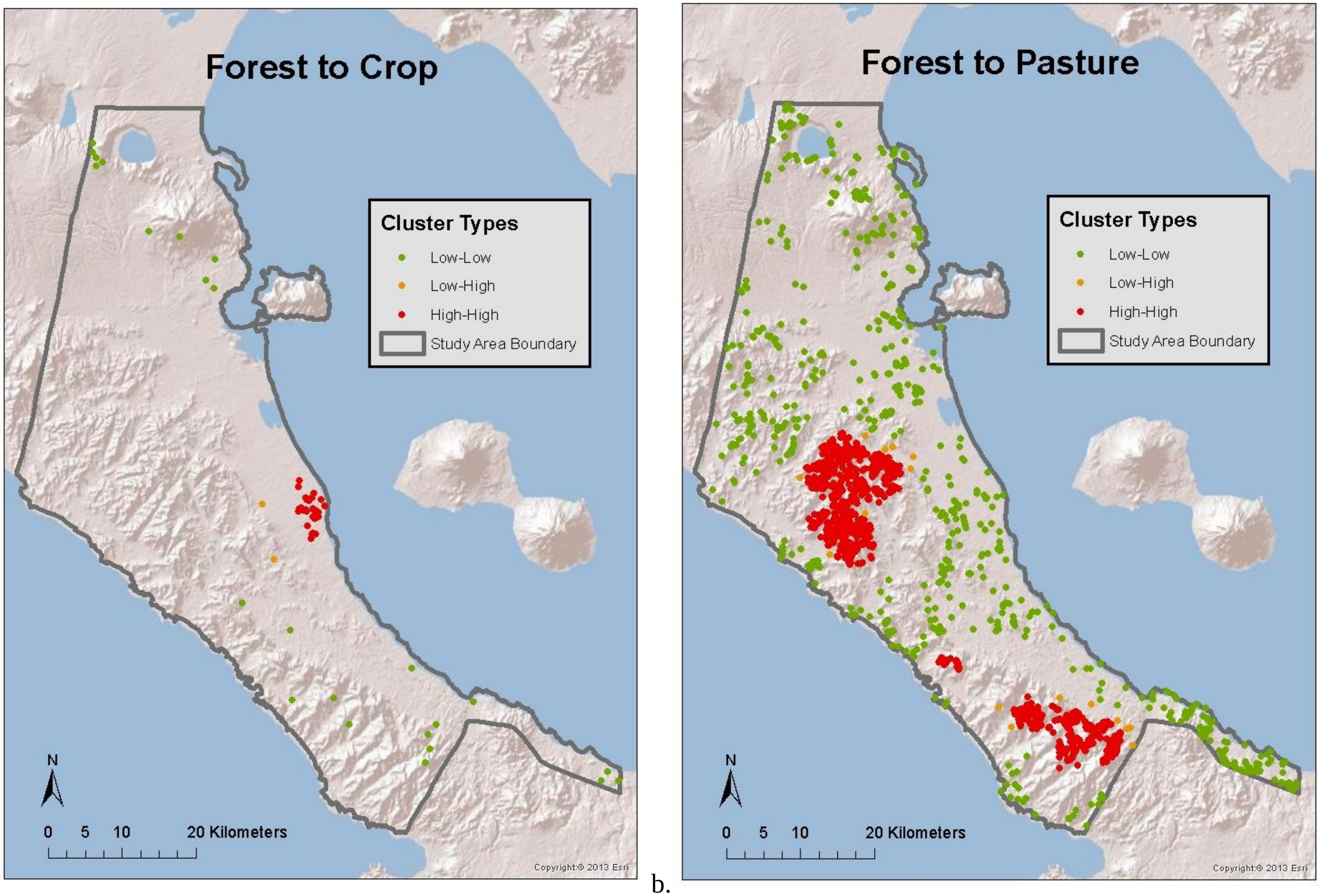


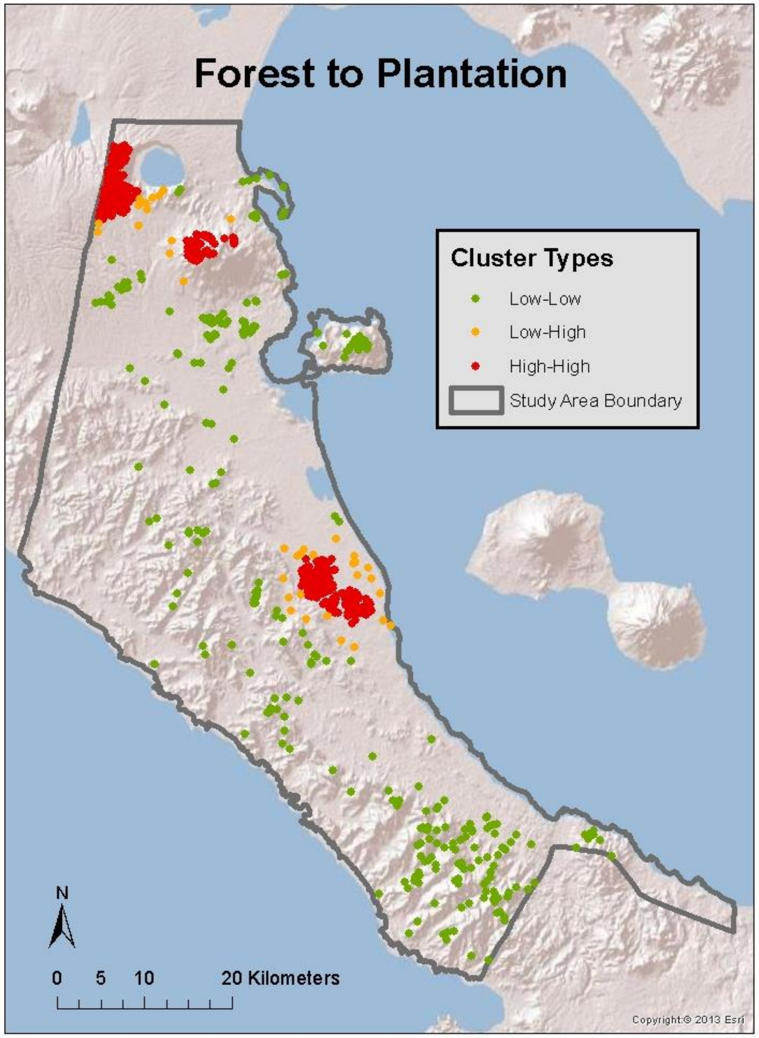
c.

Figure 3-8 (a-d): Graphs representing percent of land use change for each class between 2000 and 2009 in southwestern Nicaragua. Crop (A), Pasture (B), Regrowth (C), and Forest (D).

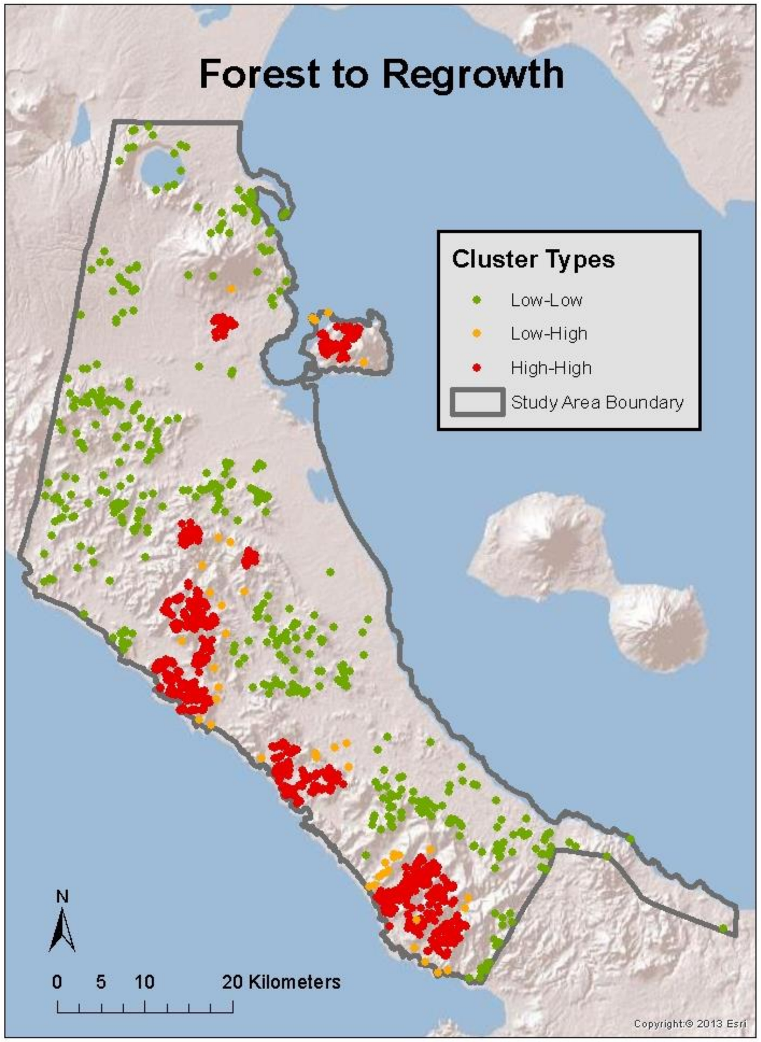
Figure 3-9 (a-d): Clustered analysis of change from forest to crop (a), pasture (b), plantation (c), and regrowth (d).



a. b.

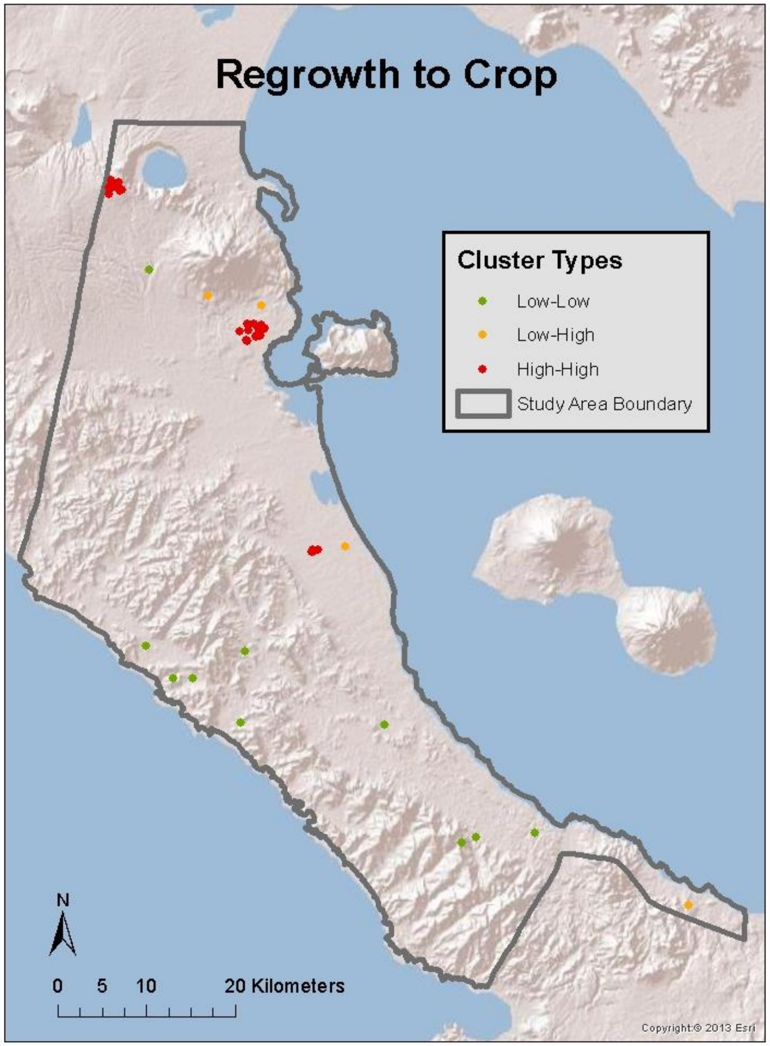

Forest to Plantation
Cluster Types
● Low-Low
● Low-High
● High-High
Study Area Boundary
N
0 5 10 20 Kilometers
Copyright:© 2013 Esri

c.

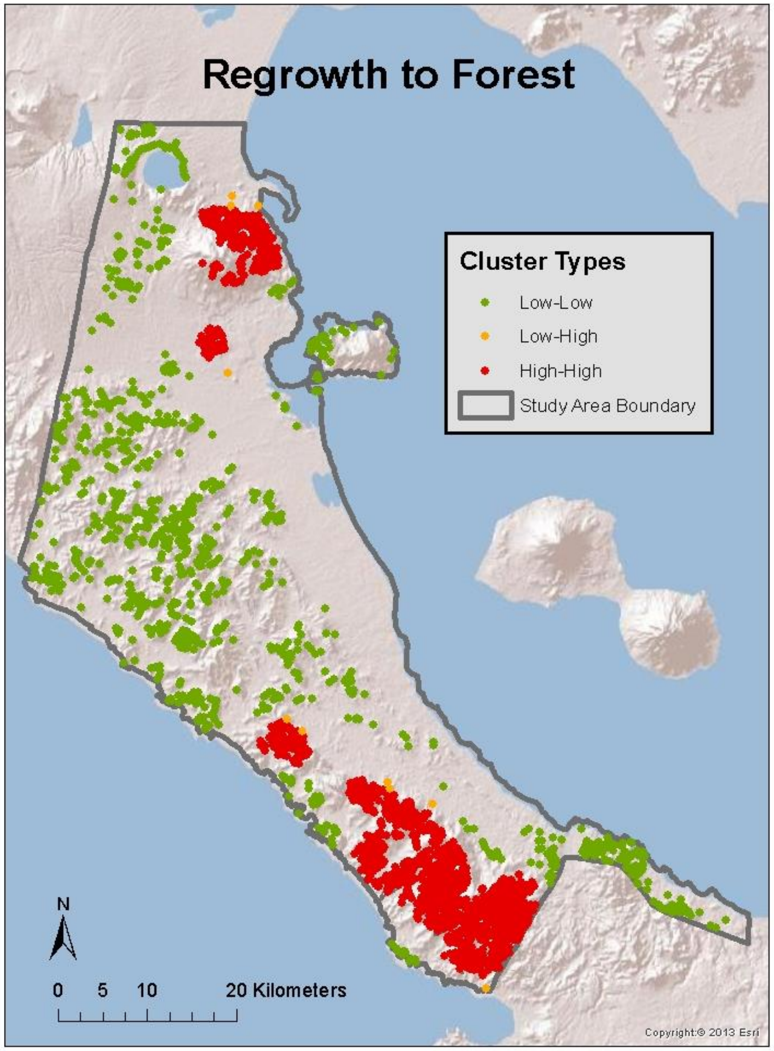

Forest to Regrowth
Cluster Types
● Low-Low
● Low-High
● High-High
Study Area Boundary
N
0 5 10 20 Kilometers
Copyright:© 2013 Esri

d.

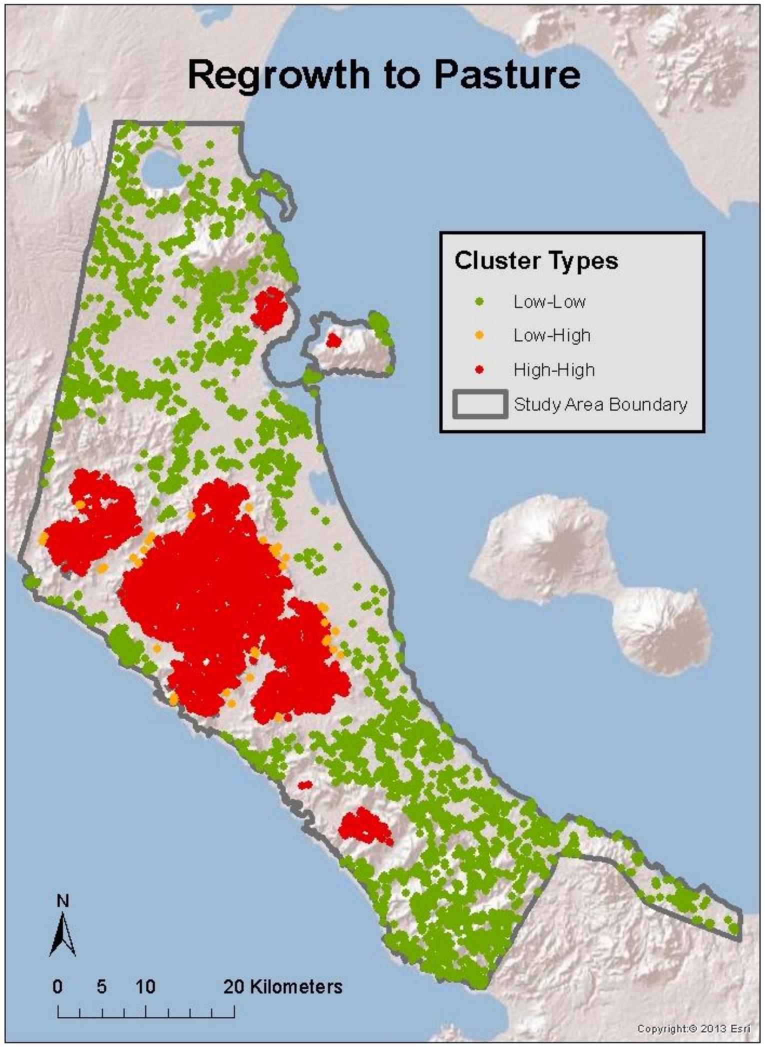
Figure 3-10 (a-d): Clustered analysis of change from regrowth to crop (a), forest (b), pasture (c), and plantation (d).



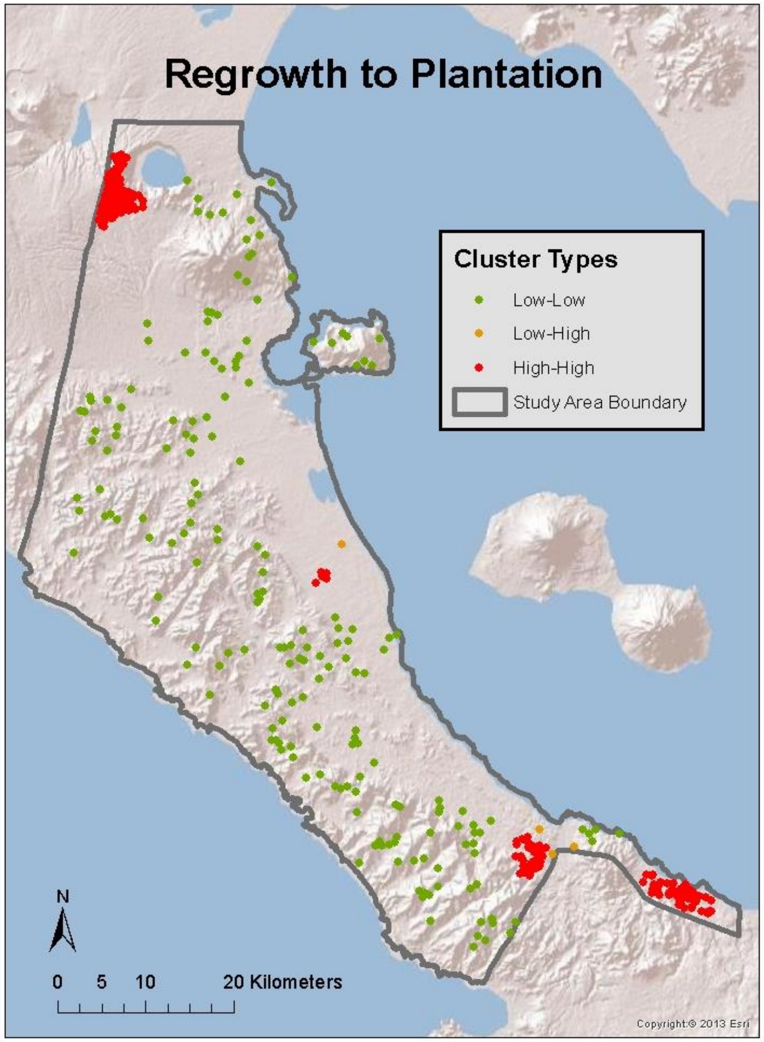
a.



b.

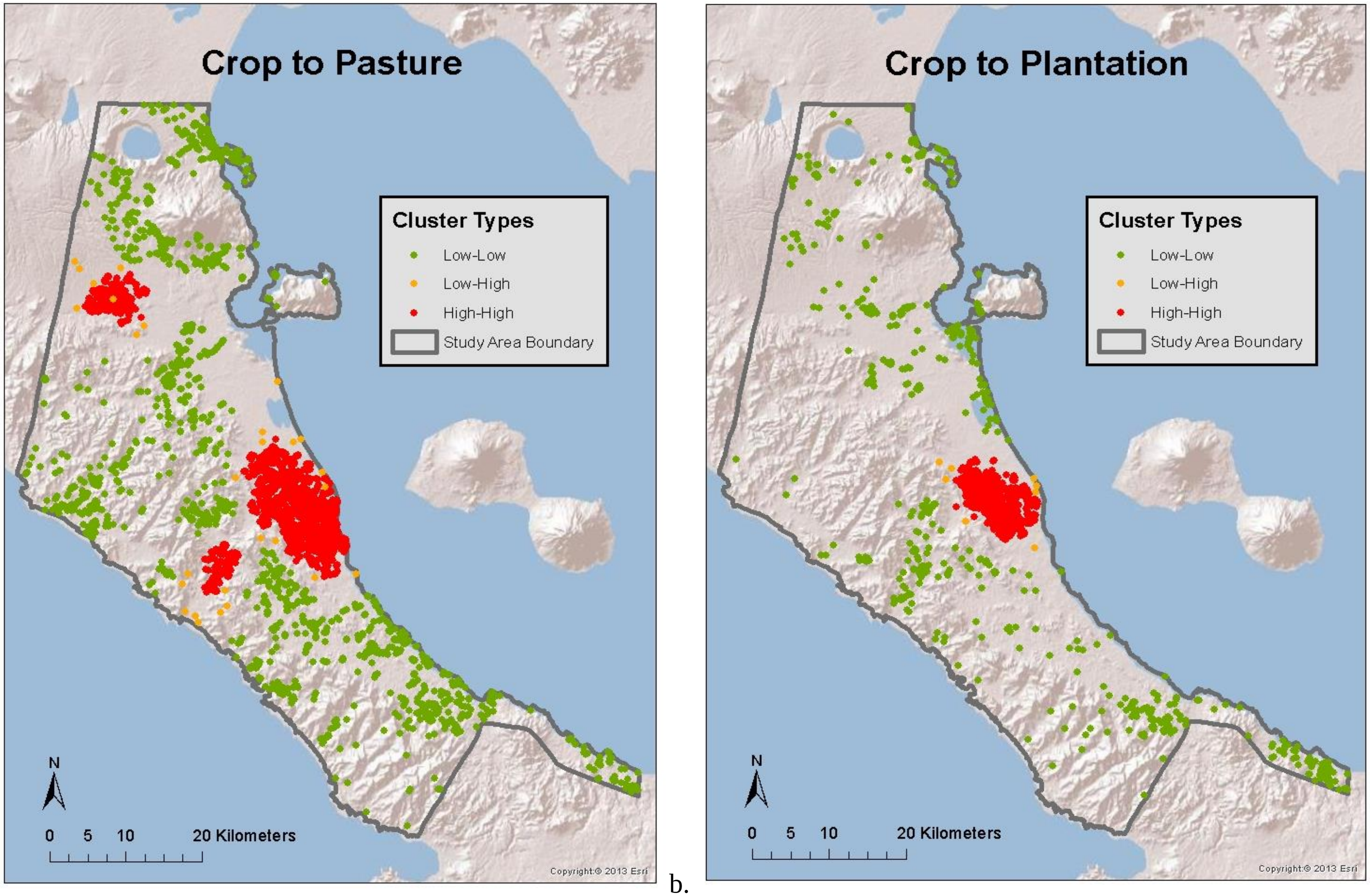

Regrowth to Pasture
Cluster Types
● Low-Low
● Low-High
● High-High
Study Area Boundary
N
0 5 10 20 Kilometers
Copyright:© 2013 Esri

c.


Regrowth to Plantation
Cluster Types
● Low-Low
● Low-High
● High-High
Study Area Boundary
N
0 5 10 20 Kilometers
Copyright:© 2013 Esri

d.

Figure 3-11 (a-c): Clustered analysis of change from crop to pasture (a), plantation (b), and regrowth (c).



a.

b.

c.

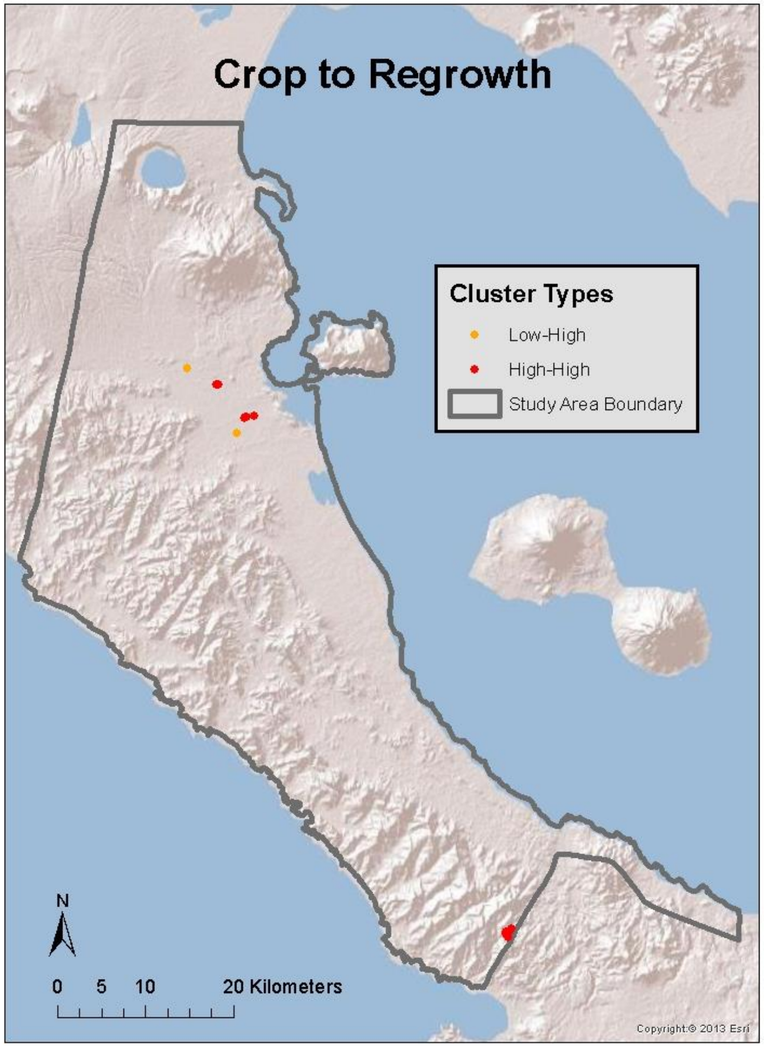
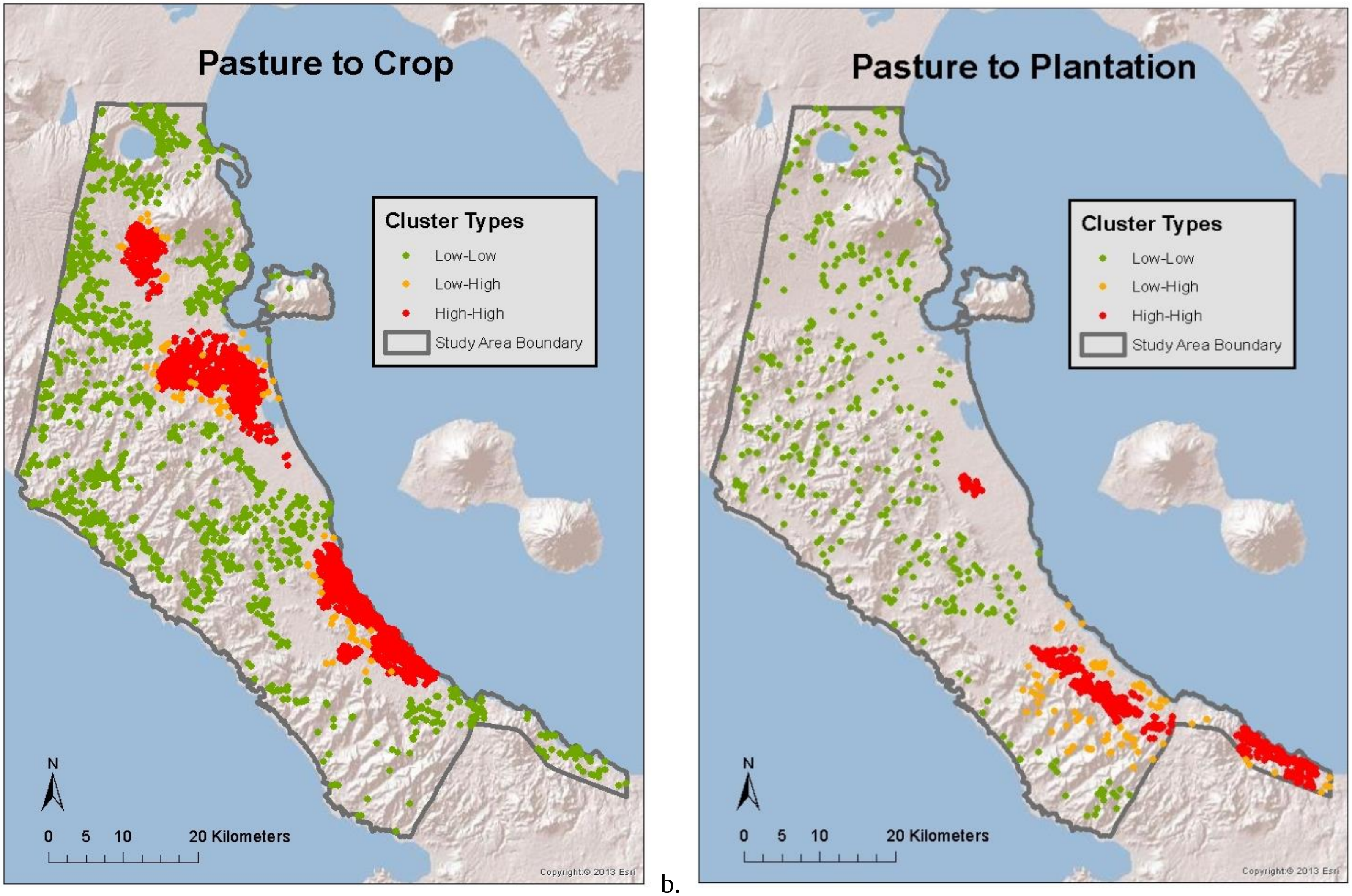
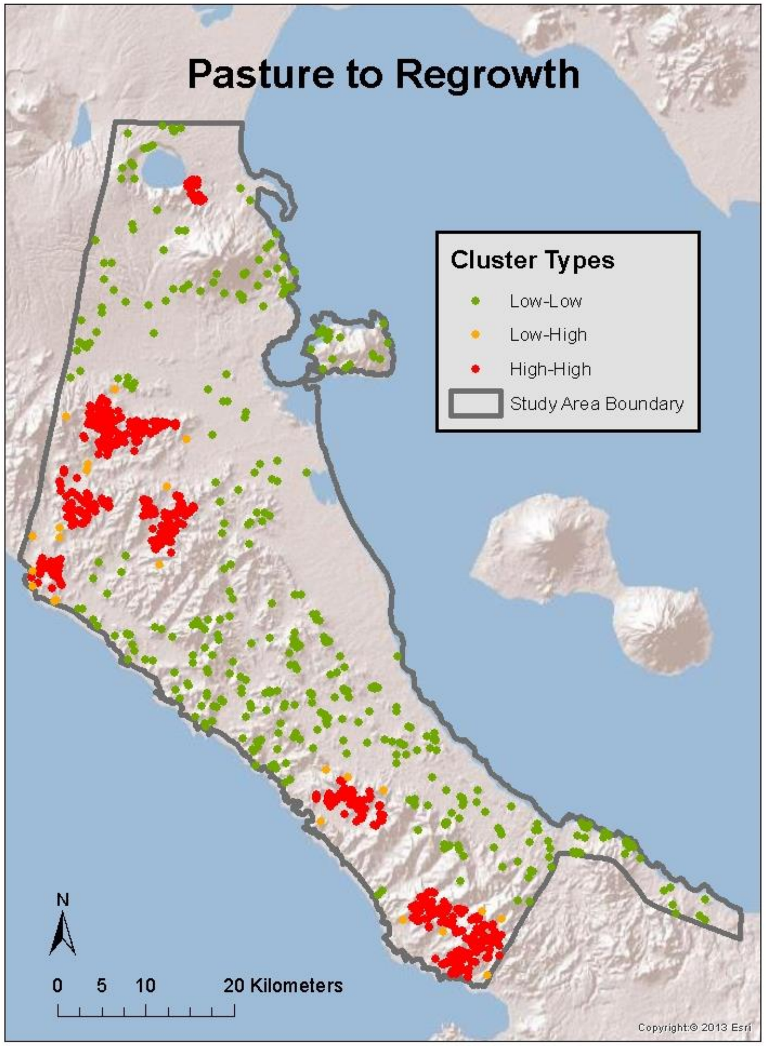

Crop to Regrowth
Cluster Types
● Low-High
● High-High
Study Area Boundary
N
0 5 10 20 Kilometers
Copyright:© 2013 Esri

Figure 3-12 (a-c): Clustered analysis of change from pasture to crop (a), plantation (b), and regrowth (c).



a. b.


Pasture to Regrowth
Cluster Types
Low-Low
Low-High
High-High
Study Area Boundary
N
0
5
10
20 Kilometers
Copyright:© 2013 Esri

c.

Chapter 4: Overall thesis conclusions and management recommendations

Effective linkage of conservation planning to on-the-ground implementation can be an arduous task, especially for small NGOs working in under-resourced tropical countries. But by combining a literature review of systematic conservation planning in the tropics (Chapter 2) with an analysis of land use and land cover change (Chapter 3), we were able to develop a working partnership with a local NGO in southwestern Nicaragua (Paso Pacífico) that provided real-world grounding to evolving conservation science.

Studying systematic conservation planning projects carried out in tropical developing countries and identifying tactics employed to overcome persistent limitations in data and human resources was an important step. From this review, we identified key ways to carry out SCP in the tropics and provided general recommendations regarding ways to overcome limitations that are typically faced by small conservation organizations attempting to carry out SCP.

Our collaboration with Paso Pacífico identified their overarching need for an LULC change analysis. By aligning our goals and expertise with the needs identified in the field, we were able to produce valuable data products and recommendations, targeting the needs of Paso Pacífico. The resulting data products can be used as key data inputs in a systematic conservation planning assessment (Moilanen, 2012; Knight et al., 2006a, b; Margules and Pressey, 2000) and are often difficult to acquire because they require heavy computational resources, local knowledge, and technical expertise (Knight et al., 2006a).

Drawing on these two distinct efforts, we were able to identify areas of high vulnerability (i.e., hotspots and cold spots of change) and high conservation value to develop preliminary recommendations for conservation actions. For example, conversion of secondary forest – the highest quality forest habitat in the study region – to pasture or commercial plantations is occurring across the Rivas Isthmus in southwestern Nicaragua. On the other hand, areas where regrowth is reverting to early successional forest are common in areas where secondary forests predominate. Understanding these specific changes go a long way toward identifying conservation and restoration priorities.

Findings from the two core chapters of this thesis provide complementary insights into how conservation organizations might meet the challenges when working in the developing tropics. First, our collaboration with Paso Pacífico exemplified the beneficial relationship between a small conservation organization and an analytical partner, a need that was evident in our literature review. As seen in chapter 2, these partnerships are advantageous for improving the quality of planning efforts, and providing continuity between analysis and implementation. We also noted that more ad hoc planning efforts that directly accessed and leveraged local knowledge and conditions were being pursued by Paso Pacífico. However, we also observed their desire for an increase in use of science-based decision making, revealed through the request of a LULC classification and change detection products to be used for future conservation planning efforts. In conclusion, we believe that a SCP assessment can and should be carried out in this region in order to guide efficient use of limited conservation resources. The beginnings of such an effort, based on the results of our two core chapters, are, we hope, the first steps in carrying out such an SCP assessment in southwestern Nicaragua.

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