IMPROVING BIODIVERSITY CONSERVATION IN THREATENED LANDSCAPES OF CENTRAL VIETNAM



Center for Biodiversity and Conservation
American Museum of Natural History
Central Park West at 79th Street
New York, NY 10024



Project Summary Report (March 2003 – September 2006)

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AMERICAN MUSEUM OF NATURAL HISTORY

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Background:

In March 2003, the American Museum of Natural History (AMNH) received a three-year grant from The John D. and Catherine T. MacArthur Foundation for a project of the Museum's Center for Biodiversity and Conservation (CBC) and the Museum's Library to improve biodiversity conservation planning in threatened landscapes of the Central Truong Son (CTS) Mountain Range of Vietnam. This area – also known as the Greater Annamites – is located along the border of Laos and Vietnam, and harbors extraordinarily diverse flora and fauna as well as high levels of endemism of both global and regional significance. The CTS retains significant forest cover, though these forests are increasingly threatened by new settlements, road construction, and government infrastructure development, among other factors. Despite existing threats, the CTS has great potential for conservation and, with effective landscape planning and management, could serve as a model for other regions.

Project Objectives:

The overarching project goal is to conserve the unique biodiversity of Vietnam's Central Truong Son by facilitating the availability of quality science for making conservation decisions.

The Museum's CBC and Library proposed four main strategies to achieve this:

1. Generate effective visual tools that aid conservation planning and decision-making;

2. Build capacity for government and protected-area staff members to use Remote Sensing and Geographic Information System (RS/GIS) tools for conservation planning and monitoring;

3. Increase access to data needed by managers, planners, community members, and decision makers on the ground to make effective conservation decisions; and

4. Promote dialogue and enhance coordination among regional stakeholders to promote integrated landscape planning.

Project Achievements:

A. Generating Visual Tools for Conservation Planning and Decision-making

Over the course of the last three years, we have created visual tools to guide and enhance conservation management initiatives in the region. These tools include a series of current and historical land cover maps that aid forest managers and conservation practitioners to understand the history of this landscape and how it has reached its current form. These maps are being utilized by Provincial Forest Protection Department (FPD) and the WWF to select field sites, assess habitat, and evaluate protected area coverage.

Staff members of the CBC's Remote Sensing (RS) and Geographic Information System (GIS) lab acquired and processed a range of data for a study area that included Thua Thien-Hue and Quang Nam Provinces, as well as Da Nang city (Figure 1) to examine land cover change. We acquired over 1,000 satellite images and aerial photographs (Table 1) from dates between 1952 and 2003, elevation and climate data, and several GIS layers, including national, provincial, district, and commune level political boundaries, and protected areas. For example, to obtain data for the earlier time periods, CBC lab staff members scanned photographic imagery from the CORONA satellite program of the U.S. military, which provided the world's first detailed satellite-based imagery of the Earth's surface. These images were highly classified and existed principally to monitor US military interests. However, the program was declassified in 1996, and it is now widely recognized that the imagery obtained from the CORONA missions, over 800,000 photographs collected from 1958 until 1972, has many uses beyond military surveillance. In combination with more recent data (Landsat satellite data from 1975, 1989, and 2003), these early images enable us to study how Vietnam's landscape has changed over time. In addition, over 900 aerial photographs from the 1950s were obtained from the Institut Géographique National in France, scanned and geo-referenced so they could be included in the analyses.

Table 1: Breakdown of all image data obtained and distributed for project study area.

Sensor	Number of images	Date Range
Landsat ETM+	13	2001 - 2003
Landsat TM	9	1985 - 1998
Landsat MSS	8	1973 - 1975
ASTER	16	2000 - 2003
CORONA	37	1967 - 1969
Aerial Photo	940	1952 - 1954

Figure 1: Study area used in the land cover change analysis (includes the Central Vietnamese provinces of Thua Thien-Hue, Quang Nam, and Da Nang. Point locations for GPS photos obtained over three field visits are noted as yellow dots.

CBC staff members also derived a digital elevation model for the central highlands to assist in determining land cover classes (such as different forest types). The elevation layer is based on the Shuttle Radar Topography Mission (SRTM) data derived from a NASA space shuttle mission. The data obtained from NASA was incomplete for this area, and interpolation methods were used to fill in missing data. Elevation data is central to conservation planning as species distributions and ranges, both plant and animal, are often related directly to elevation, slope, and aspect. Finally, climatic information, including monthly total precipitation, and monthly mean, minimum, and maximum temperature data, were obtained from Worldclim to analyze the links between climate and landscape.

During the project, CBC staff members completed a current land cover map for Thua Thien-Hue and Quang Nam Provinces. The map (Figure 2), based on Landsat satellite data from April 2003, shows the following land cover classes: forest; intermediate; tree plantations; non-forest; and water. These classes were chosen in consultation with our partners at the provincial Forest Protection Departments (FPD), and the Greater Mekong

Programme of the World Wide Fund for Nature (WWF) in Vietnam, in order to select categories useful to their work, and considering the capabilities and limitations of the imagery. We determined that these were the optimum classes that we could reasonably determine based on the moderate resolution of the Landsat imagery. The classes can be defined as:

Forest – Area covered by native tree species. These areas vary in age, density, and degradation, but these subtleties are not reasonably visible within the imagery.

Intermediate – Area covered by shrub, fallow swidden agricultural fields (areas left fallow and/or periodically cleared for crops usually by cutting and burning), or low-lying vegetation.

Tree Plantations – Area covered by monoculture planted commercial tree species, such as pine or eucalyptus.

Non-forest – Area covered by active agriculture, developed, urban or barren land.

Water – Area covered by fresh, brackish, or marine water.

Both printed and digital versions of this draft land cover map were distributed to key government agencies, universities, and non-governmental organizations in the Central Truong Son region in April 2005. We conducted an accuracy assessment of the landcover map using 414 ground control points derived from the GPS photos taken at points displayed on Figure 1. The total map accuracy is calculated at 87.2 percent (Table 2). The accuracies presented in Table 2 are determined by comparing the land cover class identified during a field visit with the land cover class assigned in the map for each of the 414 locations.

Table 2: Contingency table to assess the statistical relationship between land cover classes for the 2003 land cover map.

		Land Cover 2003 Map Class						Producer's
		Forest	Intermediate	Plantation	Non Forest	Water	Total	Accuracy
Ground Ref.	Forest	**148**	4	2	7	0	161	**91.9%**
	Intermediate	19	**117**	0	6	0	142	**82.4%**
	Plantation	2	0	**6**	0	0	8	**75.0%**
	Non Forest	3	7	1	**82**	2	95	**86.3%**
	Water	0	0	0	0	**8**	8	**100.0%**
	Total	172	128	9	95	10	414	
	User's Accuracy	**86.0%**	**91.4%**	**66.7%**	**86.3%**	**80.0%**		**87.2%**

Note: Producer's accuracy, a reference-based accuracy, measures the percentage of correct predictions for a particular class. In other words, if a particular area is forest based on a ground survey, what is the probability that the digital map will correctly identify that pixel in the satellite image as forest? Consumer's accuracy, a map-based accuracy, is determined by looking at the reference data for a class and calculating the percentage of correct predictions for these samples. In other words, if one selects any forest pixel on the classified map, what is the probability that if you were to visit that pixel in the field it would be forest? These are traditional accuracies used to quantify the validity of a derived map in remote sensing applications. The percentages in this study are in the normal to higher range of expected accuracy given the number of classes assessed.

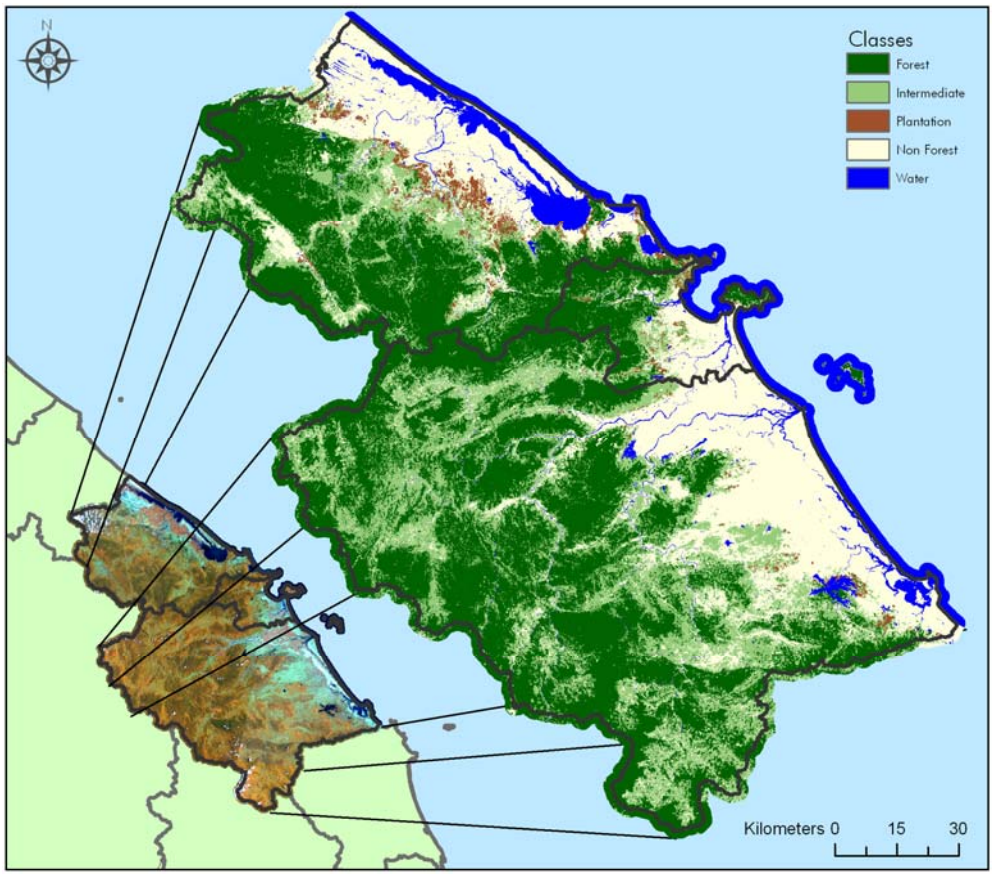


Figure 2: Land cover classification of 2003 Landsat imagery.

To understand the history of the Central Truong Son Mountain Range landscape we examined satellite images and aerial photos of Thua Thien-Hue and Quang Nam Provinces that provide snapshots in time, from 1954, 1969, 1975, 1990, and 2003. These time periods characterize recent decades that witnessed a continual rise in human population, increasing 51.6 percent between 1976 and 2002, and a concomitant increase in technology. Results of this analysis indicate that Vietnam's Central Truong Son is an extremely diverse landscape where human influence has been a part of the natural system for the five decades for which we have data. Archival research supports the idea that humans have been modifying this landscape for hundreds, if not thousands, of years.

We used a "head's up" digitizing approach to map change between the different images, creating separate land cover maps for each of the time periods. This technique involves visual interpretation of the images and digitizing change from the most recent (2003) land cover map to older imagery. The resulting maps (Figure 3) can be used to analyze both visually and quantitatively how the landscape has changed over time and provide a better understanding of the dynamics that can aid conservation management decisions and strategies.

Visual comparisons of the imagery and change-mapping results have indicated that "core" forest areas, primarily at high elevations and on steep slopes, have remained remarkably stable at a landscape scale since the 1950s. The average elevation and slope for forest areas within the study area are 17.4 degree slope and 680 meters, while non-forest areas average 8.5 degree slope and 225 meters elevation. Current sizeable contiguous forest areas, dispersed between the two provinces, appear very similar today to how they did decades ago. There are 16 contiguous forest patches with areas greater than 63 km^2. The largest of these patches covers the Song Thanh Nature Reserve through to Vietnam's western national boundary, and extends eastward along the proposed green corridor to Bach Ma National Park; totaling 3,732 km^2 (Figure 3). Several of these patches are presumably larger given that they extend beyond the boundaries of this study area. It is also notable that while change in land cover type can be seen throughout the images, much of this change has occurred in the intermediate class that has been heavily influenced by people for a long time, primarily in rotating active agricultural plots within areas where shifting cultivation is practiced, therefore, percentages of each class remain rather similar throughout the analysis, and, typically, forest loss in one area is counterbalanced by forest regrowth in another. This pattern of vegetation clearing and regrowth is visible at the temporal scale employed in this study, as there may be up to 15 years between the dates being analyzed. In addition to this pattern, the majority of active shifting cultivation fields (classified as "non forest") are rotating within the "intermediate" class, leaving minimal changes to the forest. Figures 4a and 4b display the percentages of each land cover class a) within the entire study area, and b) only for the area where 1954 aerial photographs are present. This distinction has been made to better present the results of the 1954 data, which cover only about a third of the study area (and was concentrated on forested areas) whereas the other dates cover the entire study area.

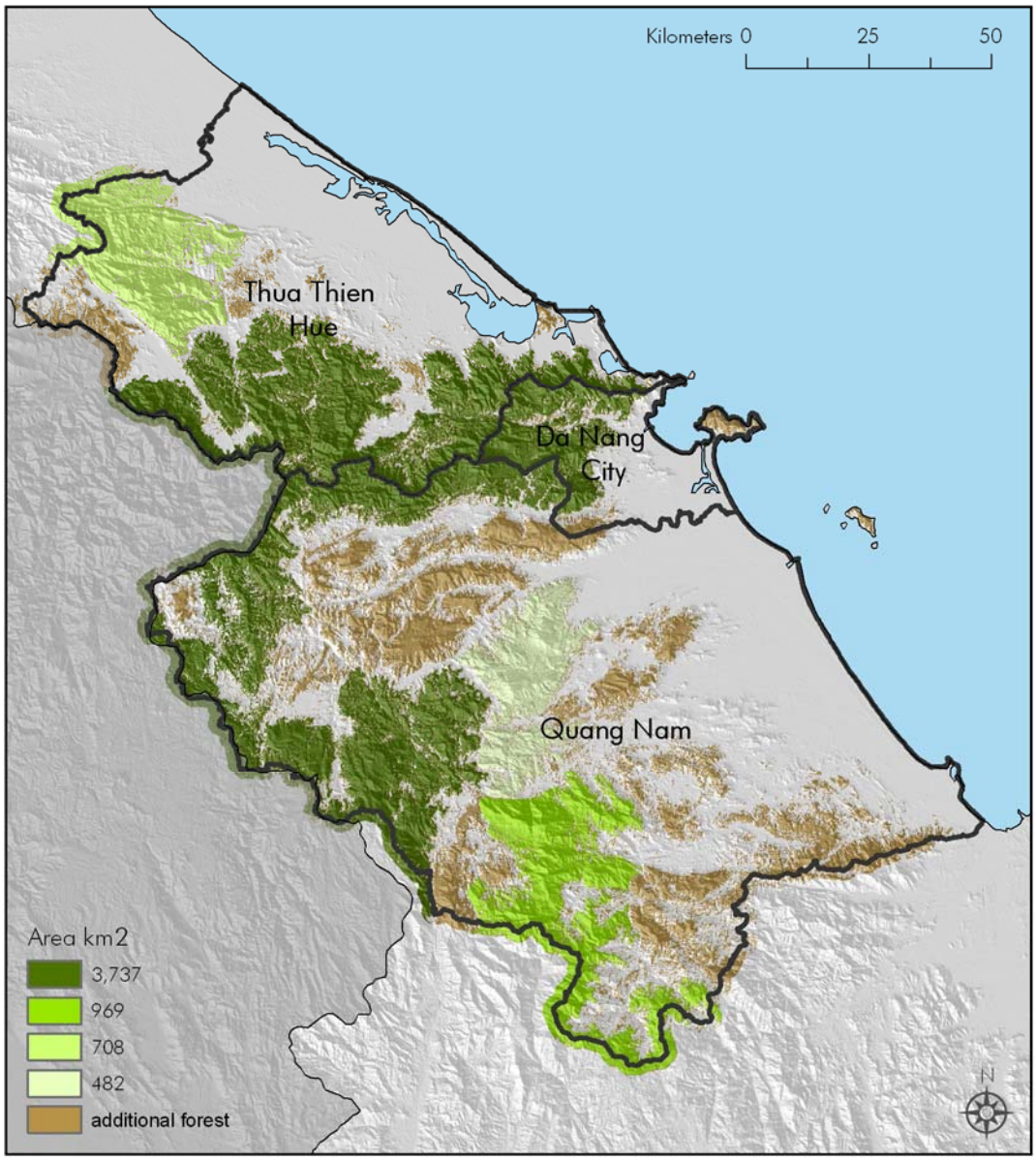


Figure 3: The four largest contiguous forest patches within the boundaries of the study area are displayed in shades of green with the largest patch in the darkest shade of green. Additional forest areas, not contiguous with the four largest ones, are displayed in brown.

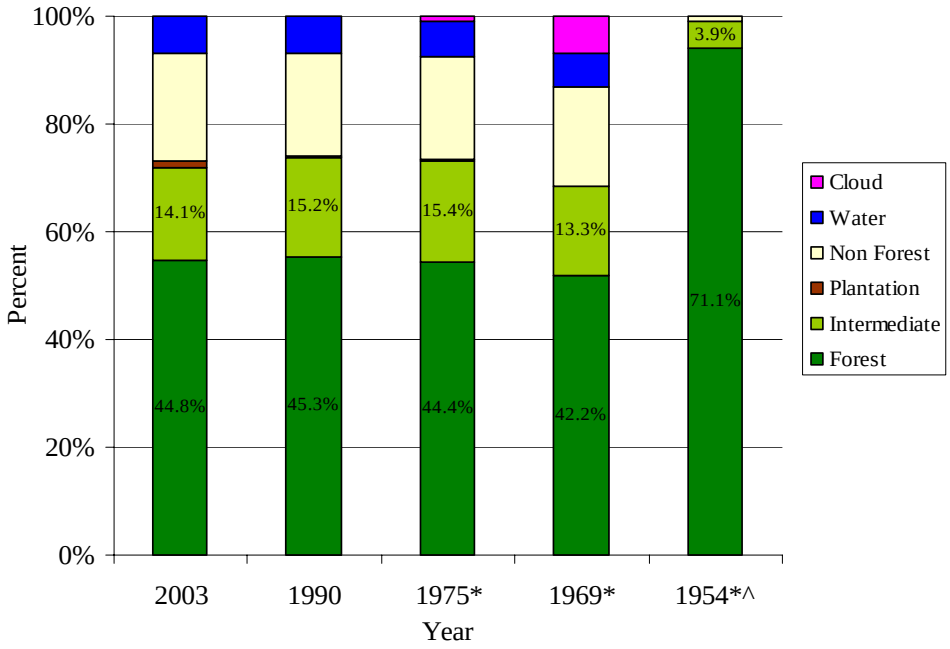


*Figure 4a: Percent of each land cover class per time period for the entire study area (18,383 km^2). Note: *Clouds present in classification (primarily over presumed forest land in high elevations). *^Aerial photos covered only a portion (~1/3) of the study area, primarily forested land; a comparison of land cover class percentages utilizing only this area is presented in Figure 4b below.*

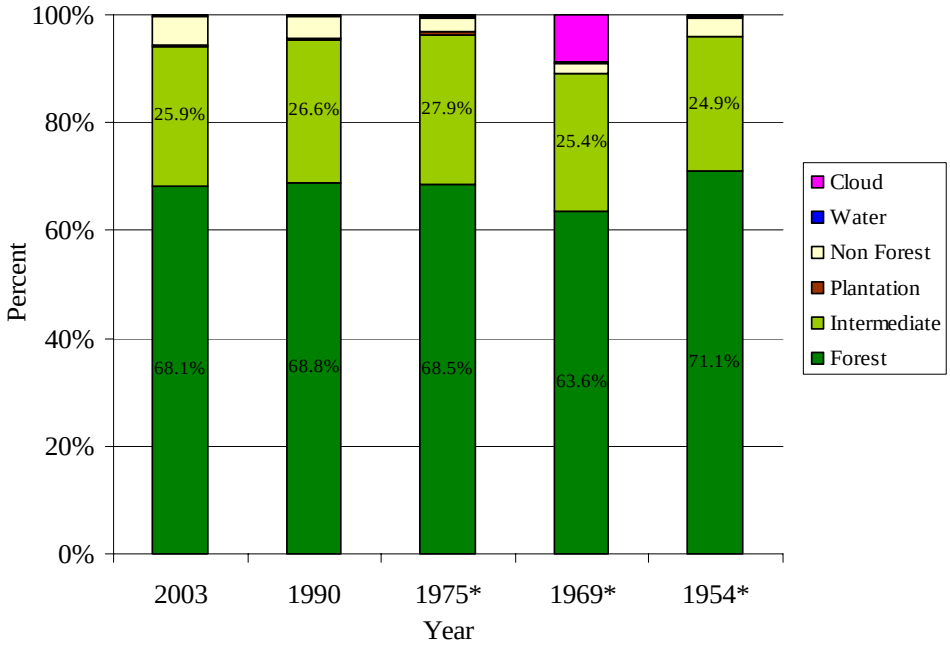


*Figure 4b: Percent of each land cover class per time period for only the area where 1954 aerial photographs are also present (This represents 5,518 km^2 or one third of the entire study area, as seen in Figure 5). Note: *Clouds present in classification (primarily over presumed forest land in high elevations).*

These map products, in digital and hardcopy form, have been widely distributed throughout Quang Nam and Thua Thien-Hue Provinces and have been used to aid planning and managing forest initiatives. For example, these land cover maps were used by Thua Thien-Hue FPD and WWF Green Corridor project staff in planning for initial activities in the region, such as site selection for field visits and for habitat assessment. The WWF MOSAIC (Management of Strategic Areas for Integrated Conservation) project has also used the maps to assess the forests of Quang Nam, as these are the only satellite-based land cover maps that cover the entire province. Lastly, these maps have also been used in relation to the planning and construction of the Song Bung #4 hydroelectric dam.

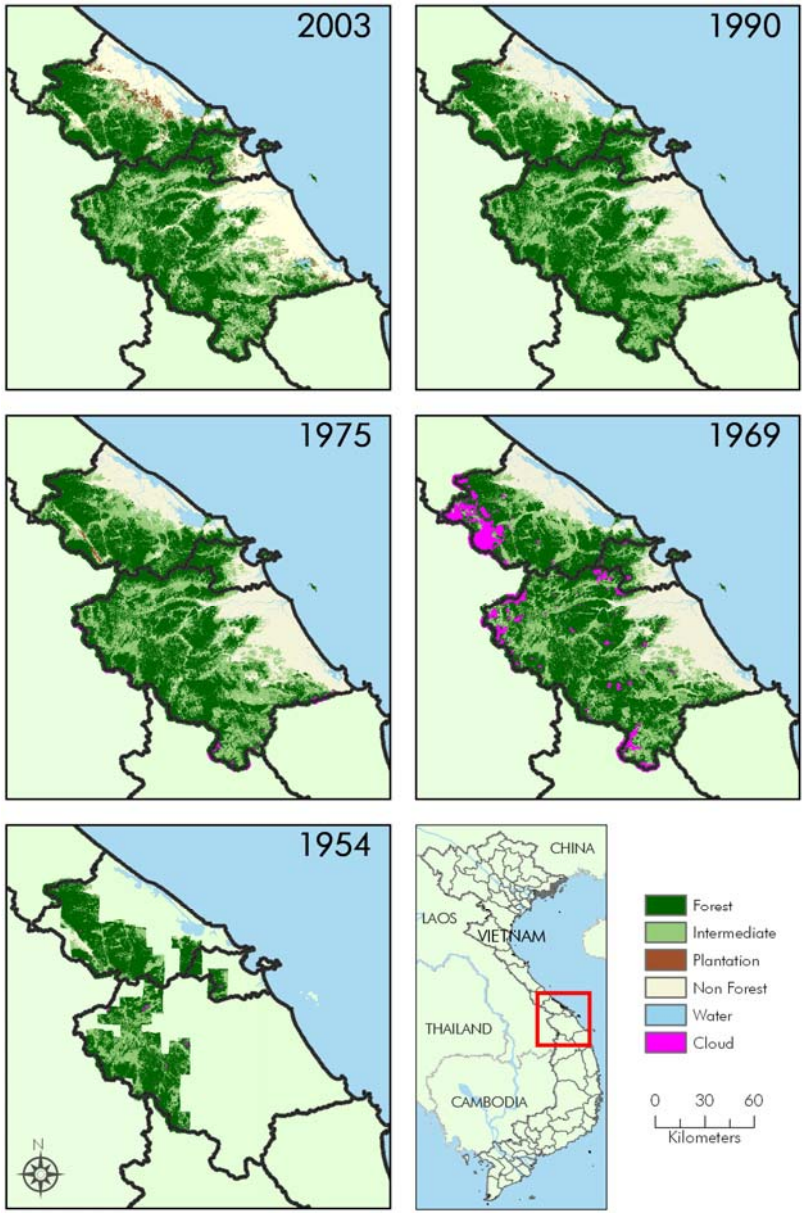


Figure 5: Land cover maps for time periods: 2003, 1990, 1975, 1969, and 1954.

B. BUILDING CAPACITY FOR CONSERVATION PLANNING AND MONITORING

Practical, In-depth Training

Beginning in January 2004, a student from the Asia Institute of Technology in Bangkok, Mr. Thiha, spent three months at the CBC RS/GIS lab. During his stay, Mr. Thiha received intensive training in preparation for his doctoral thesis research. He compiled a number of data sets central to his research, including a CORONA satellite data layer from 1969 for the entire province of Thua Thien-Hue. In creating this layer, he became proficient in converting raw photographic data from a film-based product to a geo-referenced multi-image mosaic. This layer, combined with the Landsat, Aster, and Shuttle Radar Topography Mission (SRTM) data layers that have already been compiled by the CBC, form the core data for his thesis research.

While visiting the AMNH, Mr. Thiha also gathered references and drafted his thesis proposal. His research centers on studying the socioeconomic drivers of land cover change at the district level. To experiment with this idea, he performed a small-scale landscape change analysis for the Nam Dong district in Thua Thien-Hue using a subset of the data that would be used for the province. Finally, during his internship at the RS/GIS lab, Mr. Thiha had the opportunity to experiment with multiple software packages (Erdas Imagine, ArcGIS, ENVI, PCI, and eCognition) for manipulating image and GIS data.

In January and February 2004, the staff members of the CBC lab, together with Mr. Thiha, generated the 2003 land cover map for the study area in Central Vietnam, focused on the provinces of Thua Thien-Hue and Quang Nam as described above. As the most recent and complete satellite image-based land cover map for this area, it has been used by the provincial FPD, as well as NGOs such as WWF, to aid in the planning and implementation of their forest management and conservation strategies.

April 2004 Expedition

In April 2004, CBC staff members and two students from the Institute of Ecology and Biological Resources (IEBR), Nguyen Thi Phuong Lien and Do Tien Doan, completed their first field expedition in the context of this project where they collected data on the existing ground cover in Quang Nam Province. These data were used to verify the map created from satellite images in the lab. For both students, it was their first opportunity to learn RS and GIS techniques that they can later apply to their own research. It was also their first visit to the central region of Vietnam.

CBC staff members met with members of the Forest Protection Departments (FPD) of Thua Thien-Hue and Quang Nam Provinces, researchers from the Hue University of Agriculture and Forestry (HUAF), project staff members of Tropenbos International, and staff members of the WWF Greater Mekong Programme. These meetings ensured that the CBC's efforts are coordinated with complementary conservation initiatives in the region. At HUAF, CBC staff members were also able to visit possible venues for the 2005 workshop, assess current computer facilities, and begin planning for the workshop.

Figure 6: Photos from the 2004 and 2005 field expeditions.

April 2005 Expedition

In April 2005, Kevin Koy and Martha Hurley of the CBC, together with Do Tien Doan and Nguyen Duc Hiep of the Institute of Ecology and Biological Resources, completed a second field expedition to Thua Thien-Hue and Quang Nam Provinces. They collected data on the existing ground cover using GPS and digital cameras. They were also able to test a new GPS-digital camera, which proved excellent for collecting ground truth data. The focus of the expedition included the intermediate areas between agriculture and forested land in Dong Giang district in Quang Nam and the natural forests of Phong Dien Nature Reserve in Thua Thien-Hue Province. The data were used to fine-tune the draft map created earlier in 2005, as well as to assess the map's accuracy. In particular, classification focused on further identifying features of the "intermediate" land cover class, as there is potential to protect and/or restore these areas. Photographs were also taken along the Ho Chi Minh Highway in Dong Giang district, as well as of the early stages of construction of a dam on the A Vuong River in Quang Nam. The expedition setting continues to be an important opportunity for extended, focused training of Vietnamese students in RS and GIS techniques; it was Mr. Do Tien Doan's second field expedition and the first for Mr. Nguyen Duc Hiep.

As with previous trips to Vietnam, CBC staff members took the opportunity to meet with key stakeholders to learn about current conservation initiatives and to share data that may be helpful to other conservation efforts in the region. CBC staff members met with members of the Forest Protection Departments of Thua Thien-Hue and Quang Nam Provinces, researchers from the Hue University of Agriculture and Forestry, project staff members of Tropenbos International, members of the WWF Green Corridor and MOSAIC programs, and consultants from Hatfield Consultants Ltd. of Canada.

C. INCREASING ACCESS TO DATA FOR EFFECTIVE CONSERVATION DECISIONS

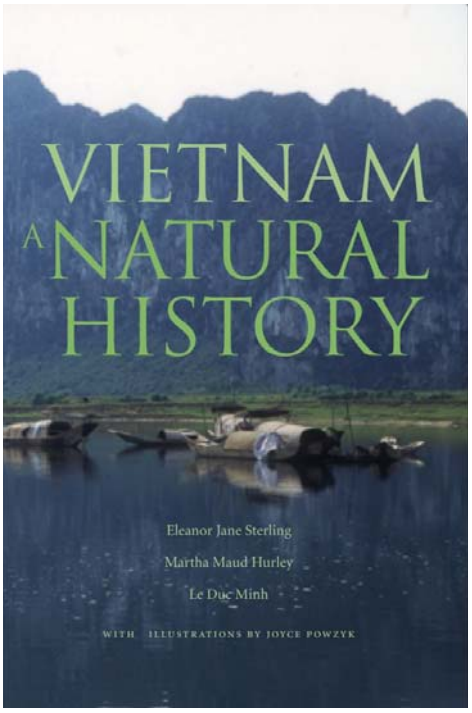
Building a Virtual Library

The CBC launched the Mainland Southeast Asian Conservation Library (SACL) (http://conservationlibrary.amnh.org/) in January 2006. The SACL and the accompanying online field guide are a work in progress and are still being developed. Most notably, we have received permission to scan and make available numerous documents from the World Conservation Union,

the Wildlife Conservation Society, and the Oriental Bird Club, among others, so we are now building up the document library.

Vietnam: A Natural History

Spring 2006 marked the release of *Vietnam: A Natural History*, published by Yale University Press and authored by the CBC's Eleanor Sterling, Martha Hurley, and Minh Duc Le. The book is designed to bring to the general public the research that Museum and other scientists have undertaken, and includes illustrations by Joyce Powzyk and maps by Kevin Koy. The book is the first comprehensive volume on the country's extraordinary flora and fauna and diverse natural areas. Spectacularly illustrated with maps, photographs, and 35 original watercolor illustrations, this 406-page book offers a complete tour for scientists, naturalists, and the general reader of Vietnam's plants and animals along with an in-depth discussion of the factors shaping their evolution, distribution, and conservation. In the next phase of the project, the authors plan to translate this volume into Vietnamese for distribution to conservation professionals within Vietnam.



RS/GIS Website

With partial funding from NASA, the RS/GIS lab has developed a website http://geospatial.amnh.org, which includes interactive tools, tutorials, and data from the region. These tools introduce online users to fundamental remote sensing concepts. The tools have been quite popular among conservation practitioners wanting to learn remote sensing methods, as well as faculty and teachers looking for useful visual tools to assist in their teaching. Materials from the workshops held in Vietnam are also available at the site. A major restructuring of the website is under way to permit the addition of new branches or sub-sites on topics such as open source software and species distribution modeling. A content management system is also being developed to facilitate rapid updates of the site. Data from this project will be available at the site by the summer of 2007. Results will also appear in peer-reviewed publications in the future.

D. PROMOTING DIALOGUE AND ENHANCING COORDINATION AMONG REGIONAL STAKEHOLDERS

Remote Sensing and Monitoring Workshop, Hue, 2005

In collaboration with Vietnam's Institute of Ecology and Biological Resources, the Hue University of Agriculture and Forestry (HUAF), and the Thua Thien-Hue Forest Protection Department, the CBC RS/GIS staff members conducted a workshop on Remote Sensing and Monitoring Land Cover Change at the Learning Resource Center in Hue from May 9 to 14, 2005. After reviewing the workshop materials (i.e., presentations and tutorials) created by the CBC and with some training by CBC staff members, two instructors from Vietnam's Institute of Geography, Nguyen Hanh Quyen and Tran Minh Y, Remote Sensing Specialists, conducted the workshop in Vietnamese. Thirty participants attended this workshop, representing several forestry and conservation sectors in Vietnam; they included students and staff members of the HUAF, and staff members of the Forest Protection Department in Thua Thien-Hue and Quang Nam Provinces. Prior to the workshop, we conducted a two-hour seminar 100 HUAF students. During the seminar, Kevin Koy of the CBC provided a basic introduction on the use of remote sensing for conservation; Mrs. Y of the Institute of Geography introduced fire impact and monitoring studies; and Ms. Quyen presented her research from Ha Long Bay.

Figure 7: Photos from the workshop in Hue, 2005.

During the workshop, participants learned practical skills and techniques that will enable them to incorporate remotely sensed imagery into their work using open-source and free software packages. These skills included: locating and downloading satellite imagery from the Internet, learning to relate features in satellite images with observations on the ground, and using satellite imagery to monitor changes in land cover over time. Manual interpretation methods and methods that use remote sensing software on a computer were taught. The participants also put the skills they developed in the classroom to the test in the field. For one day of the workshop, the class visited Bach Ma National Park and learned how to collect "ground-truth" data using a GPS unit, compass, and digital camera. They also improved their ability to interpret satellite images. At the end of the workshop, a CD-ROM was distributed with all of the training material in both English and Vietnamese, the data layers used during the course (such as satellite imagery from Thua Thien-Hue and Quang Nam Provinces), and the installation files for the open-

source and free software used throughout the week. All of these materials are currently freely available on the RS/GIS lab web site: http://geospatial.amnh.org.

Introduction to Modeling and Systems Thinking, Workshop Quang Nam, 2006
In March 2006, CBC staff members, together with staff of Quang Nam's Forest Protection Department, and staff members from Can Tho University in Vietnam and the Gund Institute at the University of Vermont, conducted a workshop on systems thinking and modeling using the case study of the Song Bung #4 hydroelectric dam to be constructed in a watershed in Tam Ky, Quang Nam, Central Vietnam. This five-day workshop provided an introduction to watershed modeling and systems-based approaches to natural resource management. Environmental managers can use modeling as a way to explore the effects and predict the outcomes of different management decisions. During the course of the workshop, participants learned to build conceptual models, develop scenarios based on different management options, and formulate simple dynamic spatial models using the software program STELLA™. The Song Bung #4 hydroelectric dam, located in the northwest of Quang Nam Province, served as a case study to introduce these concepts. The Song Bung #4 dam is the first of several hydroelectric dams being planned for Quang Nam Province, and one of three dams planned for the Song Bung River. Workshop participants examined some of the impacts of the dam and explored different scenarios of possible changes as a result of the dam's construction. The course was attended by a diverse group of faculty, students, government workers, and conservation practitioners coming from all over Vietnam; there were a total of 45 participants. Materials for the course were translated into Vietnamese and provided to the students on a CD.

Suggestions for the Way Forward

Building on the partnerships and capacity developed over the course of this project and working closely with our partners on-the-ground, we designed the second phase, ***"Capacity Building for Conservation Monitoring and Planning in Threatened Landscapes of Vietnam and Lao PDR,"*** for which we are thankful to have received continued funding and support from the MacArthur Foundation.

This second phase will continue to build capacity and resources for monitoring. The focus will be the design of on-the-ground applications, working directly with protected area managers to ensure that the tools are integrated directly and seamlessly into their daily work. Efforts will include making the transition from data collection for monitoring to the actual analysis of that data, and, finally, its application to management decisions.

Importantly, CBC staff members are working to further build and expand conservation management efforts from the local to the national and regional levels. This will include increasing conservation across borders by building parallel monitoring and data collection efforts in Lao PDR and building the capacity to manage biodiversity across borders using transboundary management techniques. Among these will be encouraging data standardization and continuing to improve capacity to train local staff members in monitoring, data collection, standardization, and analysis. We hope to improve interactions across all levels from local to regional to national within Vietnam and Lao

PDR, across boundaries, to ensure better coordination of conservation efforts and planning.

During the second phase of our work, our overarching goal is to conserve the unique biodiversity in protected areas and threatened landscapes of Vietnam's Annamite region and selected sites in Laos by building capacity and providing appropriate monitoring and planning tools, as well as strengthening the science available for making conservation decisions. As outlined in our 2006 proposal to the MacArthur Foundation, the CBC has four main objectives as part of this overall goal:

1. Expand and strengthen the capacity for conservation practitioners, including provincial forestry and protected-area staff members in Vietnam and Laos, to integrate data from multiple sources for effective conservation monitoring and planning

2. Enhance the capacity of university professors to teach applied conservation monitoring to conservation professionals who will ultimately be managing protected areas

3. Develop, distribute, and promote the use of visual tools that aid conservation monitoring, planning, and decision-making

4. Foster standardized data collection and monitoring and enhance coordination among regional stakeholders, thus leading to more informed management and, in turn, better decisions for conservation.

Specific activities toward these objectives are detailed in the 2006 proposal. In brief, CBC staff members will expand the capacity of conservation practitioners in Vietnam and Laos to conduct effective conservation monitoring and planning by promoting simple, sustainable tools for threatened landscapes and protected areas. These tools will complement and strengthen existing data collection and monitoring programs by providing a spatial framework for the analysis of diverse datasets. Satellite images serve as a canvas upon which location-based data (such as camera trap surveys, ground surveys of plants and wildlife, threat assessment, and community-based monitoring) can be visualized and interpreted in a meaningful way. By the end of the project, model monitoring programs will have been established at one site in each country: Song Thanh Nature Reserve, Quang Nam, Vietnam, and at a site in Laos.

Telling the Story

In viewing the results of the land cover change analysis presented above in Section A (page 2), "Creating Visual Tools for Conservation Planning and Decision-making," it may appear that there has been little change to the landscape of Thua Thien-Hue and Quang Nam Provinces over the last fifty years, but there is more to the story. While the relative percentages of land cover types have remained similar during this time, many changes have occurred that are not described sufficiently by these numbers. In an attempt to bring light to these changes, following our two smaller case studies within the larger context of the project, infrastructure development and landscape level effects of the Vietnam-American war.

It is quite clear that Vietnam is growing rapidly, both in population and economic capacity. There have been several notable infrastructure development projects within the study area of the land cover change analysis, such as roads and hydroelectric dams, and although they may not initially add up to large amounts of physical change to the landscape, the changes that do occur may have profound long-term impacts on the landscape and the communities and biodiversity that they support.

The dynamic nature of the landscape is illustrated in Figure 8 below. This area lies at the border of Thua Thien-Hue and Quang Nam Provinces, just to the east of the national boundary with Lao PDR. Part of this area, known as the "Green Corridor," has been identified as rich in biodiversity, and, notably, the global priority landscape for conservation of the Saola, a critically endangered large ungulate endemic to the region. Map views from three dates –1969, 1990, and 2003– are displayed in Figure 8, with raw satellite images to the left and their derived land cover maps to the right. In these maps, four colors represent four different land cover classes: dark green represents forest, light green represents the intermediate (shrub) area, beige represents non forest, and pink represents cloud cover.

Starting in 1969, one can see a large amount of forest cover with smaller amounts of intermediate shrub coverage at the center and throughout the area. Concentrated in these intermediate areas are dozens of small active swidden fields. This was a very active community agricultural area at the time; there is even evidence of a field burning at the moment the satellite photo was taken, which can be seen in the small smoke plume rising from the center of the image (pink in the land cover map).

Moving up to the 1990 image and map, it appears that the community area has been abandoned, with no signs of active agricultural plots, and forest has regrown from what was formerly intermediate land cover. The surrounding forest areas remain intact, at least at the landscape level as measured from above. Other biodiversity measures, such as species richness and abundance, are not measured in this analysis.

Lastly, in the 2003 image and land cover map, it is evident that the majority of this forest area persists. Much of the intermediate area also remains largely the same as it was in the previous decade. The most striking change in this image is the linear feature running down the center (blue in the satellite image, and beige in the land cover map). This is where the newly developed Ho Chi Minh highway has been engineered through the forest and intermediate areas. Although this change does not drastically alter the amount of forest cover in the area, the impacts of the highway, in terms of access for settlement, will undoubtedly be felt in the coming years. While this area has experienced change due to its history of swidden agriculture, these new developments offer novel challenges to this dynamic landscape.

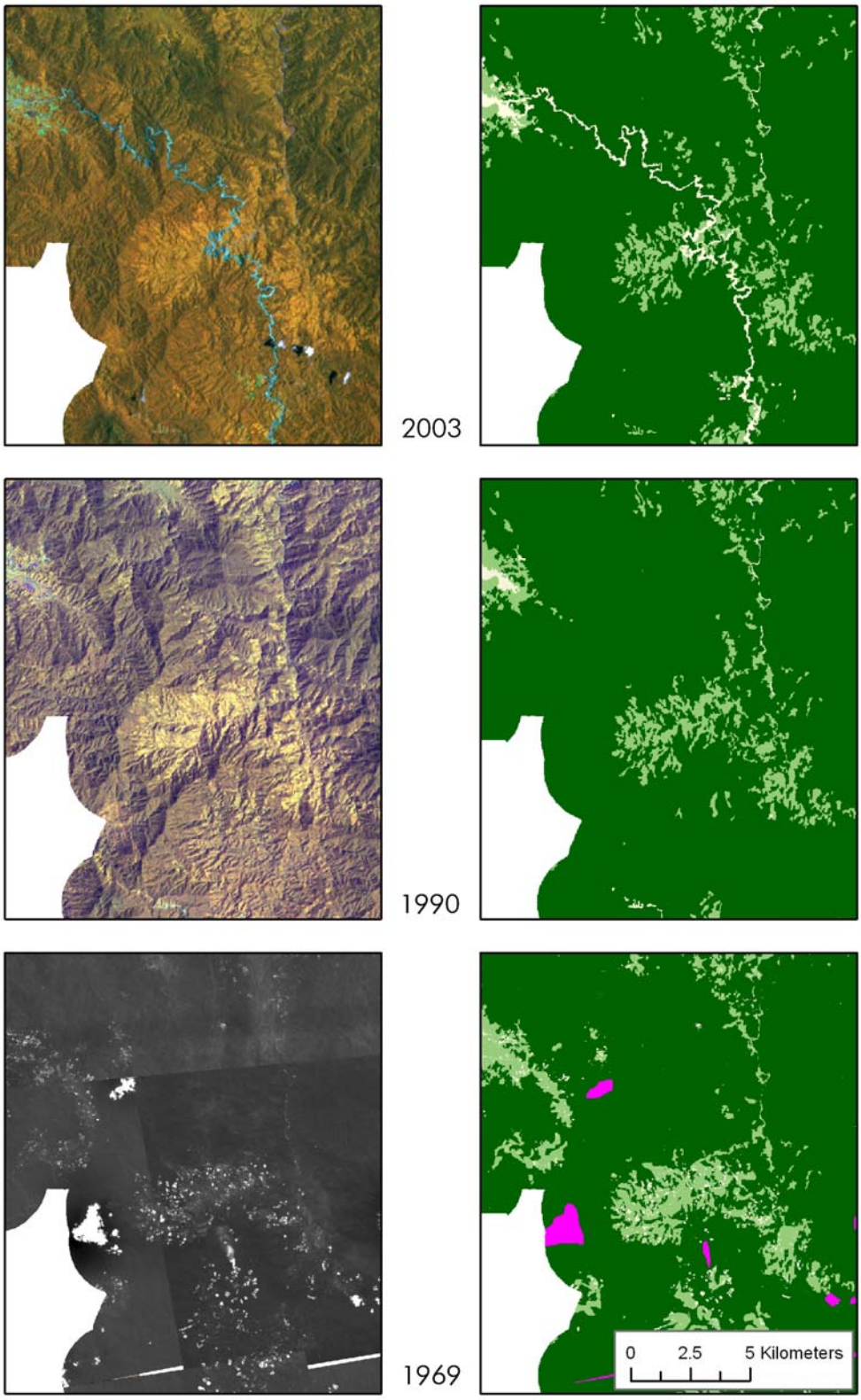


Figure 8: Border area between Thua Thien-Hue and Quang Nam Provinces, represented by satellite images to the left and their derived land cover maps to the right. A description of the changes seen in this area is detailed in the text above.

In addition to the changes seen in this area in terms of infrastructure development, the temporal scale of this analysis captures a historically significant snapshot of the landscape during the height of the Vietnam-American war. The CORONA satellite images used in this analysis were acquired in 1969, and viewing them makes it clear that the war had a significant impact on the area, even seen at the somewhat broad landscape scale. Both defoliation due to the use of defoliant sprays, such as Agent Orange, and bomb craters can be seen in the imagery.

Figure 9 shows a series of images focusing on a small 6km by 9km subset within the Nam Dong District of Thua Thien-Hue, with examples from four of the time periods used in the study. The images in the left column display the raw aerial or satellite imagery for the corresponding year. The images in the right column display the same images, but also include flight lines (red) that denote defoliant spraying missions (flight line data provided by Hatfield Consultants, Ltd.).

Starting at the top, the 1954 image displays samples of the aerial photographs for this area. This image is panchromatic, meaning that it is displayed in shades of grey. The darker shades in this image represent forest cover, while the lighter shades represent areas without forest cover (shrub, bare, and water). The same area is seen in the 1969 image, which is also displayed in panchromatic. The same color scheme applies to this image, however they appear slightly different due to the differing resolutions and time of day the image was acquired. The bright white spot in the lower right hand corner indicates a cloud. In this image, the linear patterns of defoliation can be seen corresponding with the flight lines.

Continuing down Figure 9, the 1990 image is displayed in color infrared composite (specifically a 4,5,3 RGB band combination). In the nearly twenty years elapsed between this image and the previous one, it appears that some areas that were defoliated have returned to forest, such as the area just to the right of the flight lines. It also appears that some areas are not forested, such as the linear path that follows the topmost flight line. The same pattern is evident in the most recent image from 2003.

Although the effects of these missions are clearly visible in the image from 1969, it is less evident in the future imagery (1990 and 2003). Of course this evidence is only at a landscape level and may not be indicative of the conditions on the ground; however, it appears that the overall forest cover in some areas was not permanently affected by the chemicals used at the time in this place. The patterns seen in Figure 9 are not conclusive as to whether or not the present forest conditions can be attributed to the use of defoliants, and there are a number of factors that may influence these results, including: the number of times the area was sprayed; what kind of defoliant was used; whether or not the area was also bombed or napalmed; the topography (this area is rugged); the relative susceptibility of the forest community to the defoliants; and how the defoliated area was subsequently used by people.

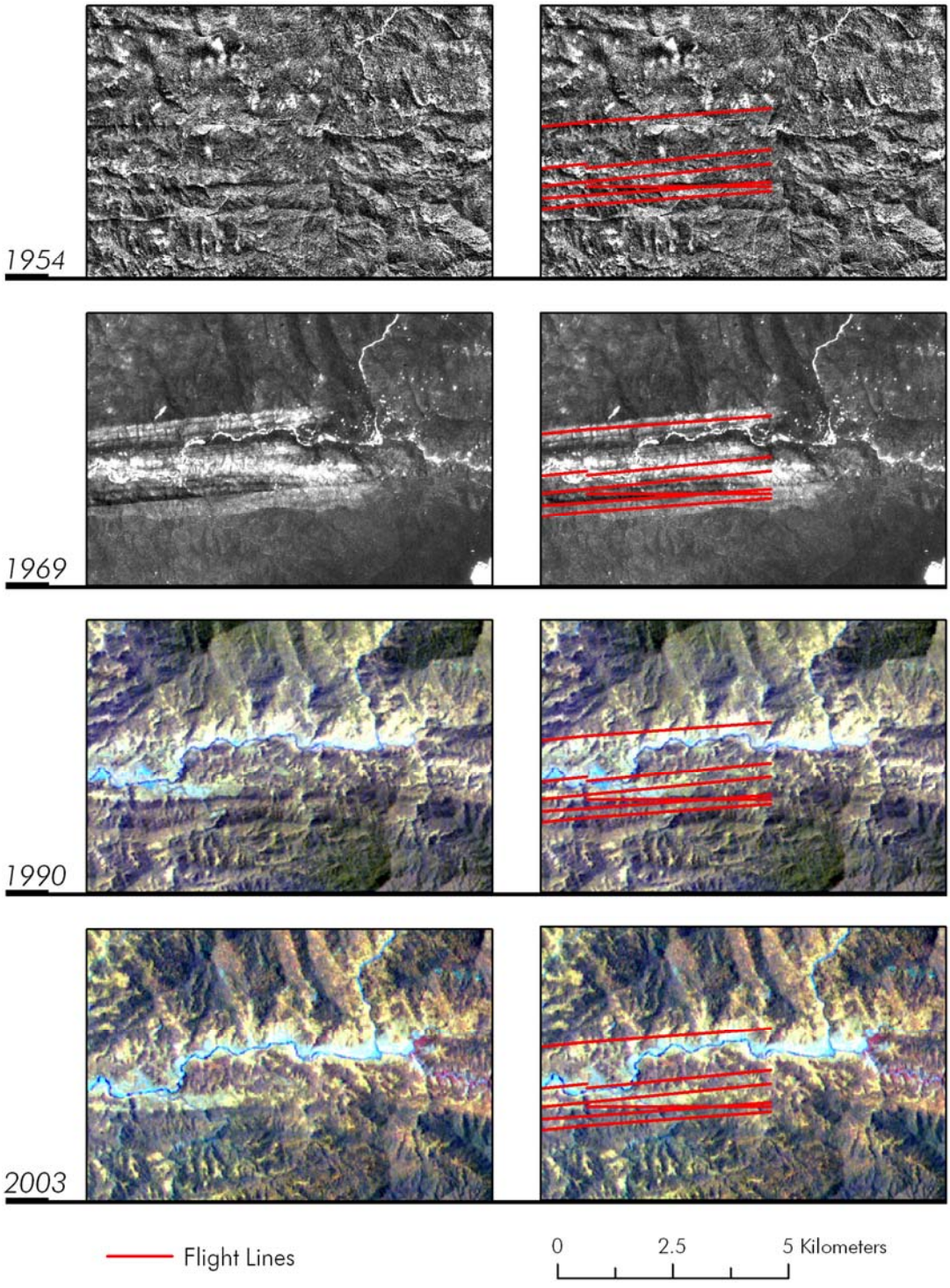


Figure 9: Aerial and satellite images displaying an area sprayed with defoliants during the Vietnam-American War. Images to the left are displayed natively, while the corresponding images on the right display the same imagery and also include flight lines recorded from defoliant spraying missions in red. An interpretative description of the changes seen in these images is in the text above. Flight line data provided by Hatfield Consultants Ltd.

In addition to defoliants, evidence of bombing throughout the forested areas can be seen in the 1969 CORONA satellite imagery. As seen in Figure 10, linear streaks comprised of dozens of smaller white bomb craters appear in this area of Que Son (southern) and Dai Lac (northern) Districts of Quang Nam Province. The more recent (2003) Landsat image to the right shows the same area. There are hardly any signs at this scale of the dramatic bombing runs evident in the previous image.

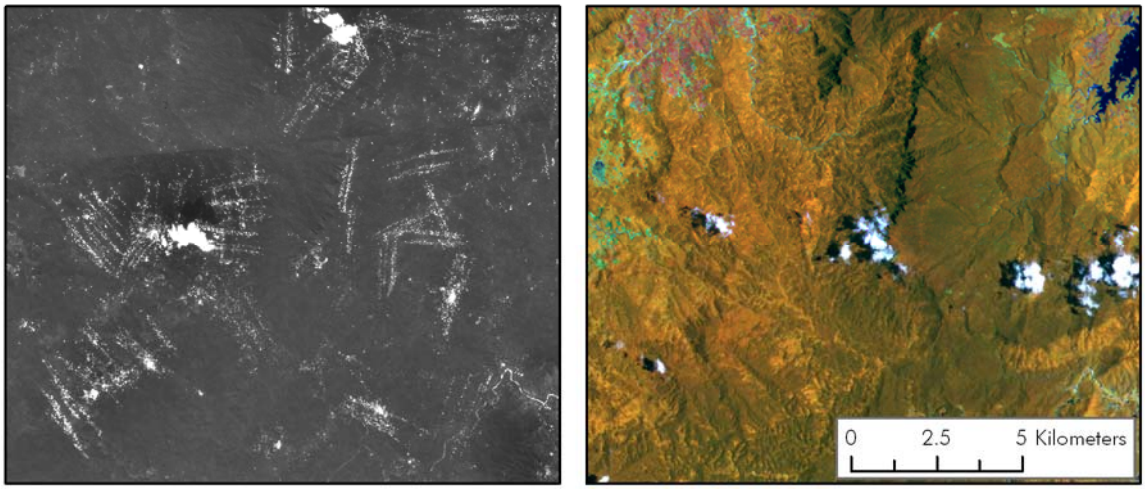


Figure 10: Bombing runs seen in white linear streaks within the 1969 CORONA satellite image to the left. The same area as seen in 2003 with Landsat satellite imagery to the right.

The landscape of the Central Truong Son is dynamic and unique, and the images hold many surprises. It is our hope that bringing the history of this landscape to light provides a valuable knowledge base from which the future of this landscape may benefit. Through increasing the availability of a vast array of data, literature, and technological expertise, the history of this landscape can continue to be monitored and documented in the coming years and decades. We hope that this unique and incredible landscape will continue to support the mosaic of communities that it has sustained throughout history.

* * *

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