Ground-Based Photomonitoring of Ecoregional Ecological Changes in Northwestern Yunnan, China

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Abstract—*Barring abrupt natural or anthropogenic disasters, ecological changes in terrestrial landscapes proceed at a pace not readily detected by humans. The use of historical repeat photography can provide valuable information about such changes, but, these studies are opportunistic in that they must rely on old photographs. Hence, their ecological interpretative power is compromised by the intention of the original photographer, the quality of the original photographs, an incomplete and potentially misrepresentative sampling design, and a limited analytical framework for interpreting ecological changes. The Nature Conservancy (TNC) has been using historical repeat photography to document ecological changes in northwestern Yunnan Province as part of its conservation planning efforts in China. This experience supported the development of a forward-sampling, ground-based, photomonitoring methodology designed around a high quality digital camera and a comprehensive database management system, which was tested during the summer and fall of 2003 across two adjacent ecoregions in northwestern Yunnan: the Hengduan Mountains and the Nujiang-Lancang Gorge. Based on results from a collaborative ecoregional conservation assessment for the region, visual indicators obtainable from the resulting photographs were identified and used to assess the threat status (for example, logging, grazing, mining) for five key ecosystem conservation targets (cold evergreen oak, evergreen broadleaf forest, mixed forest, subalpine forests, alpine mosaic). A sampling design strategy then was developed based on the inherent geographical variation in the distribution of targets, ethnic minorities (a surrogate for land-use), and climatic zones (based on precipitation and temperature) across the region. This distribution information is being used to design photomonitoring transects for establishing the baseline for the long-term monitoring of ecological changes. The photographic temporal assessment that eventually will result will help assess conservation and development activities across geographically extensive and diverse ecoregions, and serve as a means for monitoring the outcomes of conservation programs at specific locations.*

Introduction

Northwestern Yunnan Province in southwestern China is considered a conservation 'hot spot' worldwide owing to its spectacular landscapes and abundant biological diversity (Myers and others 2000). This region is also home to three million people, whose lives depend on the sustainable utilization of its natural resources. Faced with rapidly changing socio-economic conditions and development expectations, however, some of their livelihood strategies (specifically, enhanced agricultural and livestock production, and the increased collection of wood and various non-timber forest products) are now threatening the area's rich biodiversity (Li 2002, Xu and Wilkes 2004). As a consequence, northwestern Yunnan (NWY) is receiving much attention from the international conservation community, as well as all levels of the Chinese government.

The Nature Conservancy (TNC) was invited by the provincial government in 1998 to address the threats to biodiversity in the NWY using its collaborative and systematic 'Conservation by Design' process (TNC 2001). Called the Yunnan Great Rivers Project (YGRP), the collaboration produced an ecoregional assessment in 2002, which identified 19 conservation areas of biodiversity significance across the five ecoregions that intersect NWY (YGRPPT 2002).

Following the assessment phase, TNC and local partners then concentrated their efforts at five action sites within the YGRP to produce conservation plans and strategies for effectively protecting and enhancing biodiversity and the livelihoods of local people (Moseley and others 2004). However, TNC and the Yunnan government also are concerned about conservation and rural development across the portfolio of 19 conservation areas of biodiversity significance identified during the ecoregional assessment. While some species-level inventories exist and detailed vegetation maps are being assembled for the region, there has been little research on important landscape-level questions, such as rates of ecosystem succession, scale and frequency of disturbance regimes, and patterns and intensity of past and ongoing threats to conservation targets (Moseley 2004).

TNC has been using repeat historical photography (for example, see Rogers 1984, Hall 2001, Turner and others 2003) to understand rates and patterns of ecosystem change under varying land-uses, to set realistic goals for conservation programs, and to establish reliable methods for measuring conservation successes (Moseley 2004). Such investigations also provide a base for developing a comprehensive photomonitoring system for the entire YGRP. Such forward-sampling, ecological studies of landscape changes are very important to designing and implementing sustainable conservation and management strategies (Lunt 2002, Pickard 2002) and, hence, are critical to the future of biodiversity and local people in NWY, and elsewhere.

Here we report the development of a relatively simple, yet rigorous, methodology that employs ground-based, repeat photography as an extensive, efficient, and cost-effective means for monitoring ecological changes at the landscape level across expansive ecoregions. Specifically, this study: (1) designs, tests, and refines an image capturing and processing workflow methodology that includes image and metadata management; (2) develops and tests an indicator-based analytical framework for assessing ecological changes identifiable and quantifiable from oblique, ground-based photographs; and (3) designs a sampling methodology for selecting photomonitoring transects representative of spatial and temporal variations in landscapes across NWY.

Study Area

This study was conducted across the Yunnan Great Rivers Project (YGRP), an area of over 66,000 km2, comprising 15 counties and four prefectures (fig. 1). The region's biophysical uniqueness arises from its location between the Qinghai-Tibet and the Yunnan-Guizhou Plateaus and from the four major rivers (Jinsha, Lancang, Nu, and Dulong) that cut deep, parallel gorges in the landscape all within 90 km of one another. This results in very steep elevation gradients that can rise from river valleys below 1500 m to glaciated peaks at over 6500 m within a distance of 20 km or less. Although at a subtropical latitude, the region's climate is characteristically temperate, modified by a summer monsoon season leading to warm, wet summers and cool, dry winters. The topographic extremes that characterize the region cause major microclimatic differences associated with changes in elevation, slope, and aspect.

The region's wide ranging environmental conditions support a biological diversity that rivals that found in the tropics (CBD 2001). Five World Wildlife Fund (WWF) ecoregions (Olson and Dinerstein 1998) are found within the YGRP, the largest being the Nujiang-Lancang Gorge and the Hengduan Mountains (fig. 1). Ten different vegetation types occur across the region with the most important being the alpine mosaic and a variety of natural forest ecosystems, the latter covering over 60 percent of region (Xu and Wilkes 2004).

All landscapes in NWY have been influenced by human activities for thousands of years. Population density is relatively low, especially compared to eastern China, and except for a few modest urban centers, most people live in rural areas. Although income-generating endeavors are becoming more important, local people historically have focused on subsistence agriculture, including livestock production and the collection of plants and animals from natural areas. All but two counties in the YGRP are considered poverty counties under the Chinese classification system. Fourteen ethnic minority groups are living within the region, which is significant because of their differing cultures and practices relative to land-use (Xu and Wilkes 2004).

Methods

Workflow Development

An extensive review of repeat photography literature and modern photographic techniques and equipment was conducted. Equipment had to be durable and dependable under wet or dusty field conditions, extremely portable, able to take and process potentially thousands of images, and capable of daily operation for multiple weeks without access to AC power. We examined data management programs for their comprehensive capabilities to catalogue a large number of images in formats useful for future analysis. Back up and archival needs were examined in relation to current technology. A comprehensive workflow was designed in Ithaca, New York during the first half of 2003, and tested during the summer and fall in NWY, all leading to a refined system for image capture, management, and storage.

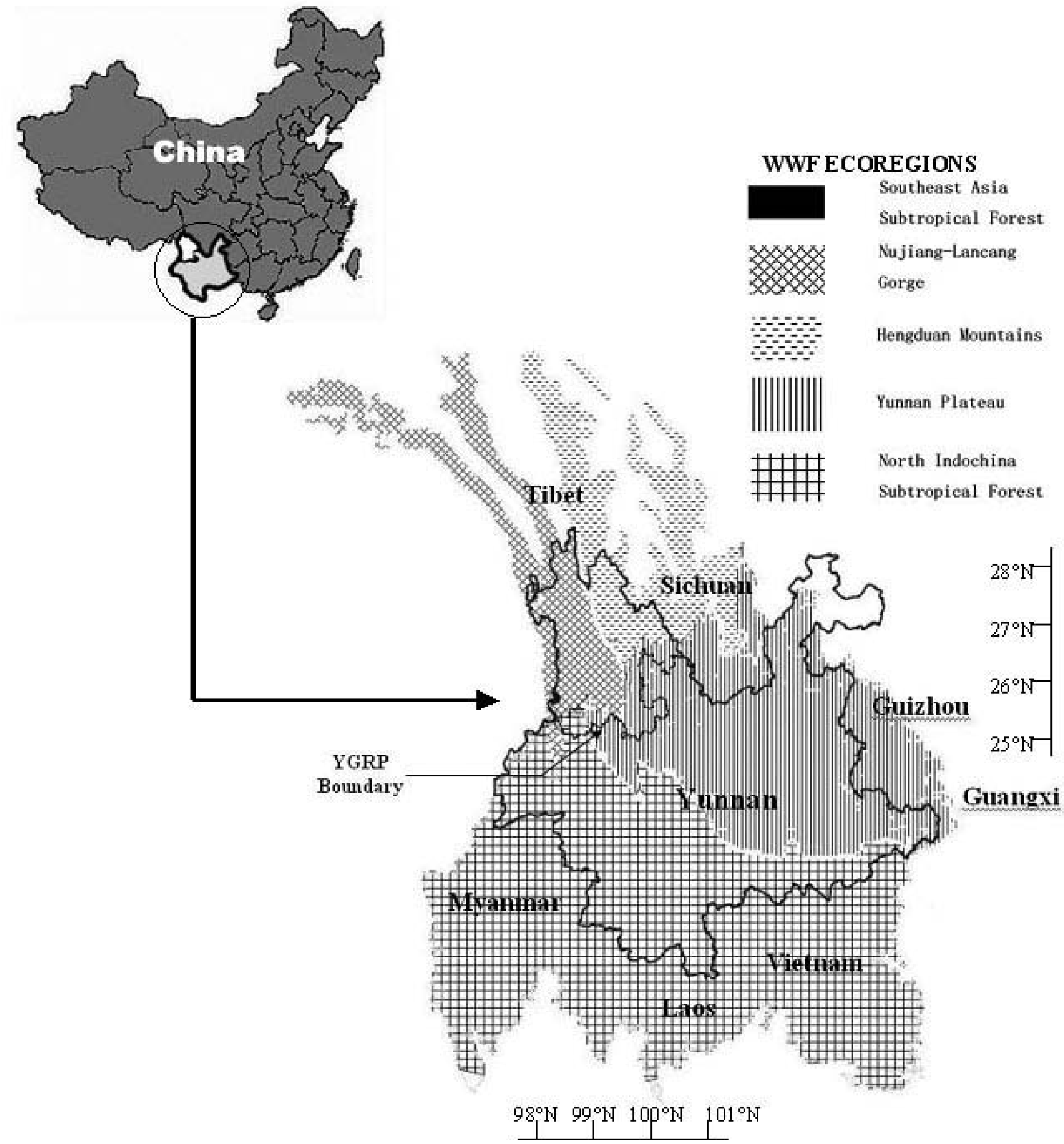

Figure 1. Map Showing Location of the Yunnan and Yunnan Great Rivers Project (YGRP) in Relation to Five World Wildlife Fund (WWF) Ecoregions.

Analytical Framework

Critical to the successful use of repeated photographs for measuring the impacts of conversation programs is the analytical framework for interpreting indicators of change to biodiversity and threats. TNC's four-part conservation framework called 'Conservation by Design' provides this important analytical context (TNC 2001). The framework was developed to systematically focus conservation action on priority biodiversity and critical threats in a dynamic, adaptive process involving setting geographic and threat priorities through ecoregional assessments, developing strategies, taking actions, and measuring conservation impacts (Groves and others 2002, Groves 2003).

The conservation planning framework for ecoregional assessments includes four steps relevant to the current study: (1) selecting focal conservation targets from the universe of possible species and ecosystems, (2) setting representation and quality goals for conservation targets, (3) evaluating the ability of conservation targets to persist (in other words, assessing viability and ecological integrity) and (4) selecting and designing a network of conservation areas of biodiversity significance (Groves 2003). Because Conservation by Design is an adaptive process, it requires monitoring the conservation status of ecoregions. Critical attributes of ecoregional measures include:

- Tracking progress toward quantitative goals set for each conservation target during ecoregional assessments.
- Informing whether current management is sufficient to protect the viability and persistence of conservation targets in the long run.
- Providing a gauge of conservation priorities and whether they should shift as environmental conditions change over time.
- Measuring threat status within an ecoregion to provide an 'early warning system' to detect changes more quickly than relying solely on biodiversity health measures.

After completing the YGRP ecoregional assessment, we developed a monitoring framework of 28 prioritized indicators—nine being health indicators (for example, size, erosion, fragmentation) for conservation targets and 19 being threat indicators (for example, unsustainable collection of fuelwood and non-timber forest products, over-grazing, mining). This ecoregional photomonitoring methodology is designed to assess several of these threat and target health indicators that are observable from examining photographs of landscapes. These were tested for usefulness based on earlier work using historical photographs by Moseley (2004). Additional land cover, land-use, development infrastructures, geopolitical and conservation classifications were developed based on experience in the study area. Combined, all were used as 'keywords' for classifying images taken during the 2003 field season.

Sampling Design

A unique feature of the work presented is the development of a sampling methodology that accurately represents the diversity inherent across extensive ecoregions. Even stratified randomization is inoperable here owing to the extent of the areas involved, challenges of accessibility in rugged landscapes, and the need to gain a landscape perspective that is often distant from the indicator(s) under consideration. Our approach was to stratify the study area by features central to the analytical framework and then to use TNC's GIS database to determine the area represented by each. This work was carried out during the summer of 2004 in preparation for the fall field season. The features examined were: (1) WWF ecoregions, (2) conservation areas of biodiversity significance identified during the ecoregional assessment, (3) distribution of key conservation targets from the ecoregional assessment, (4) principle ethnic minority present (a surrogate for culturally based land-use practices), and (5) modeled climatic zones (B. Baker, Climate Change Scientist, TNC; personal communication) (table 1). Next, we designed transects for obtaining 'baseline' photographs. The scheme devised sampled each feature proportional to its distribution within each stratum. For example, if the mixed forest target covers 34 percent of the Baima Conservation Area, then about 34 percent of the photographs in this area should be taken of this target. Each feature was examined in relation to one another to gain a qualitative assessment of the sampling needs. Since the location of roads and/or trails is critical logistically, accessibility also was addressed when designing transect locations.

Results and Discussion

Workflow Development

The workflow process was designed to yield images and their supporting metadata that could be used in the analysis of indicators of landscape change over time (discussed later). It consisted of four interrelated steps: (1) initial image capture, metadata collection, and

Table 1. Features used to stratify Yunnan Great Rivers Project area to determine photomonitoring sampling design.

Feature	Elements
Ecoregions (n = 5)	e.g., Hengduan Mountains, Nujiang-Lancang Gorge, Yunnan Plateau
Conservation Areas (n = 19)	e.g., Baima, Nushan, Zhongdian Highlands
Conservation Targets	CEO: cold evergreen oak; EBF: evergreen broadleaf forest; MF: mixed forest SAF: subalpine forests; AM: alpine mosaic (shrub, meadow, scree)
Ethnic Minorities (n = 14)	e.g., Lisu, Naxi, Tibetan
Climatic Zones (Clusters)	1: hot summers, cool winters, very wet; 2: cool summers, cold winters, moderate precipitation; 3: warm summers, cool winters, moderate precipitation; 4: warm summers, warm winters, moderate precipitation; 5: warm summers, cool winters, dry

temporary storage; (2) imaging processing; (3) image and metadata management; and (4) storage of working and archival data files. It is presented in generic fashion, but specifications for all equipment and software are available from the senior author. Although the entire process could be conducted under field conditions, it was found that inclement weather conditions and the lack of AC power over long periods of time made computer processing difficult, thus making all but the image capture step better suited for the office.

Image capture

The system was built around a professional quality, high resolution, digital single lens reflex camera capable of accepting exchangeable lenses. Such cameras offer many options for capturing, modifying, and storing images. For this study, settings were selected to maximize the quality of resulting images, which simplifies to holding the camera steady and striving for the highest quality captures possible. A sturdy tripod matched with a ball head was used to precisely position the camera enabling level, overlapping images typically representing views of 180-360o and, as necessary, to hold it steady during long exposures. A low effective ISO rating (125 – 200) was used to reduce digital noise (similar to grain in film cameras). Images were taken in the RAW 12-bit data file format yielding uncompressed files approximately 8 MB in size. When storage capacity in the field was limited, RAW files were compressed by 50 to 60 percent using a proprietary process reported to cause only a minor loss in image quality (Cardinal and Peterson 2002). The RAW format yields unadjusted data from the camera's CCD sensor, thus providing the greatest amount of image information possible while also allowing the greatest amount of post-exposure manipulation (Cardinal and Peterson 2001).

Lens quality is an important variable in photography and various high quality professional zoom lenses representing digital camera focal lengths from 30 to 600 mm were tested during the 2003 field season. Based on this work, two new lenses designed for the digital camera were purchased for the 2004 field season. These yield an effective focal length range of 18 to 180 mm, which is well suited to expansive landscapes typical of NWY.

In-camera image capture and temporary storage capacities must be relatively fast and large owing to the large files involved. Although we found that carrying two 512 MB cards provided enough storage capacity for two or three days of intensive photo-sampling, there was a need to have a portable image storage unit during longer trips into remote areas. A number of rechargeable storage devices are available, the most useful and expensive being those capable of image display. However, because of a concern over battery longevity, we used a relatively inexpensive (about US$200), 220-volt rechargeable, 20 GB Chinese unit that lacked image display capabilities. The major considerations when deciding to rely on such devices are their battery life, durability under adverse conditions, and their cost relative to purchasing multiple, in-camera storage cards. For this project, having three or four 1 GB cards would be sufficient storage for a field trip lasting two weeks, thus forgoing the uncertainty of an additional piece of battery-powered equipment. The use of multiple cards is recommended because of the possibility of malfunctioning of a single, large-capacity card.

The rechargeable proprietary battery used in our camera proved to be long lasting under the conditions of this study (approximately 100 images/day, no flash, and limited use of the camera's LCD screen), and two were sufficient for trips lasting up to two weeks. However, digital cameras, and most of their modern film counterparts, are totally inoperable without battery power. Hence, adequate back up is a must – this project used a 30-watt, 220-volt rechargeable unit during long periods in the field. The auxiliary battery also allowed greater use of the camera's LCD screen to examine tonal histograms in the field leading to improved exposures (Cardinal and Peterson 2001).

Metadata associated with each image arose from two sources. First, the camera tags an EXIF (Exchangeable Image File Format; see: http://www.exif.org/) text file to all images that provides a record of shooting information (for example, date, time file format, lens, focal length, shutter speed, etc.). In addition, when properly connected to a GPS unit (Cardinal and Peterson 2002), longitude, latitude, and elevation are added to this file. Comments also can be added at the time of downloading images to the computer. The second source of metadata was a written record of location; transect, stop, and view numbers; weather conditions; and camera compass and tilt orientations. This information was added to each image's IPTC (International Press Telecommunications Council; see: http://www.iptc.org/metadata/) file during the image processing stage.

Imaging processing

Once in the office, RAW images from the camera's storage cards (or the storage unit) were transferred to a high capacity laptop computer using proprietary transfer software. These were opened using 12-bit RAW software and adjusted as needed (for example, tonal range, color balance, sharpening, white balance, etc.) to provide the high quality images possible. Camera data from the EXIF files were automatically added to the IPTC files while written information had to be added manually. These images can be opened in any professional image processing software and further manipulated as needed. All images were numbered consecutively from 00000 and stored in folders by transect.

Image and metadata management

A high capacity, versatile professional software package was used for image and data management. This program uses low-resolution 'thumbnail' images linked to original files, which are rapidly searchable using a system of predetermined keywords and custom fields (for example, date/time, numbers, text, etc.). Each thumbnail also carries general information that is not searchable (for example, title, IPTC data, information about the image file and when it was catalogued, etc.).

The linchpin for any searchable database is the development of standardized framework for cataloging individual pieces of stored information. For this study, such characterizations had to describe visible or otherwise discernable indicators of impacts or threats on key conservation targets. Custom fields were designed for this study primarily to identify photomonitoring locations in relation to geographical, ethnic, conservation, and political boundaries (table 2), while keywords focused on identification of ecoregional conservation targets, land cover, land-use, infrastructure, and disturbance (table 3).

Data storage

Great care was taken in developing and utilizing a multiple storage/archival system owing to the large investment of time and money that was required to obtain the original images. Original RAW images and resulting processed images were backed up on the laptop computer's secondary hard disk and a portable hard disk, as well as archived on a desktop workstation's hard disk and on high quality DVDs. The final image database catalogue was backed up on the portable hard disk and archived on a high quality CD-R.

Analytical framework

The YGRP ecoregional monitoring framework identified indicators for discerning trends in key conservation

Table 2. Custom fields used for cataloging images in database management system.

Custom Field Name	Definition
Camera Orientation	Direction (degrees) camera is pointed for image
County	County where image is located (n =16)
Ecoregions	Ecoregion where image is located (multiple entries possible) (N = 5)
Ethnic Groups	Ethnic groups found in area image is located (multiple entry possible) (N = 14)
Focal Length	Lens focal length (mm) used for image
GPS	Latitude (UTM), Longitude (UTM), and Altitude (m)
Image Repeat # (0=original)	Identifies whether image is original, 1st retake, 2nd retake, etc.
Location/Directions	Description of the location and directions to photo-stop
Miscellaneous	Other information including whether telephoto lens is used, whether camera is tilted up or down, whether there was a mistake in the shot, or whether the image is linked to other projects (e.g., Alpine Ecosystem Project, Historical Repeat Photography Project, etc.)
Conservation Areas	TNC identified Conservation Areas where image is taken in (multiple entries possible) (n = 19)
Prediction/Significance	Comments on whether we predict any changes or see any significant impacts worth mention
Prefecture	Prefecture that image is taken
Protected Area	If applicable, government protected area where image is taken
Stop Code	The photo-stop number along the given transect
TNC Conservation Action Area	If applicable, TNC Conservation Action area where image is taken (N =5)
Transect Code	Transect number (e.g., 1-15 for 2003 field season)
View Code	View number for a given photo-stop number
Weather, Air/Light Quality	Description of weather and air/light quality when image is taken

Table 3. Selected list of keywords used in image database.

Ecoregional Targets	Land Cover	Land Use	Infra-structure	Disturbance
alpine mosaic	warm conifer forest	commercial logging	bridges	disturbed forest
evergreen broad-leaf forest	warm scrub	crop fields	roads	human caused fire
mixed forest	upper/lower timberline	grazing	trails	logging roads
dark needle conifer forest	humid shrub	horticulture	public utilities	natural forest disturbance
deciduous broad-leaf forest	arid grassland	fuelwood harvesting	seasonal houses	skid trails
cold evergreen oak forest	lacustrine aquatic	mines & mining	towns & villages	soil erosion

Table 4. Example of indicator matrix for Evergreen Oak Forest Target in the Hengduan Mountains Ecoregion.

Target	Threat	Target Health Category	Visual Indicators
Evergreen Oak Forest	Fuelwood	Size	Clearing
		Condition	Structural changes Extraction methods
	Livestock Bedding	Condition	Structural changes
	Tourism & Infrastructure	Size (loss of native habitat)	Roads, Buildings/structures for tourism, trails, cableways, billboards
		Condition (erosion, pollution)	Roads, Buildings/structures for tourism, trails, cableways, billboards
		Landscape context (fragmentation)	Roads, Buildings/structures for tourism, trails, cableways, billboard
	Mining	Size (loss of native habitat)	Mines, roads, waste material, buildings, impacts to hydrology, evidence of soil erosion
		Condition (erosion, pollution)	Mines, roads, waste material, buildings, impacts to hydrology, evidence of soil erosion
		Landscape context (fragmentation)	Mines, roads, waste material, buildings, impacts to hydrology, evidence of soil erosion

targets and related threats. As illustrated in table 4 for the Evergreen Oak Forest Target in the Hengduan Mountains Ecoregion, this information was used to generate related indicators of changes in target health that could be visually detected from landscape images. These were in turn either tied to specific keywords used to catalogue landscape images in the database (table 3) or were detectable from examining changes in the target over time (for example, structural changes in canopy, extent of burning or clearing, etc.). Figure 2 illustrates how a few of these indicators appear in an image from about 3900 m in one conservation area in the Hengduan Mountains Ecoregion.

When accessing the image database, custom fields are used to restrict the search to certain ecoregions, specific conservation areas, and/or other geopolitical units (table 2), and then keywords (table 3) are used to further sort for conservation concerns. For example, all photographs of dark needle forests (with their respective ICPT information), in Baima Conservation Area and also Deqin County, that show commercial logging, logging roads, and soil erosion can be quickly located from a catalogue of thousands of images from across the entire YGRP area. The power of the system as a search engine is obvious, but its real value to this project arises from its use as an analytical framework for assessing changes in conservation targets and threats over time.

This project has developed a new methodology that will be used for an initial survey to document 'baseline' conditions of the YGRP. Hence, comparison photographs will not be available until some time in the future. However, Moseley's (2004) historical repeat photography work makes it possible to test the potential interpretative value of having an extensive set of paired and well-documented photographs for all conservation targets across all ecoregions and conservation areas in the YGRP area. For example, Moseley (2004) presented two photographs separated by almost 80 years looking into a Tibetan alpine valley in the Nushan Conservation Area. This comparison illustrated marked increases in the ecological impacts of yak grazing on the Alpine Mosaic Conservation Target: increased number of trails through meadows and rhododendron shrublands, increased number of herder camps, and reduced cover of juniper shrublands due to burning. The conclusion was, at least for this area, that there has been an increase in grazing pressure by yaks during the past 80 years. Moseley (2004) went on to analyze 115 paired photographs basically assessing whether they showed an increase, decrease, or no change in area or density of various land cover (for example, settlements, glaciers, lower and alpine treelines) and vegetation (for example, crop fields, subalpine forests, alpine meadows) types, drawing ecological and conservation conclusions based on the changes observed. This 'qualitative' assessment of temporal ecological change has been a common and useful approach to interpreting repeated historical photographs (for example, Meagher and Houston 1998).

However, the high quality images resulting from this methodology offer more options for interpretation. Figure 3 illustrates the same valley just discussed, but taken in the fall of 2003. The ability to digitally 'stitch' multiple images together into panoramas greatly enhances the landscape perspective over single images, and the use of high-resolution color strikingly improves the ability to discern vegetation, landscape, and land-use features

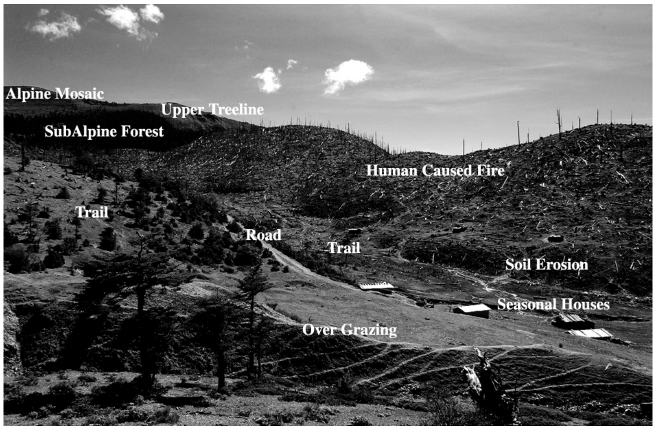

Figure 2. Visual Indicators in an Image from Shangri-La Gorge Conservation Area, Hengduan Mountain Ecoregion, Yunnan Great Rivers Project.

Figure 3. 2003 Three-Image Photomontage of Alpine Pasture from Dokela Pass in Nushan Conservation Area, Yunnan Great Rivers Project. (see fig. 3 and text for explanation).

over using black and white images, which is necessary when comparing them to historical photographs. In addition, the high image quality means that post-capture digital enlargements or telephoto images in the field of portions of a landscape can provide excellent details for fine-scale interpretations.

Sampling Design

A significant limitation of repeat historical photography as an ecological tool is the inherent lack of a sampling methodology that assures representative coverage of natural variation within and between ecologically diverse areas (Pickard 2002, Moseley 2004). This study attempted to overcome this problem by first examining the general variation represented across the YGRP, and then by designing a series of photomonitoring transects that proportionally sampled this variation. A comprehensive GIS database, developed by TNC, was used to examine the variation in key features across the region (table 1). The proportional coverage of particular targets for each conservation area was found to best serve the purposes of this study (table 5). Distribution maps of dominant ethnic minority groups and climatic zones were used in refining the sampling conclusions arising from an examination of the proportion of targets sampled (discussed later).

2003 data set

During the summer and fall of 2003, 15 transects along roads and trails were conducted in NWY, yielding 157 geo-referenced photo-points and 1501 images (fig. 4). Overlapping, multiple images at different camera orientations were taken at each photo-point to allow photomontages (fig. 4) and to avoid the ‘subject bias’ criticism commonly directed at historical repeat photography studies (Pickard 2002). This data set primarily served to test and refine the methodological workflow

Table 5. Comparison of photomonitoring coverage of five conservation targets relative to their geographical extent for three conservation areas.

Conservation Areas	Total for all Area[a]		Conservation Targets[b] EBF		CEO		SAF		MF		AM	
	Images %	Area %	Images %	Area %	Images %	Area %	Images %	Area %	Images %	Area %	Images %	Area %
Baima	14	18	2	1	5	6	41	47	25	4	42	28
Nushan	20	18	<1	4	0	1	17	35	37	12	35	23
Zhongdian Highlands	48	24	0	<1	10	2	50	46	10	6	34	35

[a] Images N = 1501; Area N = 3.033 x 10^6 ha for 19 areas
[b] See Table 1 for codes
[c] Percentages of images from conservation area (N: Baima = 202, Nushan = 303, Zhongdian Highlands = 726; 270 of 1501 were from outside the conservation areas)
[d] Percentage of conservation area

discussed earlier. As such, the focus was on developing appropriate camera techniques and image and meta-data management, and not on acquiring a representative sample. Hence, some images and transects were flawed making their analysis difficult. However, those that were adequate for the purpose of analysis, particularly transects from the latter part of the 2003 field season (fall), will become part of the baseline sample (discussed in the next section).

Fieldtrips were opportunistic in that they took advantage of trips arranged for other TNC program purposes. As a result photographs came from only two (Hengduan Mountains and the Nujiang-Lancang Gorge) of the area's five ecoregions, and only three (Baima, Nushan, and Zhongdian Highlands) of its 19 conservation areas. Only three minority groups (Lisu, Nu, and Tibetan) were represented out of 14 inhabiting the region. All five conservation targets were sampled, but since much of the fieldwork was conducted in association with TNC's Alpine Ecosystem Ecology Project, there was a disproportionate sampling of the Subalpine Forest and Alpine Mosaic targets relative to their areas. For similar reasons, almost 90 percent of the images represented landscapes influenced by Tibetan communities, as they predominately graze livestock at higher elevations throughout the YGRP area (Xu and Wilkes 2004).

Baseline sample

The three conservation areas surveyed in 2003 were examined to determine voids in the database and to design transects needed to complete the coverage of the variation represented by the conservation targets, principle ethnic minorities present, and the climatic zones. For example, for Baima additional images of the Subalpine Forests Target are needed in the northern portion of the area (table 5), and a complete sampling scheme is needed for the southern portion in order adequately represent the area's distribution of two additional ethnic groups and two additional climatic zones (fig. 5).When working in this southern portion, transects and photopoints will be established to sample the distribution of targets proportional to their representation (table 5),

Next, the locations of the transects required to cover the sampling requirements need to be determined. Owing to the rugged topography, existing roads and trails must serve as transect paths. Fortunately, the long history of human use in NWY means that trails are common, even across the most isolated regions. GIS-generated maps show the general location of roads and trails in relation to conservation targets (fig. 5), but determining the exact location of transects requires input from professionals and local people knowledgeable of the region.

Future sampling

The baseline photomonitoring survey will be completed over the next two or three years, yielding thousands of images across the YGRP area. The health indicators identified in this project change relatively slowly, but there is little doubt that repeated photographs 50-100 years hence will illustrate marked differences (Moseley 2004). However, if repeat photomonitoring is to be useful to conservation planning by TNC and others, it must yield insights much quicker, within a decade or less.

It is expected that photo-sample points will be relocated and landscapes re-photographed in 3-8 years. This time period will illustrate relatively little ecological change in undisturbed landscapes. However, socio-economic conditions are changing quickly in NWY leading to rapid changes in land-use and infrastructure, which are represented by changes in threat indicators. For example, a current government program aimed at rehabilitating many over-grazed lands is fencing thousands of hectares

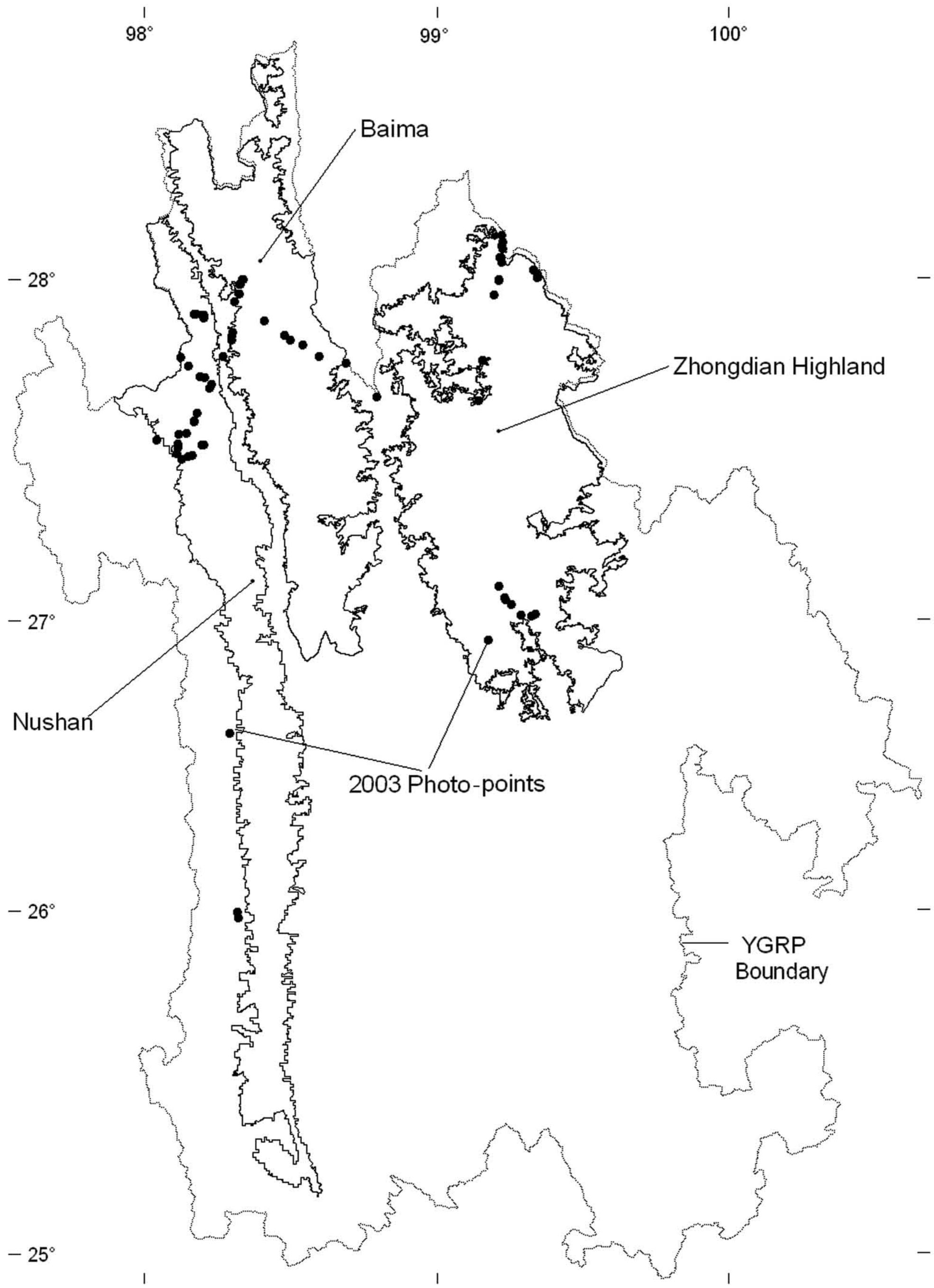

Figure 4. Location of 2003 Photo-points Across three Conservation Areas in the Yunnan Great Rivers Project (YGRP) Area.

across the region ('Grazing to Grassland'), roads are being built to improve access to remote areas as well as to open new routes for mining and tourism development, and the 1998 logging ban remains in effect. In addition, intensive conservation efforts underway by TNC and other organizations and government agencies are influencing indicators of target health and threats. Hence, it is highly probable, depending on the location, the degree of human disturbance, and the type and extent of conservation interventions, that marked changes in certain landscapes might be detected within a few years. How TNC and its partners address these changes in relation to their conservation activities across the YGRP area is a challenge they are currently addressing. In any case, the systematic and complete ecoregional photomonitoring of NWY will provide one tool, an analyzed visual database, to help with such determinations.

Conclusions

This project developed a forward-sampling, ground-based photomonitoring system for examining ecological changes in landscapes within five major ecoregions in northwestern Yunnan, China. It is unique in its design, as other studies rely on historical photographs to support conclusions concerning the present ecological conditions of the landscapes in question. The approach reported will yield a comprehensive inventory of such conditions over time and a means for analyzing visual indicators of ecological change across extensive ecoregion.

Three features of this study are critical to its future success as a tool for measuring the impact of conservation programs. First, is the use of high quality photography techniques and the efficient management of the resulting images and metadata. Second, is the design of an analytical framework for identifying and measuring visual indicators of change that are tied to a comprehensive conservation planning scheme, here TNC's Conservation by Design process. Lastly, is the design of a sampling methodology that accounts for the variation inherent in the ecoregions under consideration.

This project was designed within a conservation context specific to protecting biodiversity and local livelihoods in northwestern Yunnan. Hence, it will prove useful in monitoring not only TNC-specific activities in the region, but also the efforts of other organizations and government agencies concerned with the conservation and sustainable development of this particular biodiversity hotspot. However, this methodology also should be adaptable to other locations and different conservation contexts – especially situations where detailed ecological data are sparse, access to aerial photographs and satellite data is limited, and relatively rapid and inexpensive landscape-level or ecoregional inventories are needed.

References

Cardinal, D.; Peterson, B. M. 2001. The D1 generation. Moose Press, Mammoth Lakes, California. 255 p.

Cardinal, D.; Peterson, B. M. 2002. The D100 D1 generation update: an eBook. Moose Press, Mammoth Lakes, California. CD-R. 101 p.

CBD (Convention on Biological Diversity). 2001. Global biodiversity outlook. Secretariat of the Convention on Biological Diversity, Montreal, Canada. (1 November 2002; www.biodiv.org/gbo/).

Groves, C. G. 2003. Drafting a conservation blueprint. Island Press, Washington, D.C., 457 p.

Groves, C. G.; Jensen, D. B.; Valutis, L. L.; Redford, K. H.; Shaffer, M. L.; Scott, J. M.; Baumgartner, J. V.; Higgins, J. V.; Beck, M. W.; Anderson, M. G. 2002. Planning for biodiversity conservation: putting conservation science into practice. BioScience. 52(6): 499-512.

Hall, F. C. 2001. Ground-based photographic monitoring. General Technical Report PNW-GTR-503, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon. 340 p.

Li, Bo. 2002. The lost horizon: in search of community-based natural resource management in nature reserves of northwest Yunnan, China. MS Thesis, Cornell University, Ithaca, New York. 257 p.

Lunt, I. D. 2002. Grazed, burnt and cleared: how ecologists have studied century-scale vegetation changes in Australia. Australian Journal of Botany. 50(4): 391-407.

Meagher, M.; Houston, D. B. 1998. Yellowstone and the biology of time: photographs across a century. University of Oklahoma Press, Norman, Oklahoma. 287 p.

Moseley, R. K. 2004. Ninety years of landscape change in the Tibetan region of Yunnan, China. The Geographical Journal. (in press).

Moseley, R. K.; Tam, C.; Mullen, R.; Long Y. C.; Ma J. Z. 2004. A conservation project management process applied to mountain protected area design and management in Yunnan, China. In: Harmon, D.; Worboys, G., eds. Managing mountain protected areas: challenges and responses for the 21st century. Andromeda Editrice, Colledara, Italy: 227-234.

Myers, N.; Mittermeier, R. A.; Mittermeier, C. G.; da Fonseca, G. A. B.; Kent, J. 2000. Biodiversity hotspots for conservation priorities. Nature. 403(6772): 853-858.

Olson, D. M.; Dinerstein, E. 1998. The Global 2000: a representation approach to conserving Earth's most biologically valuable ecoregions. Conservation Biology 12(3): 502-515.

Pickard, J. 2002. Assessing vegetation change over a century using repeat photography. Australian Journal of Botany. 50(4): 409-414.

Rogers, G. F.; Malde H. E.; Turner, R. M. 1984. Bibliography of repeat photography for evaluating landscape change. University of Utah Press, Salt Lake City, Utah. 179 p.

TNC (The Nature Conservancy). 2001. Conservation by design: a framework for mission success. The Nature Conservancy, Arlington, Virginia. (5 October 2003; www.conserveonline.org).

Turner, R.; Webb M.; Bowers, R. H.; Hastings, J. E.; Rodney, J. 2003. The changing mile revisited: an ecological study of vegetation change with time in the lower mile of an arid and semiarid region. The University of Arizona Press, Tucson, Arizona. 334 p.

Xu, J.C.; Wilkes, A. 2004. Biodiversity impact analysis in northwest Yunnan, southwest China. Biodiversity and Conservation. 13(5): 959-983.

YGRPPT (Yunnan Great Rivers Project Planning Team). 2002. Yunnan Great Rivers Project: northwestern Yunnan ecoregional conservation assessment. The Nature Conservancy, Kunming, Yunnan, China. 78 p.

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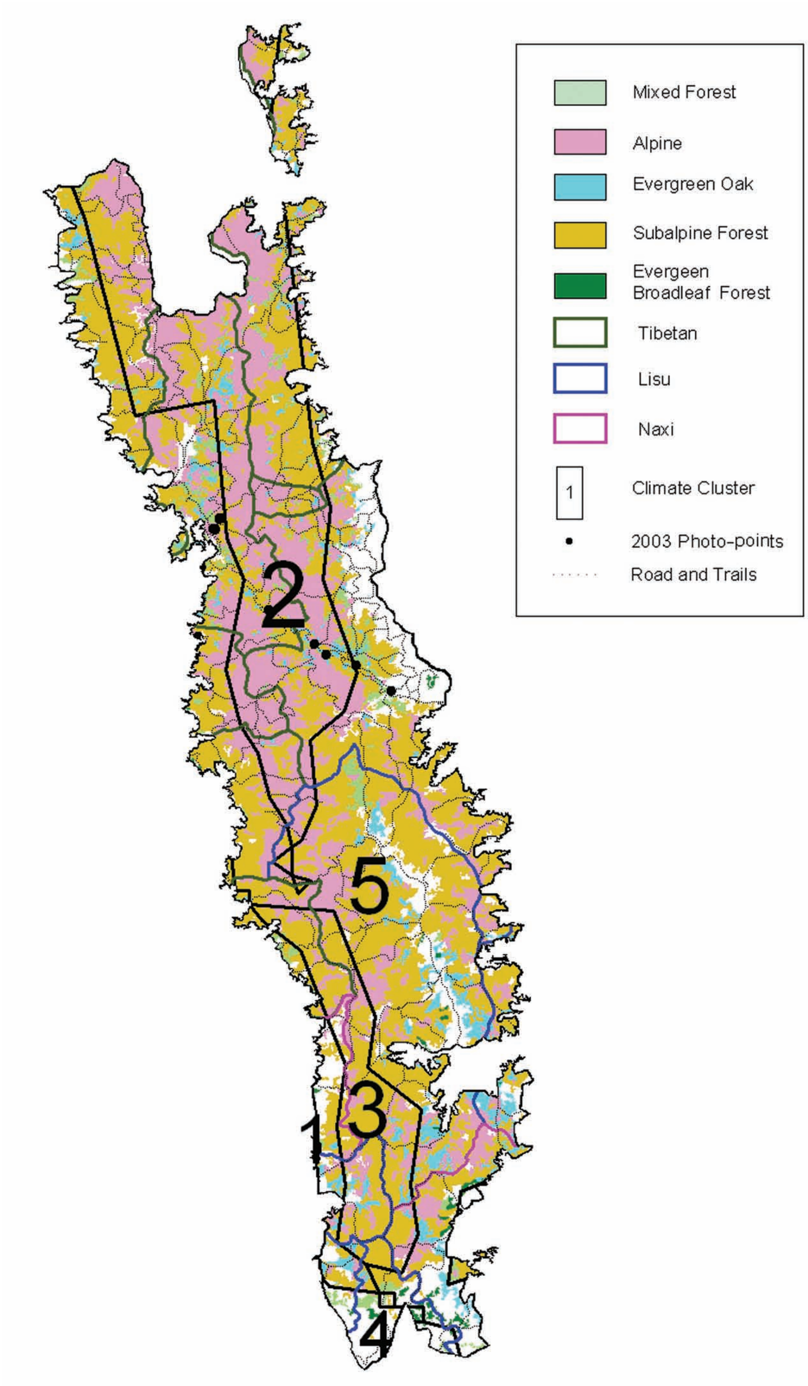

Figure 5. Distribution of 2003 Photo-points in Relation to Conservation Targets, Ethnic Minorities, Climatic Clusters (Zones) (see table 1 for key), and Trails and Roads in Baima Conservation Area, Nujiang-Lancang Gorge Ecoregion, Yunnan Great Rivers Project (YGRP).