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Research Priorities for Neotropical Dry Forests[1]

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ABSTRACT

Our understanding of the human and biophysical dimensions of tropical dry forest change and its cumulative effects is still in the early stages of academic discovery. The papers in this special section on Neotropical dry forests cover a wide range of sites and problems ranging from the use of multispectral and hyperspectral remote sensing platforms to the impact of hurricanes on tropical dry forest regeneration. Here, we present to the scientific community the results of a workshop on which research priorities for tropical dry forests were discussed. This discussion focuses on the need to develop linkages between remote sensing, ecological, and social science research. The incorporation of social sciences into ecological research could contribute dramatically to our understandings of tropical dry forests by providing important contextual information to ecologists, and by helping to develop an important science–policy–public nexus on which environmental management can succeed.

RESUMEN

El conocimiento actual de las dimensiones humanas y biofísicas de los cambios en los bosque secos tropicales y sus efectos acumulativos esta en las etapas iniciales del descubrimiento académico. En este articulo, introducimos una serie de artículos científicos asociados a este número especial sobre bosques secos en los Neotropicos. Estos artículos provienen de una distribución muy variada de sitios en las Américas y van desde las aplicaciones de sensores multi- e hiperspectrales, hasta el estudio del efecto que los huracanes causan en la regeneración de los bosques secos. Presentamos a la comunidad científica los resultados de un taller dirigido a la discusión de aquellas prioridades de investigación en bosques secos. La discusión se enfoca a lo largo de los vínculos que se necesitan entre percepción remota, ecología y ciencias sociales. La incorporación las ciencias sociales dentro de la investigación ecológica podría contribuir dramáticamente al entendimiento de los bosque secos tropicales, así como tienen len a posibilidad de ayudar en el desarrollo de vínculos importantes entre ciencia y política dirigida al manejo de los recursos presentes en este importante ecosistema.

Key words: ecological succession; remote sensing; social science; sustainable forest management; tropical dry forest ecology; tropical dry forests; TROPI-DRY.

THE BIODIVERSITY OF HUMAN-DOMINATED LANDSCAPES is strongly linked to the socioeconomic (political, economic, and cultural) and biophysical forces driving land use and land cover change. These forces, acting at different scales (from the international sphere to the production unit), contribute to regional environmental deterioration patterns that in many cases can only be fully understood using well-designed, integrated, multi- and trans-disciplinary approaches.

Forty nine percent of the vegetation of Mesoamerica (southern Mexico and Central America) and the Caribbean, along with 42 percent of all intratropical forest vegetation worldwide is considered tropical dry forest (Murphy & Lugo 1995). Various political and economic factors have increased anthropogenic stresses in these ecosystems, leading to severe disturbances and widespread clearing. In this ecosystem, environmental and biotic constraints on human activities are lower compared to other tropical life zones, which tend to be too cold, too hot, too dry, or too wet (Ewel 1999). Therefore, dry forests have been the preferred zones for agriculture and human settlement in Mesoamerica, the Caribbean, and South America (Murphy & Lugo 1986, 1995; Maass 1995; González 2003) and are among the most heavily utilized, perturbed, and least conserved of the large tropical ecosystems (Quesada & Stoner 2004).

Currently, dry forest research has lagged behind research in tropical moist or rain forests, where, for many complex political and institutional reasons, international funding has been more prominent (Quesada & Stoner 2004; Sánchez-Azofeifa *et al.* 2005). Our understanding of the human and biophysical dimensions of tropical dry forest change and its cumulative effects is still in the early stages of academic discovery. Between 1945 and 2004, approximately

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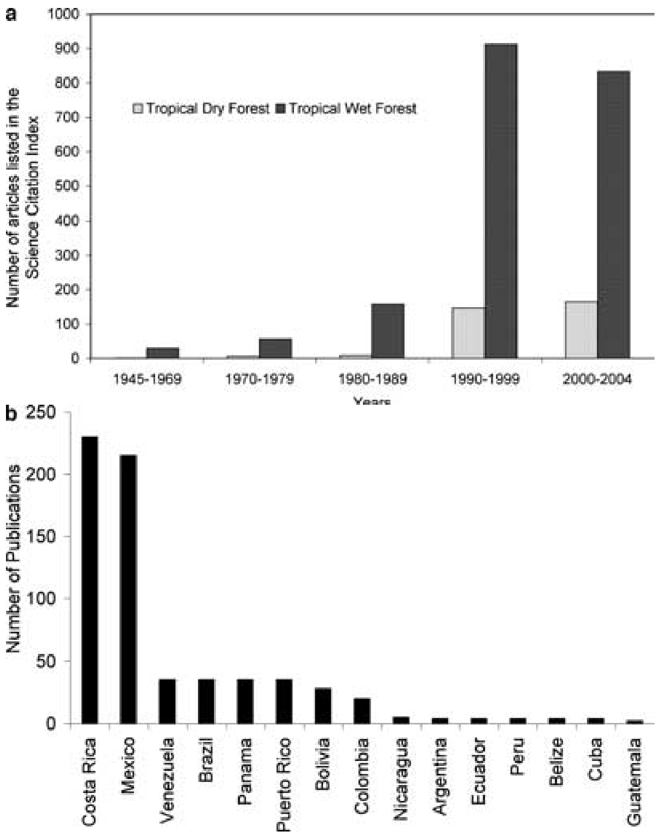

FIGURE 1. Distribution of scientific papers between 1945 and 2004 for tropical dry and tropical wet forests (a) and distribution of scientific papers produced from tropical dry forests by country (b).

14 percent of the articles on tropical forest research listed in the Science Citation Index focused on dry forests, whereas 86 percent referred to wet forests (Fig. 1a). Efforts aimed at generating information regarding tropical dry forests are scattered and limited to a few sites worldwide. Most published studies in the Neotropics describe research conducted in limited number of sites in Mexico and Costa Rica (Fig. 1b).

Long-term, systematic, and coordinated efforts must be undertaken to understand and integrate our biological knowledge of tropical dry forests with the social and ecological drivers that determine their change (Fig. 1a and b). The TROPI-DRY network was created in 2004 to meet this challenge and to bring together researchers in conservation biology, ecology, remote sensing, and social sciences to develop a comprehensive, "state-of-the-art" understanding and explanation of the structure, functioning, and dynamics of tropical dry forest ecosystems (Fig. 2). The unifying topic in the research agenda of TROPI-DRY is the study of the natural regeneration of tropical dry forests in the Americas in the context of ecosystem services provided to human society. The TROPI-DRY agenda and goals focus on developing a common multidisciplinary strategy in collaboration with local and national policy-making organizations actively working in regions of tropical dry forest within the network. Our ultimate objectives are to develop a critical mass of local scientific capacity able to conduct comparative studies on tropical dry forests using standardized protocols and to make this information widely available. The linkage between physical, ecological, and social sciences in TROPI-DRY is directed toward creating interconnections and permanent dialogue among all disciplines involved. TROPI-DRY is composed of researchers from Brazil, Canada, Costa Rica, Cuba, Mexico, the United States, and Venezuela.

TROPI-DRY defines tropical dry forests in a broad sense as a vegetation type typically dominated by deciduous trees (at least 50% of trees present are drought deciduous), where the mean annual temperature is $\geq 25°C$, total annual precipitation ranges between 700 and 2000 mm, and there are three or more dry months every year (precipitation < 100 mm/mo). Other forms of associated vegetation types may be included in the matrix of the tropical dry forest such as savannas, coastlines, gallery forests, and mangroves.

This special section is presented to the tropical biology community in the context of the goals of the TROPI-DRY network and our consensus regarding research priorities for tropical dry forests. In this introductory position paper, we first describe the scope and relevance of the papers published in this special section. Next, we present a series of basic recommendations on research priorities for tropical dry forests derived from an international workshop sponsored by the Inter-American Institute (IAI) for Global Change Research and held in August 2004 in Los Inocentes, Costa Rica. Finally, we close with a discussion on the need for further linkages between ecological research in tropical dry forests and the science–policy interface.

Our recommendations derive from discussions among the three working groups currently existing within TROPI-DRY: ecology, remote sensing, and social sciences. Although the ecological and remote sensing component are commonly discussed in the tropical biology community, the human component is rarely considered in depth, despite the widespread view in the literature that recognizes people as an integral part of ecosystems (Sauer 1956; Budowski 1965; Nigh & Nations 1980; Balée 1988, 1989; Williams 1990, 1998; Bawa *et al.* 2004). The social (ethnic, cultural) and individual praxis and ideology of humans have been appropriately considered as triggers of environmental change (Zent & Zent 2004a) and at least over the last 15 years, scientists have increasingly recognized that the complexity of environmental functioning and problems can only be understood by including humans in the analysis (Gunderson *et al.* 1995, Folke *et al.* 1996, Pace & Groffman 1998, Holling 1998, Berkes & Folke 2000, O'Neill 2001, Bawa *et al.* 2004). TROPI-DRY's research agenda strives to give the same priority and analytical weight to each research branch (ecology, geography, and social). Finally, we close our position paper with a discussion on the need for further linkages between ecology and the science–policy interface.

SCOPE AND RELEVANCE OF THIS SPECIAL SECTION

This special section presents ten contributions from research conducted in tropical dry forest sites spanning a wide latitudinal

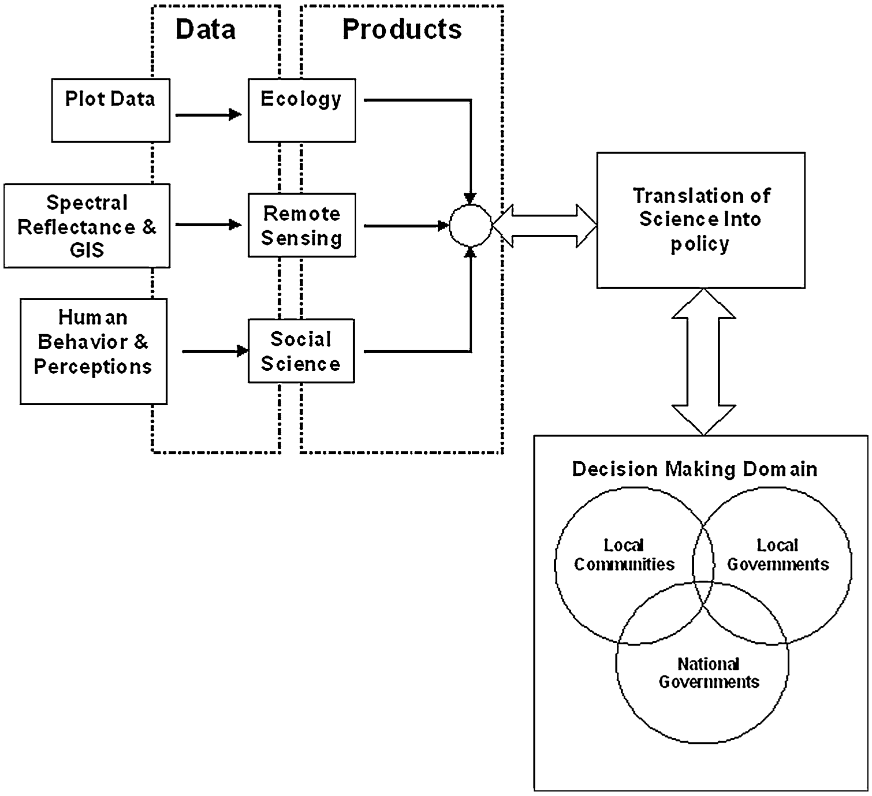

FIGURE 2. TROPI-DRY conceptual framework.

gradient and climatic variation (Fig. 3). The first five papers explore the use of remote sensing in studying ecosystem structure and composition at five different tropical dry sites. These contributions highlight emerging links between ecosystem structure/composition and tropical remote sensing data, and illustrate how different spectral analysis techniques and approaches at the multispectral level can be used to characterize different stages of tropical dry forest succession. The first of these papers presented by Kalacska *et al.* (2005) deals with the effects of successional stage on leaf area index and spectral vegetation indices derived from remote sensing (Landsat TM, 30 m spatial resolution) in three Mesoamerican tropical dry forests. Arroyo-Mora *et al.* (2005) expand on the previous paper by examining how high-resolution remote sensing information from the IKONOS satellite (4 m spatial resolution) can be used in conjunction with Landsat TM to define more precisely the extent of different successional stages at the Santa Rosa National Park, Costa Rica. Feeley *et al.* (2005) explore the use of different spectral indices derived from Landsat TM to study linkages between ecosystem structure and composition of tropical dry forest communities in Lago Guri, Venezuela. Ruiz *et al.* (2005) describe changes in vegetation structure, composition, and species richness across a 56-yr chronosequence of tropical dry forest in Providencia Island, Colombia, based on study sites selected using Landsat TM data and aerial photographs. Fajardo *et al.* (2005), also using Landsat TM information, provide the first validated estimation of the extent and degree of fragmentation and protection of tropical dry forests of Venezuela.

Departing from the use of multispectral remote sensing addressed in the past papers, Gamon *et al.* (2005) present a new approach for linking hyperspectral reflectance data with leaf photosynthesis properties during the dry season at the canopy crane site in Parque Natural Metropolitano, Panama. The authors directly assess the validity of remote sensing vegetation indices as measurements of canopy light absorption (APAR) and describe how these indices can be linked to photosynthesis down-regulation and associated declines in instantaneous photosynthetic light-use efficiency. This study is the first conducted in tropical forests to examine these processes at this spectral scale.

Four papers in this special section focus specifically on ecological studies of Neotropical dry forests in Mexico, Jamaica, and Puerto Rico. Lawrence (2005) examines effects of forest age and rainfall on patterns of litterfall in secondary tropical dry forests from the Yucatan Peninsula, Mexico. Van Bloem *et al.* (2005) explore the influence of hurricanes on the structure and composition of tropical dry forests in a Puerto Rican tropical dry forest. McLaren and McDonald (2005) describe temporal variations in reproductive phenology in a tropical dry forest of Jamaica and evaluate how these patterns are correlated with rainfall seasonality. Finally, Stoner (2005) compares ground-level phyllostomid bat community structure between two tropical dry forests with different precipitation

FIGURE 3. Origin of papers presented in this special issue. Seasonal and dry tropical forests are indicated in light green.

regimes in Mexico and Costa Rica, documenting differences in bat communities and relating these differences to ecosystem structure and composition.

In summary, these papers first present a panoramic view of the application of state-of-the-art remote sensing science to characterize the status and extent of Neotropical dry forests. Second, these papers demonstrate how tropical dry forests respond to different anthropogenic and natural disturbances and to climatic gradients in rainfall and seasonality. They showcase emerging issues associated with interdisciplinary work between ecology and remote sensing, which is moving from multispectral remote sensing (*e.g.*, Landsat TM and IKONOS) to hyperspectral remote sensing satellites (*e.g.*, NASA's EO-1 satellite).

RESEARCH PRIORITIES IN TROPICAL DRY FORESTS

The recommendations presented here are the product of a workshop held at Los Inocentes, Guanacaste, Costa Rica, between 8 and 15 August, 2004. We recognize that these recommendations are not exhaustive since each area may present specific demands that are discipline-dependent. However, we aim to define a common framework for comparative studies between tropical dry forests in the Americas. Our vision is to establish an ecological network that generates comparable baseline datasets and that continues to expand both quantitatively and qualitatively on behalf of tropical dry forest research. Expansion can take place by the addition of new study sites and institutions, or by the incorporation of new disciplines and methodological approaches. Even though the network initially comprised the current TROPI-DRY partners located in Brazil, Canada, Costa Rica, Cuba, Mexico, United States, and Venezuela, new partners will be added in locations that represent major gaps in our knowledge of tropical dry forests. We undertake our synthesis as a decentralized, distributed network that transcends the work of individual scientists and fosters multisite, multi-institutional efforts.

ECOLOGICAL RESEARCH PRIORITIES.—Ecological research in Neotropical dry forests has been uneven, both from a geographical and a disciplinary perspective, with most of the available knowledge originating from a handful of sites, such as Guánica in Puerto Rico, Guanacaste in Costa Rica, Chamela in Mexico, and the Brazilian Caatinga (Fig. 1a and b). The few studies at these sites have concentrated on topics related to floristic composition and structure, ecophysiology, plant reproduction, plant–animal interactions, primary productivity, and nutrient cycling, involving methods and spatial scales that generally vary across study sites (Bullock 1995). Vast dry forest areas in South and Central America (*e.g.*, in Bolivia, Colombia, Ecuador, Guatemala, Perú, and Venezuela), and the Caribbean (*e.g.*, in Bahamas, Cuba, Dominican Republic, Haiti, and Jamaica), remain virtually unstudied from an ecological perspective. In fact, the extent of the Neotropical dry forests itself remains an open question, as various existing definitions provide different area estimates (Fajardo *et al.* 2005). Although there have been attempts to communicate and estimate the status and degree of threat faced by tropical dry forests, many of these statements are based on expert opinion and cannot be verified quantitatively (Janzen 1988, Dinerstein *et al.* 1995, Quesada & Stoner 2004).

To advance our knowledge and improve our management of tropical dry forests, several fundamental questions must be addressed. First, we need to determine the distribution and extent of Neotropical dry forests (see Remote Sensing Research Priorities). We propose that the TROPI-DRY definition presented here be adopted widely and used to develop the definitive map of this ecosystem. The original extent can be estimated from a combination of historical sources and potential distribution maps based on climatological variables (Fajardo *et al.* 2005), whereas the current extent can be calculated using remotely sensed data and verified in the field. Quantitative measurements of the total change in land cover of Neotropical dry forests can be used to express the degree of threat that they face, while also generating a baseline for future monitoring.

Second, common ecological patterns should be identified within Neotropical dry forests, as well as the major differences among locations, using standardized methods that permit valid and robust comparisons across sites. How do species composition, forest structure, and phenology of Neotropical dry forests vary along a latitudinal gradient? If there is species turnover, are dominant functional groups present? Are diversity patterns in Neotropical dry forests similar to those observed in wet forests? Answers to these questions will set the stage for a better understanding of why Neotropical dry forests are found where they are, and will help to identify the principal ecological processes that maintain biodiversity in this ecosystem.

Finally, ecological research should focus on uncovering the basic mechanisms of regeneration of tropical dry forests. What is the relative importance of vegetative versus sexual reproduction? How dependent are Neotropical dry forests on plant–animal interactions for pollination and seed dispersal? What is the specific role and relative importance of different animal groups in the natural regeneration process? What is the influence of herbivory on species composition and forest dynamics? What are the differences in phenological responses estimated from remotely sensed data (*e.g.*, MODIS Aqua and Terra satellites) and the relationship to ecosystem composition and structure along a latitudinal gradient? Answers to these questions are fundamental for linking ecological knowledge of Neotropical dry forests with their conservation and sustainable use. As these ecosystems exist as a matrix of patches with different degrees of disturbance and recovery, detailed knowledge of regeneration mechanisms at different successional stages will assist ecological restoration efforts.

In the next decade, TROPI-DRY aims to make major contributions to the questions outlined above. Among the various proposed topics, we have identified several priority areas. Specifically, we plan to (1) develop a protocol for identifying different successional stages of tropical dry forests, and build a model of tropical dry forest succession; (2) compare tropical dry forest composition, structure, phenology, functional groups, and regeneration processes over a latitudinal gradient; and (3) quantify the ecosystem services provided by tropical dry forests in the Americas (mainly carbon sequestration).

We propose a methodological approach with two principal components: the creation of a tropical dry forest "Virtual Biodiversity Information Center" (VBIC) and the establishment of permanent field plots across a latitudinal gradient in the Neotropics. The tropical dry forest VBIC would be a web-based database and information exchange facility for integrating available bibliographical information with results from ongoing projects, as well as with specimen data obtained from museums and herbaria and ecological data. It would also be a clearing house of remotely sensed data, including an extensive spectral response database of various spectral reflectances of tropical dry forest successional stages along with their entire geographical extent. Likewise, VBIC would provide a user-friendly geographical information system interface, where visitors and users would be able to generate their own maps and perform spatial analyses (see http://www.eosl.eas.ualberta.ca/website/guanacaste/viewer.htm).

The second component involves implementation of a network of permanent field plots in each of the participating countries of TROPI-DRY. Plots would be chosen and designed systematically to provide the ecological information necessary to address the short-term objectives and questions outlined above. These plots will also be the setting for a series of long-term, recurrent ethnobotanical and ethnoecological structured interviews, used to understand local patterns in forest resource use, as well as the construction of the land-use history of the area (see Social Sciences Research Priorities). Standardized field protocols would be replicated in all plots for at least 5–10 yr, with the expectation that they would be maintained indefinitely. Ideally, the plots will serve as the first step in the creation of a network of Neotropical dry forest field stations.

Plots will be 1 ha in size, with three treatments related to their successional stage (3 replicates of each treatment = 9 plots): early, intermediate, and old growth (based on forest structure and composition). Standardized field protocols will be implemented including: (1) plant inventories (trees >2.5 cm DBH, lianas >1 cm DBH); (2) studies of reproductive and vegetative phenology, tree height and crown dimensions, and wood density; (3) censuses of annual plant growth and seedling demography; (4) studies of annual variability of leaf area index (LAI) via optical and littler trap approaches; (5) surveys of seed rain and seed bank composition at different soil depths; (6) surveys of animal populations, focused on key faunal groups that are important for pollination and seed dispersal (*i.e.*, insects, birds, bats, and rodents); (7) studies of plant–pollinator and plant–disperser interactions; (8) studies of functional aspects of regeneration, both aboveground (*e.g.*, seed germination, vegetative growth) and belowground (*e.g.*, mycorrhizae); (9) studies of soil processes, especially the diversity and functioning of mycorrhizae, nutrient levels, and gas emissions.

REMOTE SENSING RESEARCH PRIORITIES.—Remote sensing research priorities in tropical dry forest regions have been recently explored by Sánchez-Azofeifa *et al.* (2003). In addition to the priorities discussed in that paper, TROPI-DRY believes that there is a strong need to develop a common ground between the ecological, social sciences, and remote sensing communities along with common protocols for data collection in the field. The primary purpose of

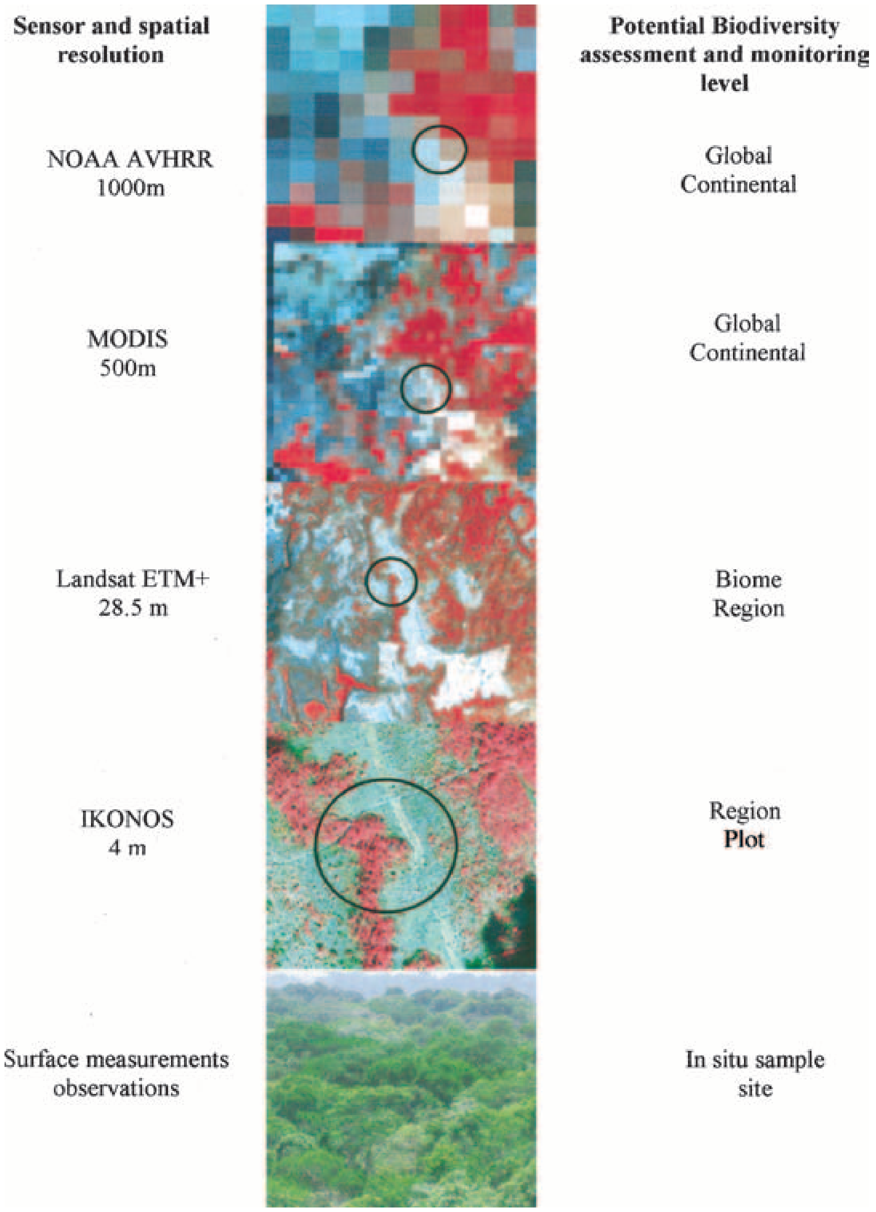

FIGURE 4. Spatial dimensions of tropical dry forest research based on remote sensing spatial resolution at the Santa Rosa National Park, Costa Rica. AVHRR = Advance Very High-Resolution Radiometer; MODIS = Moderate Resolution Imaging Spectroradiometer; and ETM+: Enhanced Thematic Mapper.

this common protocol is to facilitate the comparison of ecological studies and land-use history reconstructions of tropical dry forest sites, an issue that contributes to errors and confusion in remote-sensing-derived information (Castro-Essau *et al.* 2003; Kalacska *et al.* 2004). The challenge in establishing the protocols lies in the diversity of landscapes and land uses across sites, the different research topics, and the differences in data sources used (Fig. 4). This protocol must be flexible enough to accommodate the many different kinds of research taking place in tropical environments, and it should therefore be more concerned with ensuring compatibility and documentation, rather than with prescribing a certain type of procedure to be followed or specific kinds of data to be used. Moreover, the protocol must focus on the standardization and procurement of information products that can be used widely across disciplines as well as by the decision-making community. A recurring issue with the comparison of research results is the inability to compare studies conducted at different sites due to inconsistencies between different groups of researchers. These issues arise out of differences in sampling strategies and the diverse nature of the data collected. Thus we propose the following recommendations regarding the implementation of standardized protocols for the use of remote sensing information in tropical dry forests along three main areas: (1) mapping the true extent of the tropical dry forest in the Americas; (2) mapping the extent of tropical dry forest at each TROPI-DRY site; and (3) development of a spectral-diversity (leaf to landscape level) database for tropical dry forest environments.

Currently, we know very little about the true extent and degree of fragmentation of Neotropical dry forests. Regional efforts to map different types of ecosystems provide conflicting information on the definition of tropical dry forest and its extent. The development of a comprehensive map of the true extent of tropical dry forests in the Americas would apply the definition proposed in this paper and the methodological approaches presented in this special section (*e.g.*, Arroyo-Mora *et al.* 2005, Fajardo *et al.* 2005, Kalacska *et al.* 2005). Such a map would serve as a first step toward understanding the degree of fragmentation and level of conservation of the continent's tropical dry forest. The creation of this map should take advantage of current NASA monitoring efforts using MODIS Terra and Aqua satellites. Given the frequency of land cover data collection by these two satellites, we expect that the current map will serve as a baseline for updates at regular time intervals.

Although coarse information on the extent and status of the tropical dry forest can be provided by MODIS Terra and Aqua satellites, detailed information is needed to develop comprehensive sampling schemes by ecological researchers. To achieve this goal, we recommend that the remote sensing protocol should consider the integration of high- and medium-resolution remote sensing imagery. This specific component can help for long-term monitoring of changes in successional stages for a given region over the past 30 years (when the majority of remotely sensed data became available). Arroyo-Mora *et al.* (2005) describe this approach in detail, which eventually links to the selection of standard plot designs that can be used by both the remote sensing and ecological research groups. The data collection strategy on the ground should take into consideration two important parameters: size of the plot and the sampling size. Plot size can vary widely, depending on the data being collected, and it is not easy to set strict guidelines. Ecologists typically use a nested approach, going from the landscape scale (*e.g.*, 10,000 ha), to the landscape unit (*e.g.*, 50–100 ha), to the stand (1 ha), down to the sampling plot (10 m × 10 m). For some types of data collection, transects of small width (*e.g.*, 10 m) but considerable length (*e.g.*, 100 m) are being used. From the perspective of remote sensing, the sampling plot size is of interest. As a very simple guideline, a plot size should be chosen to match the spatial resolution of the satellite imagery, such that the plot covers an area of 3 × 3 pixels. In this manner one is assured of covering at least the average of a kernel window center on the 3 × 3 pixels. Combined with the common assumption of homogeneity within the sample plot, this would provide for a simple correlation between the sampled data and the reflectance as recorded in the satellite image. The use of higher spatial resolution imagery such as IKONOS (4 m spatial resolution) or Quickbird (2.4 m spatial resolution) could test this assumption. Alternatively, geostatistical analyses could define an "optimal" plot size for any particular region, using some established criterion for optimality. The advantage of such an approach is that the criterion can be applied elsewhere, or at some other time, and yield a plot size that would provide similar statistical properties, or other characteristics of the data collected without being specific to the type of satellite imagery used. Varying plot sizes could then be established in stands of different developmental stages, across large geographical regions, or throughout the different seasons of the year (*e.g.*, seasonality of leaf mass), while still maintaining a degree of compatibility between observations. Such a geostatistical procedure does not yet exist, but it would be of tremendous benefit in the effort to link remote sensing data with ecological plot research.

Finally, with the increased use of hyperspectral information, the remote sensing protocol should also focus on the development of site-specific hyperspectral databases of tree bark, plus tree and liana leaves, and flowers, as well as entire canopies in order to explore questions about the impact of phenology and drought effects on tree spectral reflectance. This database should also include ancillary information linked to factors contributing to spectral reflectance such as pigment concentration (chlorophyll and xanthophyll cycle), leaf internal structure, water content, and nitrogen concentration at the leaf level. In addition, this database should be flexible enough to provide easy access, manipulation, and comparison among the different collections conducted at each TROPI-DRY website. Hyperspectral information collected in the field can eventually be translated into optical-diversity indices via inverse modeling approaches that can provide conventional information on the status and extent of tropical secondary dry forests (Kalacska *et al.* 2004). The future of long-term monitoring of secondary tropical dry forests will be enhanced with the use of hyperspectral data for the various TROPI-DRY sites, as well as the use of this specific technology to estimate forest structure and diversity.

We recognize that many different approaches may exist for the interpretation of the extent of tropical dry forests. The proposed protocol is aimed to provide standardized information across sites, so comparative studies can be performed among the different TROPI-DRY research sites.

SOCIAL SCIENCE RESEARCH PRIORITIES.—The challenge of integrating concepts of human use of the environment with ecological research has occupied both scientists and policy makers for the last decades. TROPI-DRY proposes a multilevel approach linking social and ecological domains in tropical dry forests (Berkes & Folke 2000). The primary goal will be the incorporation of multiple knowledge sources into ecosystem management. This will entail a three-part data collection process incorporating social statistics, policy reconstruction, and embedded ecological knowledge. First, social statistics will analyze a set of indicators culled from population-based census data for each research site. These indicators include age/sex/income composition of each site, economic base and employment, changes in economic base over time, and urban/rural characteristics. Social statistics will be recorded as far back as possible at each site depending on the different records available (oral histories, historical and written records, landmarks, etc.). Second, environmental history and policy reconstruction will be collected by using historic documents, academic publications, and the collection of oral history data from interviews with local inhabitants and policymakers. Third, ecological knowledge and environmental perspectives will be obtained by interviewing key informants on the knowledge of local ecosystems and their use/management (*e.g.*, policymaker and institutional analysis related to environment conservation policies; local management practices, local objective, and subjective knowledge).

Other methods that will be used include ethno-botanical and ethno-ecological structured interviews at each plot, setting of local memory banks, and the reading and interpretation of satellite images by a sample of local people inquiring about environmental and social history. Quantitative ethnobotany and ethnoecology data will be obtained by a set of codified answers coming from structured interviews to understand the management of ecosystems by local people (Prance 1978; Prance *et al.* 1987; Phillips & Gentry 1993a,b; Phillips *et al.* 1994; Zent & Zent 2004b). The setting of memory banks will be conducted by recording the ecological and traditional knowledge of local people about crops (Nazarea *et al.* 1997; Nazarea 1998, 2005). Memory banks will preserve ecological cultural knowledge about the particular strategies of different human groups and their environment, including traditional uses and conservation guidelines. The memory banks will provide a useful source of conservation principles and guidelines to policymakers as well as a source of basic information for local people themselves. Lastly, the reading of satellite images by key local informants will enrich different historical accounts of each region under study. This will provide the political and territorial perspective of indigenous and local populations.

The investigation of social organization and the systems of rules that humans create for the management of common pool resources such as forests (Ostrom 1990) is crucial to complete our understanding of human interaction with ecosystems. Understanding how institutions and governments design and implement policies and how local actors interpret these policies and incorporate them into their management practices are also essential aspects of this analysis.

CONCLUDING REMARKS

The recommendations and suggestions presented here represent part of a broad spectrum of opinions on how to investigate and conserve tropical dry forest environments. We recognize that further discussion is necessary as more researchers become involved and develop new research initiatives within this rapidly disappearing ecosystem. These research initiatives must be inter-, multi-, and trans-disciplinary in nature. Strong linkages between the ecological, remote sensing and human dimensions of tropical dry forest research are necessary if we really want to make a difference in achieving sound sustainable development policies (Bawa *et al.* 2004). As we begin to assess the impact that our science has on decision-making, we believe that the suggestions presented here could serve as a basis for discussion in the three disciplines presented. These discussions appear to fit well into the research priorities recognized by the Association for Tropical Biology and Conservation (Bawa *et al.* 2004) and international research groups such as Diversitas (Rodríguez *et al.* 2005).

The incorporation of social sciences into ecological research will contribute dramatically to our understandings of tropical dry forests by providing important contextual information to ecologists (social statistics and policy history), by incorporating both expert and lay ecological knowledge, and by helping to develop an important science–policy–public nexus for launching successional environmental management efforts.

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