4 Land-Use and Land-Cover Change

Strategic Research Questions

6.1 What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics?
6.2 What are the primary drivers of land-use and land-cover change?
6.3 What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?
6.4 How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate?
6.5 What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years?

See Chapter 6 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Land-cover and land-use change affect the global climate system directly through biogeochemical and biogeophysical processes. Biogeochemical processes of land-cover and land-use change affect global climate by changing the chemical composition of the atmosphere. Deforestation, for example, is a major source of atmospheric CO_2 resulting from the oxidation and decomposition of tree biomass, because the vegetation that replaces forests frequently contains less carbon than the forests they replace. Biogeophysical processes of land-cover and land-use change affect the absorption and disposition of energy at the Earth's surface. The albedo (reflectivity) of the Earth's surface determines how much of the Sun's energy is absorbed, hence available at the surface in the form of heat. Vegetation transpiration and surface hydrology determine how the energy received at the surface of the Earth is partitioned into latent and sensible heat fluxes. Vegetation structure determines surface roughness, which in turn is directly related to momentum and heat transport.

A global modeling study has shown that the effects of projected changes in land cover lead to significantly different regional climatic conditions in 2100 as compared with climatic conditions resulting from atmospheric greenhouse gas forcings alone. For example, agricultural expansion produced significant additional warming over the Amazon Basin and a cooling of the upper air column and nearby oceans, as well as cooling and decreases in the mean daily temperature range over many mid-latitude areas. In another regional study, a CCSP collaborative research project used numerical modeling to evaluate the impact of anthropogenic land-cover change on the regional climate of south Florida. Simulations of regional climate using the Regional Atmospheric Modeling System compared climate patterns under modern and pre-development land cover reconstructed from paleoecological and historical records. Spatial patterns of surface sensible and latent heat flux differed significantly under the different land-cover schemes, and model results indicate that land-cover changes increased summertime maximum temperatures and decreased warm season convective rainfall by 10 to 12%. Refer to chapter references 4, 6, and 7 for detail regarding these illustrative findings.

HIGHLIGHTS OF RECENT RESEARCH

Global Geographically Registered Landsat Data Set.[11] Earth's land surface is spatially variable at scales of meters to tens of meters, due to local terrain variability and associated microclimatic influences on vegetation types and associations. Accordingly, spatial data at the scale of tens of meters are required to accurately map many areas, because of the low spatial autocorrelation of land-surface features. In addition, a variety of natural and human land-use changes (e.g., wildfires, deforestation, wetland conversion, and urbanization) represent alterations of landscapes, which also occur at spatial scales of tens of meters. These are important perturbations of the global environment and require similar spatial-scale data for quantification. Information is currently lacking about where environmental change is occurring, what the changes are, and what the post-change properties of the altered areas are. Landsat data are available at these spatial scales and are consequently extremely useful for studying land-use and land-cover change from space.

A global land data set having high spatial accuracy has been developed using Landsat Multi-Spectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper data from the 1970s, circa 1990, and circa 2000, respectively, to support a variety of scientific studies and educational purposes. This is the first time a geodetically accurate global compendium of multi-epoch digital satellite data at the 30- to 80-m spatial scale spanning 30 years has been produced for use by the international scientific and educational communities. These data are being distributed from multiple locations and are currently being used for land-use and land-cover change research (see Figure 21).

Landsat Mosaic over the Southern Portions of Lake Michigan

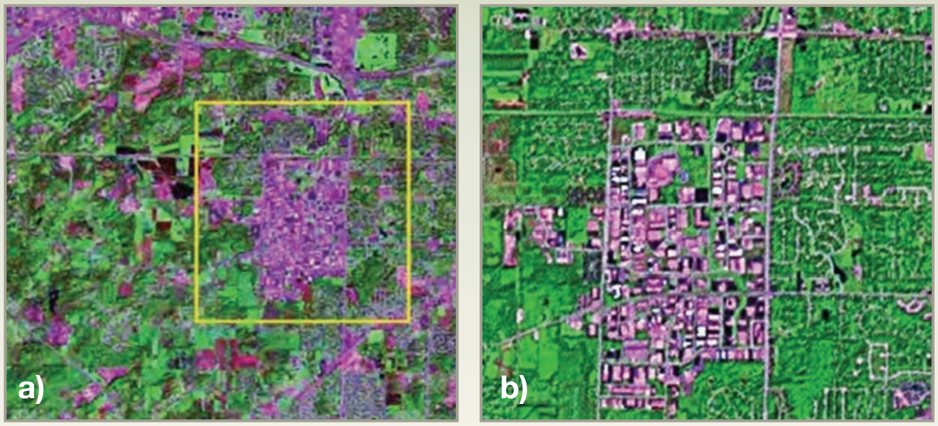


Figure 21: Landsat Mosaic over the Southern Portions of Lake Michigan. Landsat mosaic products over the southern portions of Lake Michigan and adjacent areas of the United States: (a) a full-resolution 28.5-m^2 subset for the circa 1990 epoch; and (b) a full-resolution 14.25-m^2 subset of the circa 2000 epoch. These are examples of the data available globally from NASA's Global Ortho-Rectified Landsat Data Set. *Credit: C.J. Tucker, NASA/ Goddard Space Flight Center.*

Understanding environmental or land-cover dynamics represents an important challenge in the study of the global environment, since many land-cover changes take place at fine scales of resolution, requiring Landsat-type imagery for accurate measurement. Uses for such data range from biodiversity and habitat mapping for localized areas to specifying parameters for large-scale numerical models simulating biogeochemical cycling, hydrologic processes, and ecosystem functioning. Recent work has stressed the importance of the effects of land-cover change on climate.

Landsat Ecosystem Disturbance Adaptive Processing System: A North American Forest Disturbance Record from Landsat.[8] Forest-cover conversion, disturbance regimes, and recovery from conversion and disturbance have been proposed as primary mechanisms for transferring carbon between the land surface and the atmosphere, but the area and timing of these processes is still poorly quantified. A pilot project, the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) has been initiated to "mine" the Landsat observational record, which spans more than 33 years, in order to assess forest disturbance across all of North America, in support of the CCSP's North American Carbon Program. Figure 22 shows an example of the products from this project.

Landsat Thematic Mapper and Enhanced Thematic Mapper data have been corrected for atmospheric obscuration using algorithms and processing approaches derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on the Terra and Aqua satellites. To date, some 2,200 Landsat images covering North America have been corrected, and can be downloaded from the LEDAPS web site, <ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html>. Disturbance and recovery are being mapped using a multi-spectral "Disturbance Index" algorithm. By late-2006, scientists will be able to download maps of forest change for the interval 1990 to 2000, both at full resolution (30 m) and coarse resolution suitable for carbon modeling (500 m and 0.05 degree). Later releases will cover the period 1975 to 1990. Funded by NASA, the LEDAPS project includes researchers from NASA, the U.S. Forest Service, and the University of Maryland.

LEDAPS Forest Disturbance Mapping

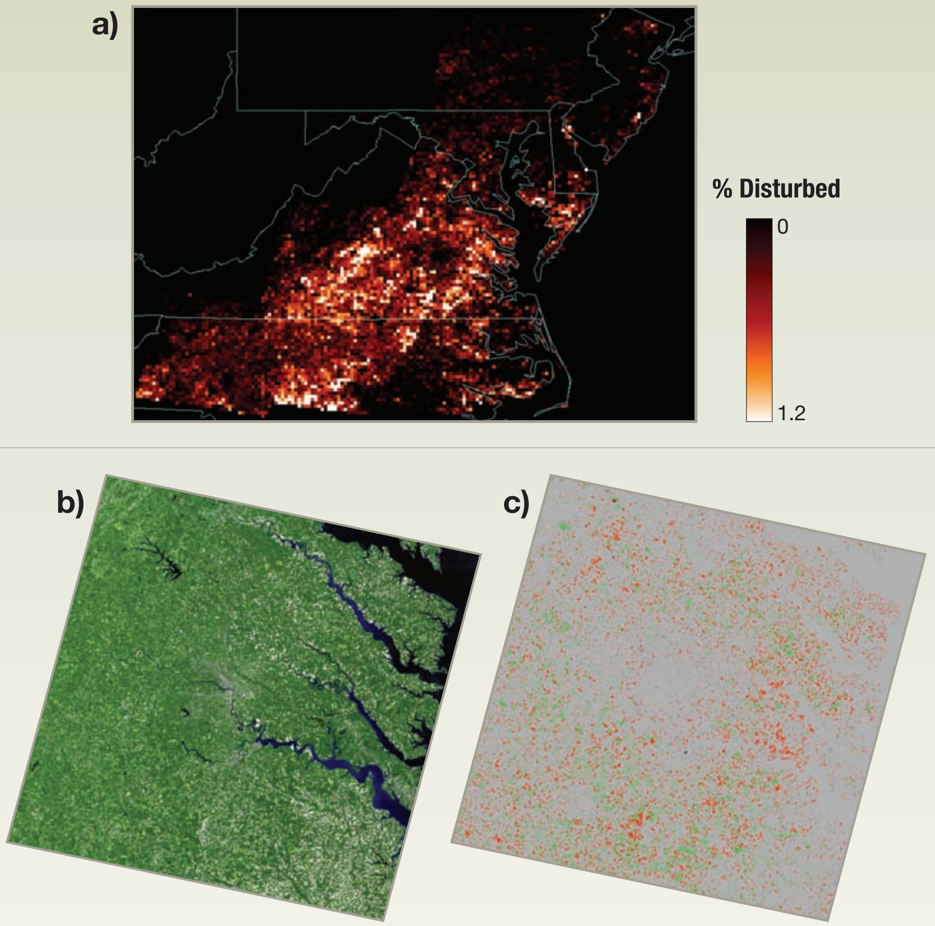
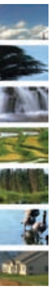


Figure 22: LEDAPS Forest Disturbance Mapping. These products provide examples of LEDAPS forest disturbance mapping: (a) 0.05° modeling grid showing the percent of each cell area disturbed (harvested) per year for the mid-Atlantic from 1990 to 2000; (b) atmospherically corrected Landsat surface reflectance image for the Richmond, Virginia, region; and (c) high-resolution map of forest disturbance (red) and regrowth (green) for the Richmond region, 1990 to 2000. *Credit: J.G. Masek, E.F. Vermote, N.E. Saleous, R. Wolfe, F.G. Hall, K. Huemmrich, F. Gao, J. Kutler, and T.K. Lim, NASA/Goddard Space Flight Center and the University of Maryland (reproduced from* **Geoscience and Remote Sensing Letters** *with permission from the Institute of Electrical and Electronics Engineers ©2006).*



Mapping 50 Years of Forest Conversion in Madagascar with Satellite Data. The Ortho-rectified Landsat Global Data were used to quantitatively determine the tropical moist forest, tropical deciduous forest, and spiny woodland of Madagascar for the 1970s, 1990, and 2000. The satellite data were analyzed and field verifications were performed by low-altitude aerial reconnaissance, errors in the analysis were corrected, and a more accurate classification for the entire island (590,000 km^2) produced. The satellite data were combined with aerial photographs to extend the work back to the 1950s.

Madagascar's forest cover decreased substantially over the 50-year period, from 27% of the island in the 1950s to only 16% circa 2000 (see Figure 23). Taking the fragmentation of forests into consideration, the decrease was even more drastic. From the 1950s to circa 2000, the area of "high-quality," or interior forest more than 1 km from a non-forest edge, decreased from 90,000 km^2 to less than 20,000 km^2, and the area in patches of greater than 100 km^2 decreased by more than half. Deforestation rates slowed in the 1990s for the tropical humid and dry forests, but not for the spiny forest. However, the clearing rates are still of concern among all forest types, considering the small portion of remaining habitat.

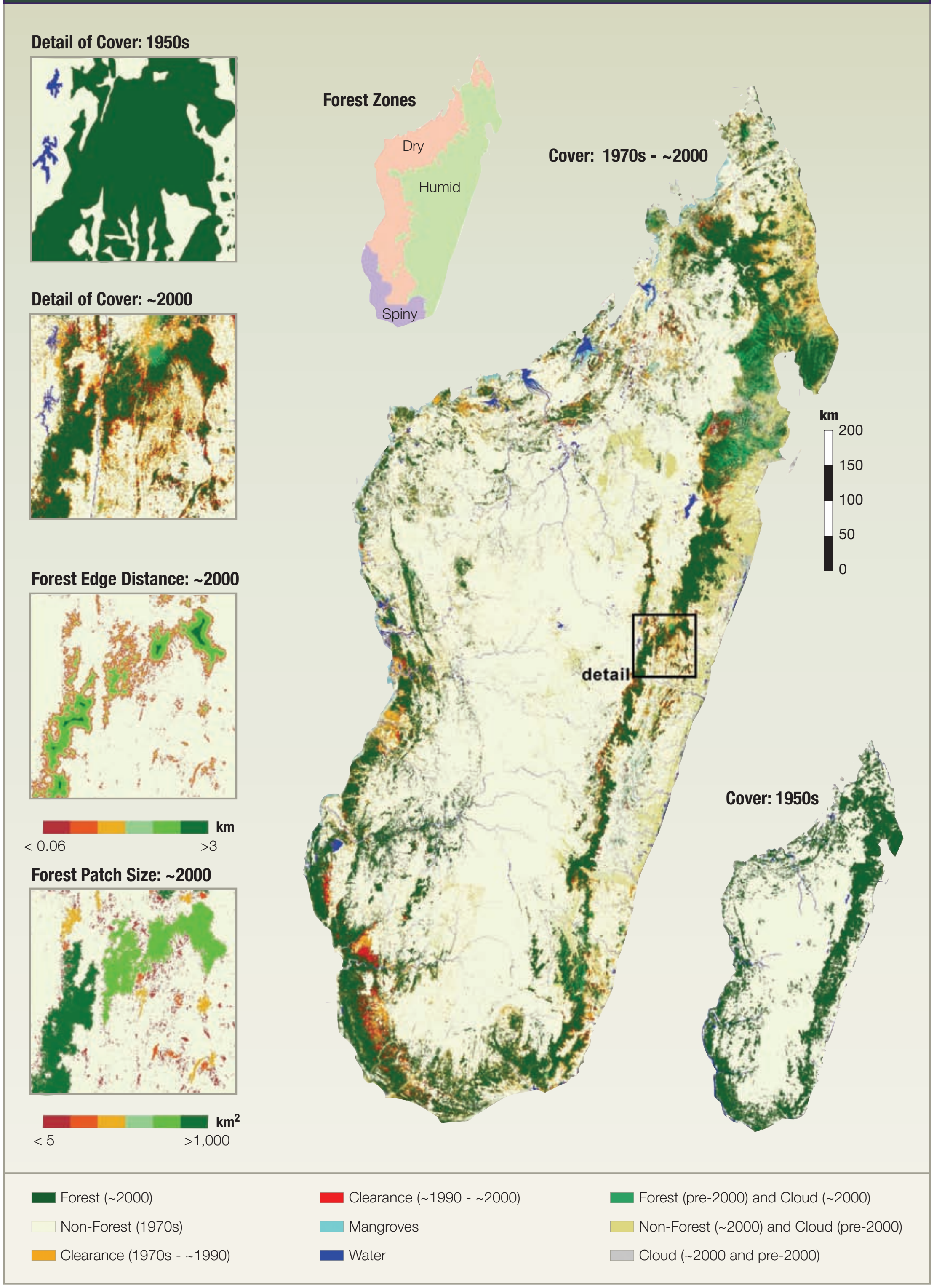
The results emphasize the need for more effective forest conservation in Madagascar. The researchers suggest goals of halting further primary forest clearance as soon as possible, and initiating strategically located forest restoration efforts. Given the lag time of species extinction after habitat destruction, it is probable that many species are living on borrowed time; forest restoration could partially mitigate this dynamic.

Land Cover, Land-Use Change, Human Dimensions, and Wildlife Conservation in Ngorongoro Conservation Area, Tanzania.[1] The Ngorongoro Conservation Area in Tanzania has a dense population of African wildlife that coexists with an expanding human population of Maasai agro-pastoralists and non-Maasai agriculturalists. The expanding human population has started to encroach upon the savanna areas that the wildlife and the domestic animals of the Maasai agro-pastoralists use in common. To complicate matters further, the savanna areas within the Ngorongoro Conservation Area are climatically variable and strongly influenced by El Niño and La Niña events: droughts are experienced under El Niño conditions and excessive rain occurs under La Niña conditions.

Landsat satellite data were used to map the conversion of pastoral areas to cultivation. By 2000, cultivation had increased to 40 km^2 of the 8,300-km^2

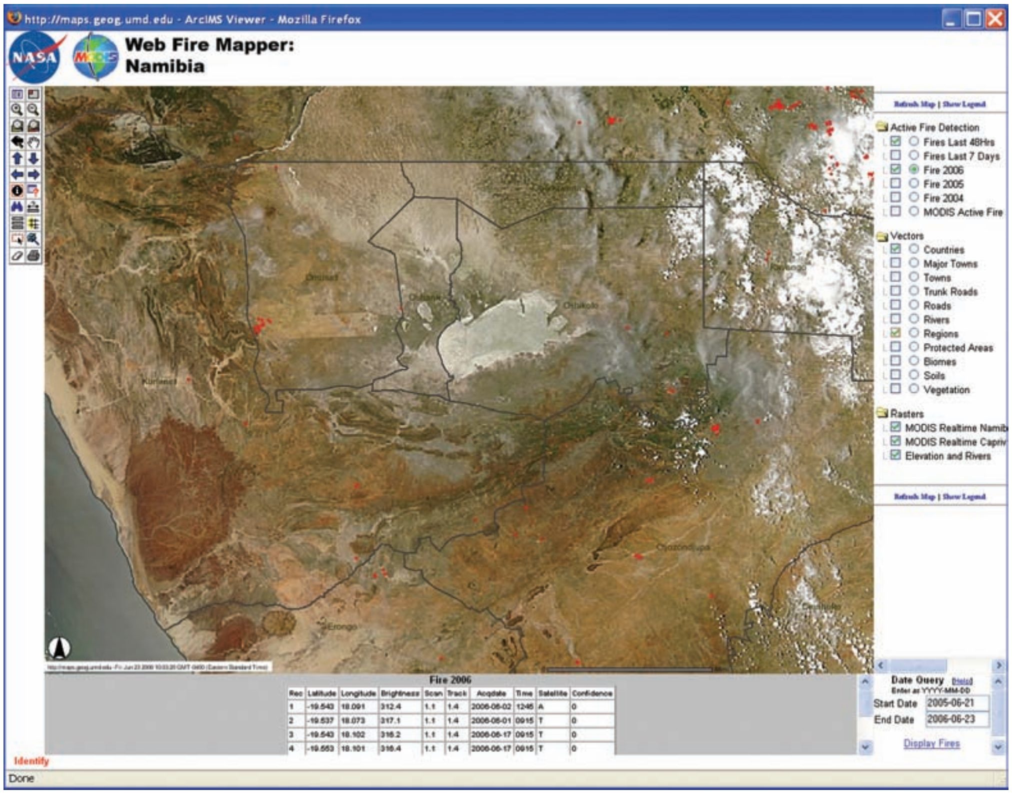
Figure 23: Forest Cover of Madagascar, 1950s to ~2000. Forest cover changes from the 1970s to circa 2000 are shown in the main figure. Forest cover in the 1950s is shown in the lower right inset. Boxes on the left show forest cover as well as forest near edges and in isolated patches. The bioclimatic zones used for reporting cover and rates of change are provided in the Forest Zones inset. *Credit: G. Harper, Conservation International.*

Forest Cover of Madagascar: 1950s - ~2000



Ngorongoro Conservation Area. While this was a miniscule amount of cultivation as of 2000, the potential for future increases in population and associated cultivation were modeled to assess impacts on the livelihoods of the population and on the various wildlife populations. Analysis of demographic and satellite data determined a linear relationship between population and area of cultivation. These results were extended into the future using the SAVANNA ecosystem simulation model. The study found that a doubling of the human population would lead to a doubling of the area of cultivation, to approximately 80 km^2 or 1% of the Ngorongoro Conservation Area, which would not have a negative effect on wildlife populations or on the Maasai agro-pastoralists. The work was jointly funded by USAID and NSF.

Fire Information for Resource Management System.[3] Until recently, protected area managers who wanted to use satellite-derived information to monitor fires burning within their area of jurisdiction faced considerable challenges—particularly those working in remote locations and with limited access to the Internet. Protected area managers usually want to know the locations of active fires within relatively small areas, generally their park and its surroundings. They also want this information delivered with minimal file sizes that can be accessed quickly and easily over the Internet. The CCSP Fire Information for Resource Management System is being developed to meet



Fire 2006

Rec	Latitude	Longitude	Brightness	Scan	Track	Acqdate	Time	Satellite	Confidence
1	-19.543	18.091	312.4	1.1	1.4	2006-06-02	1245	A	0
2	-19.537	18.073	317.1	1.1	1.4	2006-06-01	0915	T	0
3	-19.543	18.102	316.2	1.1	1.4	2006-06-17	0915	T	0
4	-19.553	18.101	316.4	1.1	1.4	2006-06-17	0915	T	0

Date Query [Help]
Enter as YYYY-MM-DD
Start Date 2005-06-21
End Date 2006-06-23

Figure 24: The Fire Information for Resource Management System. This tool provides web-based depictions of MODIS fire products for 1 day, in this case for Namibia. This same information is transmitted by cell phone as a text message to fire wardens in protected areas alerting them to the times and locations of the detected fires. This information has proven very useful for detecting and preventing incursions into protected areas in Africa and elsewhere. *Credit: D.K. Davies, University of Maryland (with permission from GIM International, <http://www.gim-international.com>).*

these requirements in three ways: by providing MODIS active fire information via an interactive web mapping interface; by providing true-color MODIS images, or subsets that show fires burning within specific conservation areas; and by delivering fire alerts through emails and cell phone text messages. Figure 24 provides an example of the interactive web depiction produced by this system.

Rural Sprawl an Important Land-Use Change.[2] Research jointly supported by NASA and USDA provides a comprehensive view of how the Nation's changing socioeconomic characteristics have wrought profound changes in land development, particularly in rural areas of the United States. Using archived data from the censuses of population, housing, and agriculture, the results indicate that one quarter of the 48 contiguous United States now consists of so-called exurban development with low-density housing (6 to 25 homes per km^2). This is a five-fold increase since 1950. The amounts are even higher in the eastern United States. These increases are largely at the expense of agricultural lands. Using remotely sensed data for the southeastern and mid-Atlantic states, the study also found that forest and agricultural land covers have decreased while urban and mechanically disturbed land areas have increased. The relatively widespread growth in U.S. population between 1950 and 2000, coupled with decreasing household sizes and increasing lot sizes, has resulted in major increases in rural sprawl in most regions of the United States, with the possible exception of the Great Plains region (see Figure 25). The information-driven economy has fueled rural sprawl by enabling people to make a living even in relatively isolated areas, including amenity rich areas like the upper Midwest and rural West.

Evidence of Climate Change Due to Historical Practices in Land-Use and Land-Cover Change.[9] The consequences of the land-use and land-cover practices of the ancient Mayans in sustaining a dense population in Central America might be instructive to our survival in a world with shrinking space and resources. They lived in present-day Mexico, Belize, and Guatemala, and maintained a population density of 700 to 800 people per km^2. Recently published research indicates that by AD 800, the Mayans had cut down or deforested all the tropical forests in the surrounding area. They used the wood for buildings, cooking, and manufacturing lime to pave great plazas and roads. The massive deforestation altered the pattern of rainfall, producing or exacerbating periods of drought. Mayan civilization was already in drastic decline when the Spaniards arrived in the 16th century. The present-day tropical forest in this area, once believed to be primeval, is actually only about 600 years old. This is one

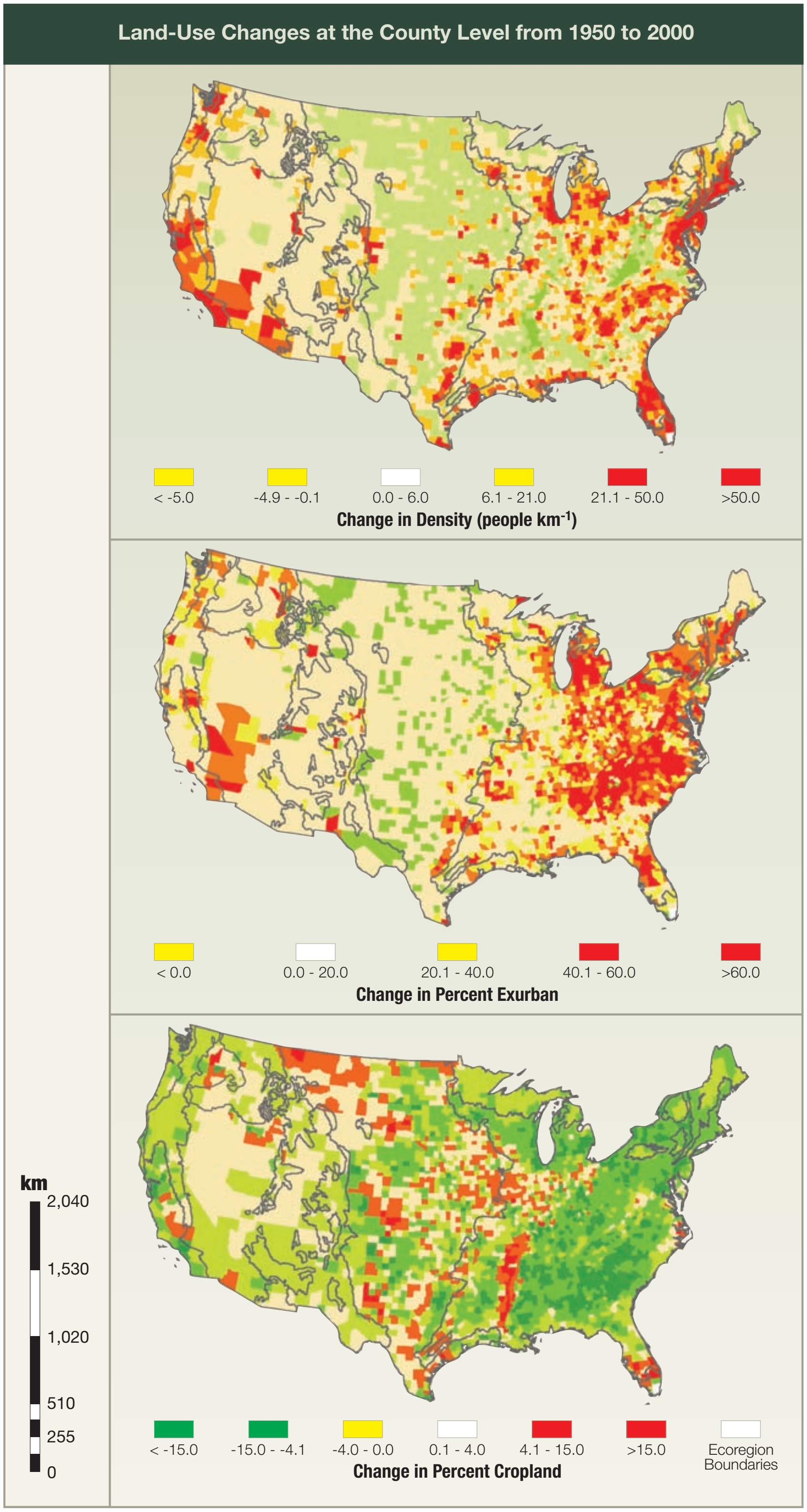
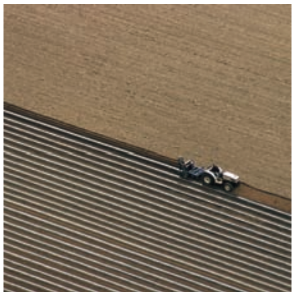


Figure 25: Land-Use Changes at the County Level from1950 to 2000. These products were generated using censuses of population, housing, and agriculture: (top) change in population density; (middle) change in land area settled at "exurban densities" (i.e., 1 house per 1 to 40 acres); and (bottom) change in percentage of cropland. *Credit: D.G. Brown, University of Michigan (reproduced from* **Ecological Applications** *with permission from the Ecological Society of America).*

example of historical land-use and land-cover changes that have affected many previous cultures and contributed to their collapse.

Satellite and aircraft remote-sensing techniques were used in this study to find abandoned Mayan cities (see Figure 26), water storage areas, and agricultural fields to document the extent of Mayan occupation of their Central American landscape. The same satellite remote-sensing techniques that are widely used to study present day land-use and land-cover change also play a key role in understanding historical land-use and land-cover change, such as that of the Mayan culture.



Urbanization, Land-Use and Land-Cover Change, and the Carbon Cycle: Consequences for Net Primary Productivity in the United States.[5] Using a combination of daytime and nighttime satellite data and a biophysical model, estimates of the impact of urbanization on net primary production have been made. Nighttime images from the Defense Meteorological Satellite's (DMSP) Operational Linescan system were used to create a thematic map portraying the extent and spatial distribution of urbanized, semi-urbanized, and non-urbanized areas in the lower 48 states (see Figure 27, top panel). The DMSP-based urban categories were geo-registered to a 12-layer map of monthly maximum normalized difference vegetation index values derived from the Advanced Very High Resolution Radiometer (AVHRR) sensor and a digital land cover map. Monthly net primary production values were calculated over the course of a year for all land-cover types and summed to provide a map of total annual net primary production for the United States at 1-km spatial resolution (see Figure 27, lower panel). The net primary production is the product of the Carnegie

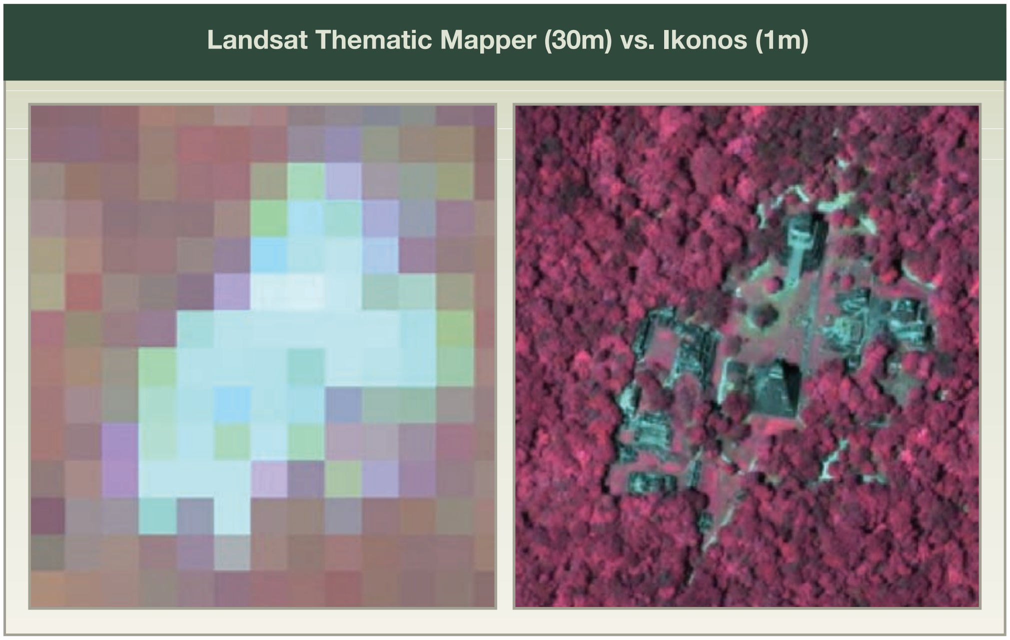
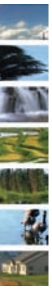


Figure 26: Landsat Thematic Mapper (30m) vs. Ikonos (1m). A side-by-side comparison of Landsat Thematic Mapper 30m (left) and Ikonos 1m (right) false-color imagery shows the ancient ruins of Tikal—a Mayan city deep in the Guatemalan rainforest that was lost for almost 1,000 years. The Ikonos imagery resolution of approximately 1 meter can detect individual pyramids, pathways, and small structures. *Credit: T.L. Sever, NASA/ Marshall Space Flight Center.*



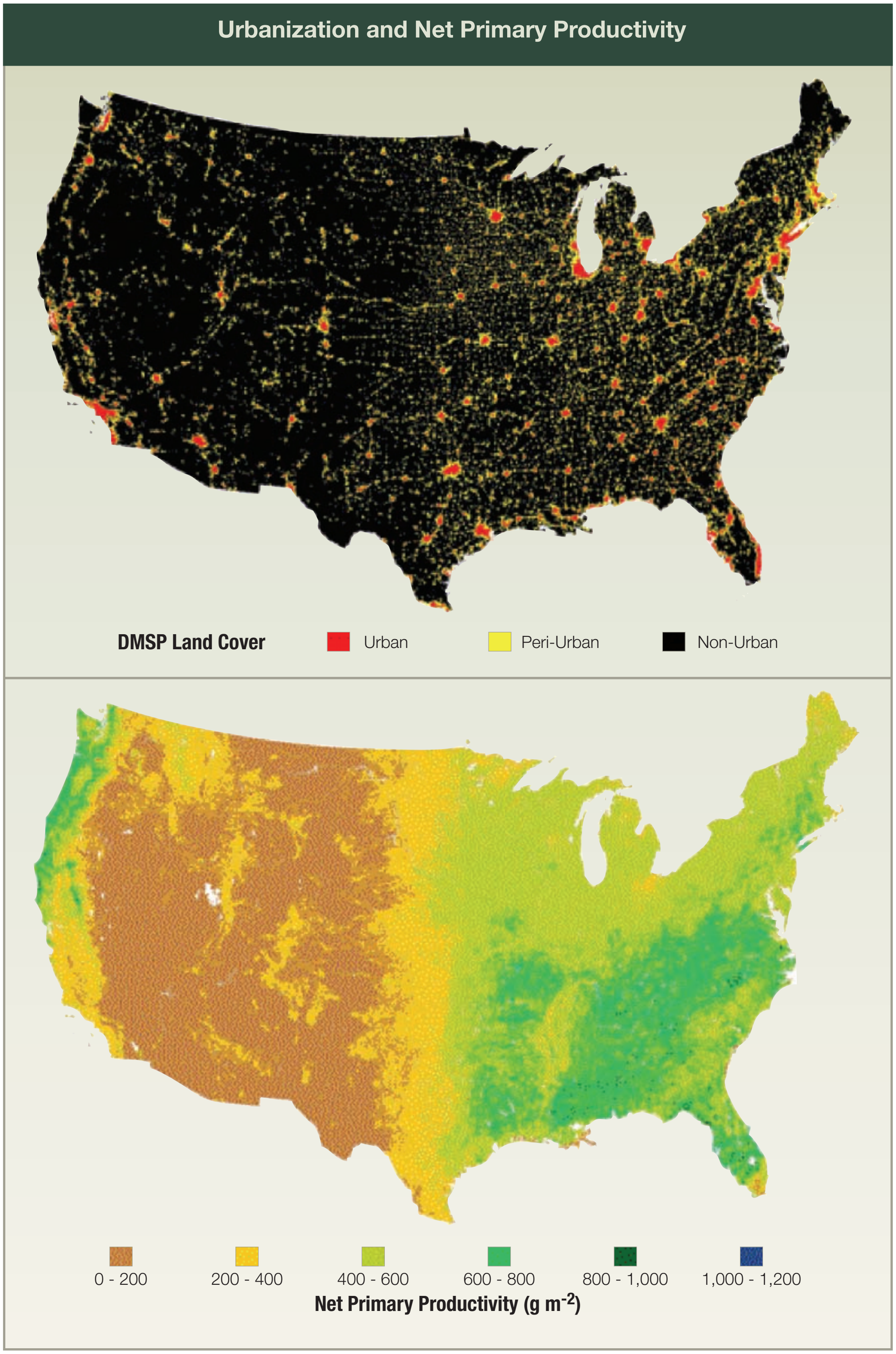


Figure 27: Urbanization and Net Primary Productivity. The top product provides an urbanization map generated from Defense Meteorological Satellite (DMSP) Operational Linescan System data collected from October 1994 to March 1995, showing urban, peri-urban, and non-urban areas. The lower product simulates total annual net primary production for the United States at 1-km spatial resolution. *Credit: M.L. Imhoff,* NASA/ Goddard Space Flight Center *(reproduced from* **Remote Sensing of Environment** *with permission from Elsevier Inc.).*

Stanford Ames Approach (CASA) productivity model driven by 1992-1993 AVHRR data and current climate, and can be considered a "post-urban" representation of the net primary productivity of the land surface.

Most of the urbanization in the United States has taken place on the lands with higher rates of net primary production. The estimated overall reduction of net primary production due to urban land transformation in the United States relative to total pre-urban production is 1.6% per year. The reduction of net primary production from agricultural lands is equivalent to food products capable of satisfying the caloric needs of 16.5 million people or about 6% of the U.S. population.

HIGHLIGHTS OF FY 2007 PLANS

Creation of a 2005-2007 Landsat Data Set.[10] Since 1972, Landsat satellites have collected data that have been invaluable for the quantitative study of land cover, land use, and land-cover change. The ground resolution of the Landsat satellites is ideal for studying a wide range of surface phenomena. In addition, a variety of natural and human land-use changes (e.g., wildfires, deforestation, agricultural activity, glacier expansion/contraction, and urbanization) represent alterations that occur at spatial scales of tens of meters. Therefore, Landsat data are invaluable for studying the land surface and how it affects and is affected by climate. Landsat data from 1972 to 2003 have provided the global coverage required to study land-use and land-cover change. However, a mechanical failure of the Landsat 7 Enhanced Thematic Mapper instrument on 31 May 2003 has degraded subsequent Landsat 7 data, and there are no other globally available Landsat-type data at these spatial scales. This problem will not be completely solved until at least 2011, when a Landsat-like instrument will be launched. This data gap from 2003 to at least 2011 makes it difficult to achieve several key CCSP goals directly related to understanding the direct impact of land-use and land-cover change on climate. U.S. government agencies affected by this include NASA, USGS, USDA, EPA, DOD, HHS, the Federal Emergency Management Agency (FEMA), and NOAA.

CCSP proposes to address this by redirecting existing agency resources in order to acquire a global collection of 2005 to 2007 data from Landsat 5 holdings of International Cooperator ground receiving stations and the U.S. archive; Landsat 7 image pairs from the U.S. archive (wherein the 25% of missing pixels in one scene are filled in from one or more subsequent scenes of the same site); the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER); Earth Observing-1's Advanced Land Imager (EO-1's ALI); and satellites now operated by foreign countries. This CCSP priority item will also be extremely important for scientific studies of the cryosphere, ecosystems, the carbon cycle, and the International Polar Year; thus, it will address multiple CCSP requirements and contribute to improved decision support. NASA and USGS, the two major users of Landsat data, will organize the project, with advice from and participation by other interested Federal agencies.

This activity will address CCSP Goals 1 and 2 and Question 6.1 of the CCSP Strategic Plan.

National Land Cover Data Set 2001. The National Land Cover Database (NLCD) has become the flagship land-cover data product, providing periodic maps showing the patterns and extents of major U.S. land-cover types. Development of NLCD has been coordinated by the Multi-Resolution Land Characteristics Consortium, which is made up of a number of government agencies including USGS (founder and *de facto* leader); EPA; NOAA; the U.S. Forest Service; NASA; the National Park Service; the Natural Resources Conservation Service; the Bureau of Land Management; the U.S. Fish and Wildlife Service; and the Office of Surface Mining. Two land-cover data sets have been undertaken. The first NLCD map, NLCD 1992, was produced through the classification of Landsat satellite imagery acquired around 1992, covers the conterminous United States, and was completed in 2001. The second map, NLCD 2001, uses Landsat images acquired around 2001 and will be completed in 2006. NLCD 2001 is also expanding the geographic coverage of the 1992 data set to include Alaska, Hawaii, and Puerto Rico; this expansion will be completed by 2008.

This activity will address CCSP Goals 1 and 2 and Question 6.2 of the CCSP Strategic Plan.

Assessment of Land-Use and Land-Cover Change Numerical Models: A Request for a National Academy of Sciences Study. Land-use and land-cover change are important processes that influence, and are influenced by, the Earth's climate, carbon, water, ecological, and socioeconomic systems. A variety of modeling approaches have been used to understand land-use and land-cover change and to encode that understanding for the purpose of projection and prediction. These approaches include Markov, econometric, micro-simulation, dynamic spatial simulation, cellular automata, agent-based, and a variety of statistical/empirical numerical models.

Attempts to couple land-use change models with models of biogeochemical, water, and ecological processes face a number of challenges. The spatial and temporal scales of land-use change models need to be compatible with both the driving processes of land-use change and models of environmental systems. The land-use and land-cover change models must also share specific semantic, ontological, and technical specifications in order to allow inter-model communication and coupling. Thus, although there has been much research that contributes to our understanding of the dynamics of land-use and land-cover change from an observational or empirical basis, a suite of models of land-use and land-cover changes at spatial scales from local to global, and temporal scales from short (<5 years) to long (>50 years), must be developed. These models must be compatible with environmental models relevant for Federal, State, and local management and policy development.

Land-use change has direct and indirect impacts on the health and sustainability of society and ecosystems. A synthetic understanding of land-use change modeling approaches is needed so that these reciprocal relations can be studied, in the case of explanatory models, and projected using computer-based tools that encode the best scientific understanding and complement the diverse applications used by agency programs. Importantly, the study will provide guidance to a diverse set of science- and application-based model users on the strengths and weakness of the various approaches and the appropriate contexts in which they can be applied. Such guidance is not currently widely available. This study will be conducted by the National Academy of Sciences.

This activity will address CCSP Goals 1 and 2 and Question 6.3 of the CCSP Strategic Plan.

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