Measuring Human Impacts On The Biodiversity And Carrying Capacity Of Ecosystems: Combining Remotely-Sensed Data With Species Distributions To Identify Conservation Priorities

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Abstract

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This proposal will combine remotely sensed data from NASA's Terra Mission (MODIS), AVHRR, and nighttime city lights data from DMSP with geospatial data on ecosystems and species distribution to quantify a variety of anthropogenic threats to ecosystems and biodiversity at regional and continental scales. It will be a joint effort between NASA Goddard Space Flight Center's Biospheric Sciences Branch, Stanford University's Center for Conservation Biology, and Bowie State University's Department of Natural Sciences.

Humans threaten ecosystems by directly destroying their native habitats and by over-taxing their capacities to sustainably support our increasing population (i.e., their carrying capacities). Rapid, quantitative analyses of the broad-scale patterns of these human threats are critically needed, so that conservation biologists can allocate limited resources most effectively. Data sets just being developed at NASA will greatly aid in these efforts. This project will use remotely sensed data from the Defense Meteorological Satellite to map urban areas and will combine them with census data to index the urban land use patterns to population and housing data. Data from MODIS's Land Discipline Group, AVHRR, and USGS maps, will be used to map vegetation land cover, estimate productivity, and collect land surface disturbance information with a special emphasis on agriculture. These data will be analyzed, validated, and merged in a geographic information system with an ecoregion coverage for North America, including species distribution data for over 20,000 species in eight taxa.

The combined geo-spatial analyses will allow us to address three issues of critical importance to the science and policy of biodiversity conservation and sustainable development: (i) identify areas of extreme threat to biodiversity due to anthropogenic habitat loss, (ii) analyze the fragmentation of ecosystems by urban and agricultural land conversion, and (iii) investigate human population and consumption patterns relative to the carrying capacity of the ecosystems that support them. These analyses will result in a series of technical articles in peer-reviewed journals, as well as several map products that will convey the same information powerfully to the public. We plan to focus initially on North America, with the goal of extending the analysis as data sets are expanded to cover the globe.

GOALS:

Category = Consequenses of land cover change.

To make spatially explicit analyses of the anthropogenic impacts on ecosystems across the United States by using remotely sensed data to define patterns of human impacts more quantitatively than has been possible previously and by merging that information with ecologically meaningful boundaries (e.g., ecoregions) as the units of analysis.

To yield, among other insights, a completely quantitative, transparent assessment of the factors determining conservation priorities on large scales, and a better understanding of human consumptive patterns relative to the carrying capacity of U.S. ecosystems.

In particular, we propose to address three broad **questions:**

1. Where are the likely conservation crises going to be? In other words, where do high levels of species richness and endemism collide with high levels of human impact (e.g., urbanization, agriculture)?
2. How have urbanization and agriculture fragmented ecosystems on broad scales, and in what areas are these impacts most severe?
3. How much of the carrying capacity of different ecosystems are human populations appropriating? In other words, how does the supply of ecosystem goods and services compare to the demand of local and regional human populations?

Datasets and Methods

Social Science 10%, Change detection 15% Carbon Cycle 25%, Biodiversity 50%

Ecoregions and species distributions

The geographic units we will use for the majority of these analyses are the 110 ecoregions composing the continental United States and Canada **(Figure 1 D)** The ecoregions in Ricketts et al. (1999b) are based on three established ecoregion mapping projects: Omernik (1995) for the conterminous United States; Ecological Stratification Working Group (ESWG 1995) for Canada; and Gallant et al. (1995) for Alaska. For these ecoregions, Ricketts et al. (1999b) compiled published and unpublished data on the distributions of over 20,000 species in eight taxa: birds, mammals, butterflies, amphibians, reptiles, land snails, tiger beetles, and vascular plants. For most taxa, published range maps were compared to the ecoregion map and each species was recorded as present or absent in every ecoregion. From the resulting database, levels of species richness as well as endemism can be summarized for each ecoregion and, for most taxa, the ecoregional distributions of single focal species can be analyzed and displayed.

Satellite- Derived Maps of Urban Land Use

We have developed currently two global DMSP/OLS data sets showing human activity through the intensity and frequency of light emission. The frequency data exist as an image composite collected from October 1, 1994 through March 31, 1995. Urban maps were created using this data showing three classes of urbanized land cover, each indexed to human demographic data through a merger with digital census data in a GIS (USBC 1991, 1992). Class 1 (Urbanized land) represents the most frequently illuminated and stable of lit areas and has an average (nationwide) population and housing density of 1064 persons and 445 housing units km^{-2}. Class 2 (Peri-urban land) has 100 persons and 38 housing units km^{-2}, and Class 3 (Non-urban land, i.e., never lit) has an average population and housing density of 14 persons and 5 housing units km^{-2}. **(Figure 1 A).**

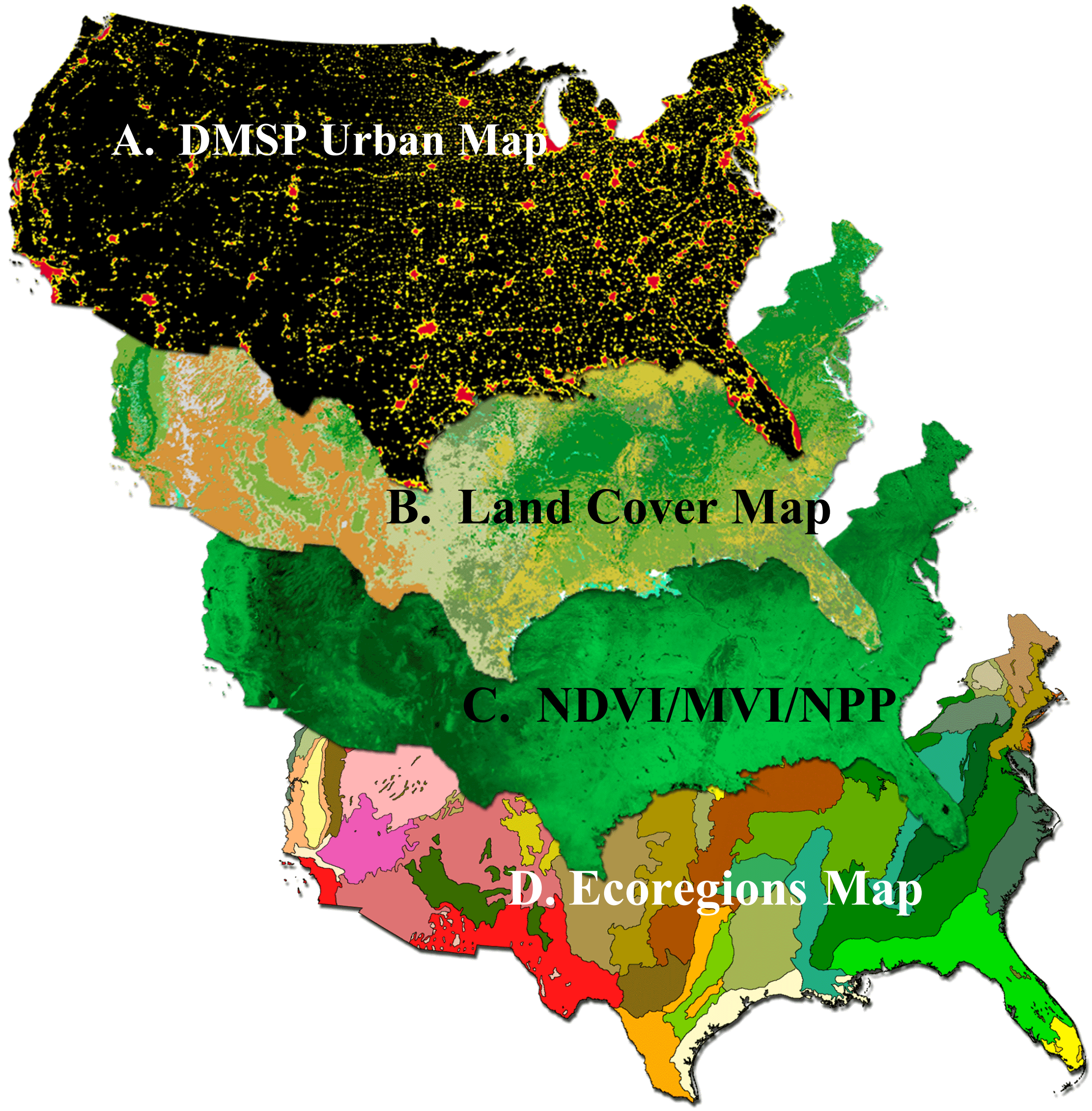

Figure 1. Data sets developed or used in this project staged in a GIS. A. is a validated urban thematic map generated from DMSP/OLS data showing three classes of urban land cover, Urbanized (red), Peri-urban (yellow) and Non-urban (black) Each class carries population and housing data. B. The USGS Seasonal Land Cover Map (shown here). C. NPP map from AVHRR. D. Ecoregions map showing 110 ecoregions with attributes files for 20,000 species across eight taxa. These data will be staged in a GIS for a series of geo-spatial analysis.

Satellite-Derived Measures of Net Primary Productivity of the Landscape

We have used data from the AVHRR (1km 1993) and the Carnegie Ames Stanford Approach and the Carnegie Modeling Environment (CASA/CME) to calculate NPP over the US at 1km spatial resolution. NPP maps of the US for each month in 1993 were generated in terms of gCm^{-2} for the land cover classes defined within each ecoregion.

Early Results

Question 1: Where are the conservation crises likely to be?

Currently we have completed the merger of the DMSP urban maps, the Ecoregions maps, and the AVHRR data. Simple analyses in a GIS have yielded, for each ecoregion, values for the percent cover of urban areas (and by extension, human population size) and the levels of species richness and endemism in eight taxa for impacted ecoregions. We are now identifying the suite of ecoregions in North America that both contain high levels of biodiversity value and face extraordinary levels of habitat loss from anthropogenic land use change (**Figure 2 and 3).** As seen in figure 3, the horizontal axis is an index of habitat loss, in this case *percent urban cover*. On the vertical axis is an index of biodiversity value, for example species richness or endemism in a certain taxon, a composite index of diversity using all eight taxa (sensu Ricketts et al. 1999a), or the number of endangered species. Each point on the plot represents an ecoregion, and the heavy gray lines denote the upper quartile along each axis. The five ecoregions that lie in the upper quartile of both the biodiversity and habitat loss indices immediately emerge from such a plot as clear priorities for conservation attention, where levels of both biodiversity and human threats to it are extraordinarily high (Sisk et al. 1994).

Figure 2. Distribution of amphibian diversity mapped onto ecoregion map from Figure 1D. a. species richness (i.e., number of species present); b. number of endemic species present (i.e., species found nowhere else on earth). The Appalachian mountains represent a significantly rich ecoregion for amphibian diversity in the US.

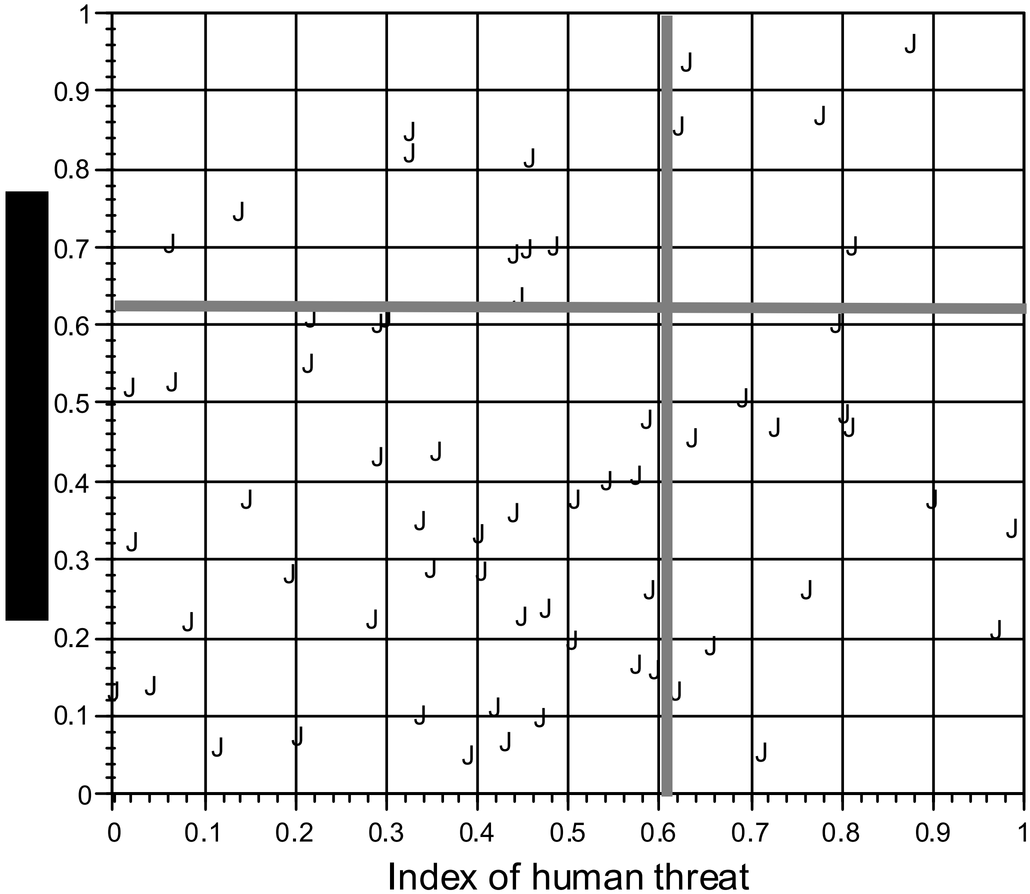

Figure 3. A recent evaluation of the biodiversity vs. human threat as a result of urbanization. On the horizontal axis is the percent urban cover. On the vertical axis is species richness or endemism in a certain taxon, a composite index of diversity using all eight taxa (sensu Ricketts et al. 1999a). Each point on the plot represents an ecoregion, and the heavy gray lines denote the upper quartile along each axis. The five ecoregions that lie in the upper quartile of both the biodiversity and habitat loss indices immediately emerge from such a plot as clear priorities for conservation attention, where levels of both biodiversity and human threats to it are extraordinarily high.

Question 2: How have urbanization and agriculture fragmented ecosystems on broad scales, and in what areas are these impacts most severe?

We have not yet begun this analysis, we need the MODIS Land Cover maps denoting agricultural land use types.

Question 3: How much of the carrying capacity of different ecosystems are human populations appropriating?

We have made great progress toward building a view of how urbanization affects the ability of the landscape to carry out photosynthesis. As a first step we used NDVI derived from AVHRR data for land cover classes (from USGS) inside and outside urbanized areas. We then culled through hundreds of seasonal NDVI curve comparisons to identify commonly repeated patterns in the data. Our results show that urbanization can have a measurable but variable impact on the primary productivity of the land surface. Annual productivity can be reduced by as much as 20 days in some areas, but in resource limited regions, photosynthetic production can be enhanced by human activity. Overall, urban development reduces the productivity of the land surface and those areas with the highest productivity are directly in the path of urban sprawl (Figure 4).

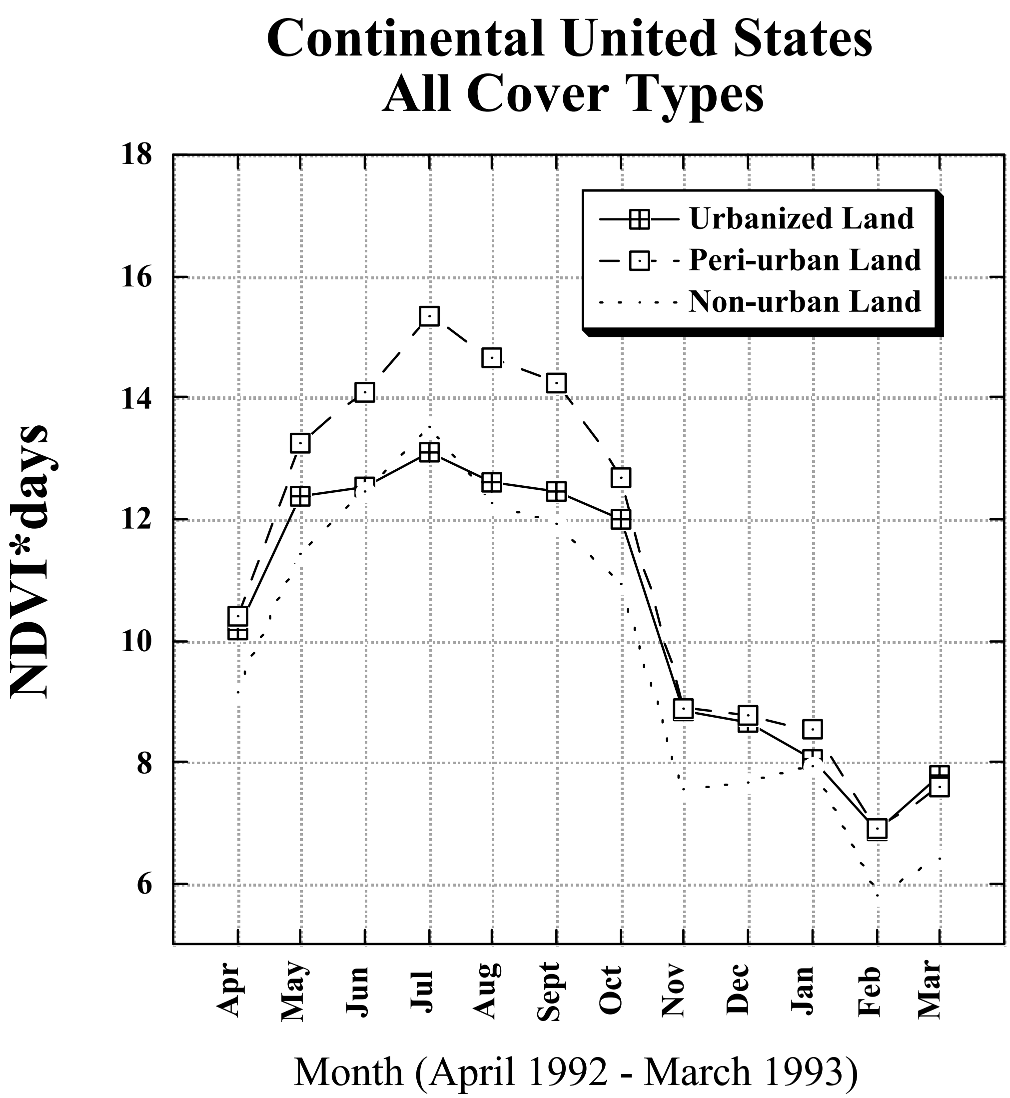

Fig. 7. Annual NDVI based productivity signatures for the three DMSP derived classes of urbanization for all of the surface area of the continental U.S. The value for each month is the mean NDVI*days calculated for all land cover types in each class of urbanization.

<u>Conclusions:</u>

The impact of urban land transformation on ecosystems is significant both in terms of habitat fragmentation and in terms of reduced primary production. Work this year is continuing to further quantify the impact on NPP and define the fragmentation effects by ecoregions.

<u>New Products:</u>

Publications (Refereed). Various aspects of these results have been published or were accepted for publication in 2000-2001:

"The Use of Multi-source Satellite and Geospatial Data to Study the Effect of Urbanization on Primary Productivity in the United States", M. L. Imhoff, C. J. Tucker, W. T. Lawrence, D. Stutzer, and Robert Rusin, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 38, No. 6 November 2000, pp. 2549-2556.

"Assessing The Impact Of Land Conversion To Urban Uses On Soils With Different Productivity Levels In The United States", Egide L. Nizeyimana, G. W. Petersen, M. L. Imhoff, H. R. Sinclair, Jr., S. W. Waltman, D. Reed-Margetan, and E. R. Levine (In Press), *Soil Science Society of America Journal*. (In Press).

"A Closer Look At United States And Global Surface Temperature Change", James Hansen, Reto Ruedy, Makiko Sato, Marc Imhoff, David Easterling, Thomas Peterson, and Thomas Karl, *Journal Geophysical Research*. (In Press).

Data sets:

Urbanization Map from DMSP
NPP Map 1 km (from AVHRR)
Earth at Night Movie (shows Seawifs NDVI data for daytime and DMSP city lights data at night) Globe rotates and data scenes shifts as terminator crosses.

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