Measuring Human Impacts On The Biodiversity And Carrying Capacity Of Ecosystems

Measuring Human Impacts On The Biodiversity And Carrying Capacity Of Ecosystems:

NASA's ESE LCLUC 99-0004-0016

Progress Report
2001 Land Cover Land Use Change Program

- **Marc Imhoff,** NASA's Goddard Space Flight Center
- **Taylor Ricketts and Paul Ehrlich,** Stanford University's Center for Conservation Biology
- **William Lawrence,** Bowie State University

Primary Objective

- Combine remotely sensed data from MODIS, AVHRR, and 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.

Specific Objectives

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

Science Implications

We plan to address three issues of critical importance to the science and policy of biodiversity conservation and sustainable development:

- identify areas of extreme threat to biodiversity due to anthropogenic habitat loss,
- analyze the fragmentation of ecosystems by urban and agricultural land conversion, and
- investigate human population and consumption patterns relative to the carrying capacity of the ecosystems that support them.

DMSP/OLS

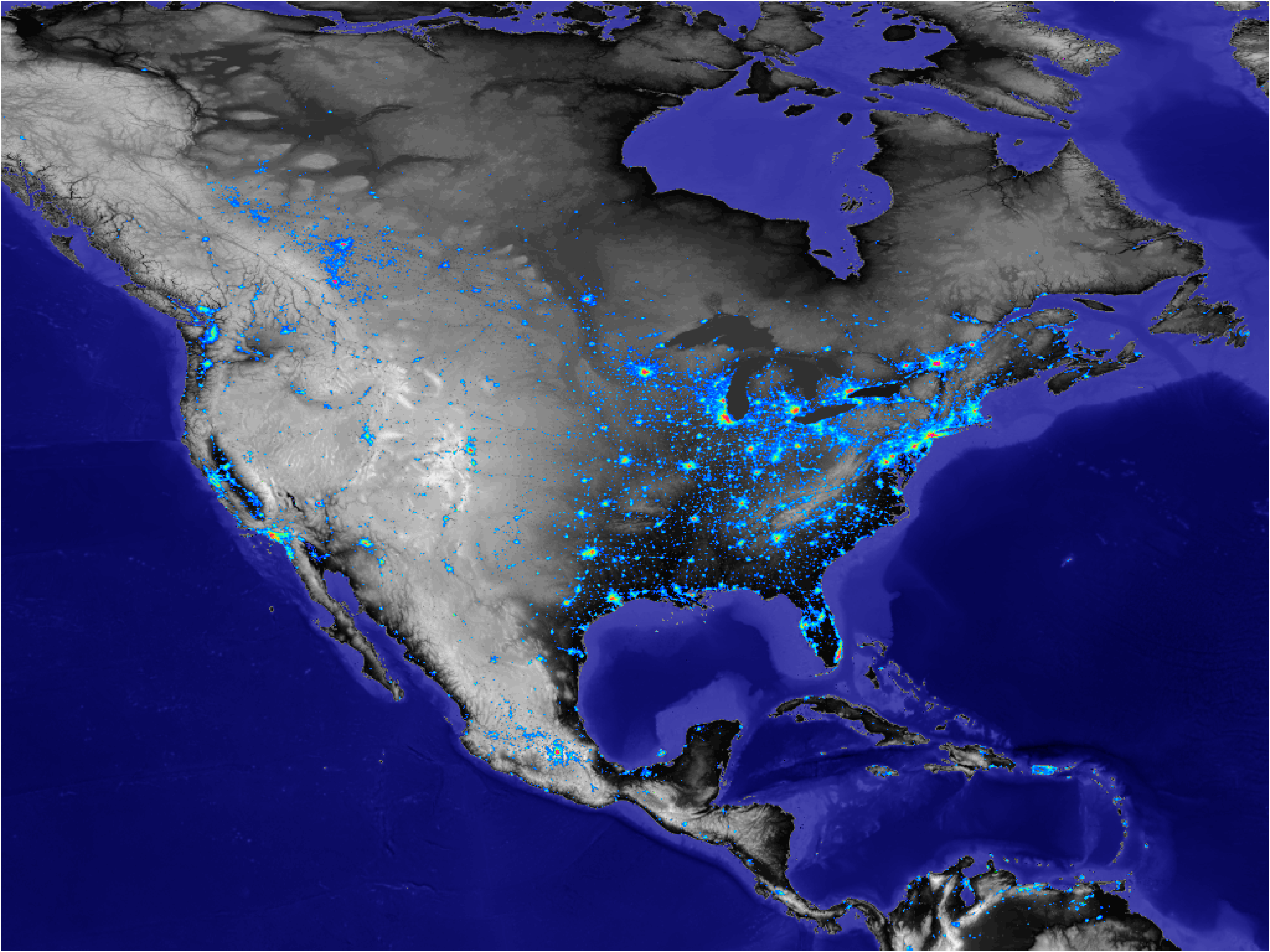
Defense Meteorological Satellite Program Operational Linescan System

"City Lights" Satellite Data

- Near Polar sensor designed to map moon lit cloud cover for weather forecasting and navigation.
- Low light VNIR Channel (0.5 - 0.9 µm) approx. 0.7µm peak. Sensitive to 10^{-9} $watts/cm^2/sr/\mu m$
- Spatial Res. - 2.7 km (smooth), 0.5 km (fine)
- TIR Channel used for cloud screening
- Nighttime passes between 20:30 and 21:30 local

Satellite Derived Urban Area Maps

- Raw DMSP/OLS image data overestimate urban area by a factor of 7 or 8.
- Thresholding techniques were developed to make accurate urban area maps.
  - Spatial Integrity Thresholding of Urban Polygons (SITUPS) for Stable Lights Data.
  - Single Point Target Merger Thresholding (SPTMT) for Gain Controlled data.
- Both techniques yielded excellent results when compared to census data in the US.



Methods

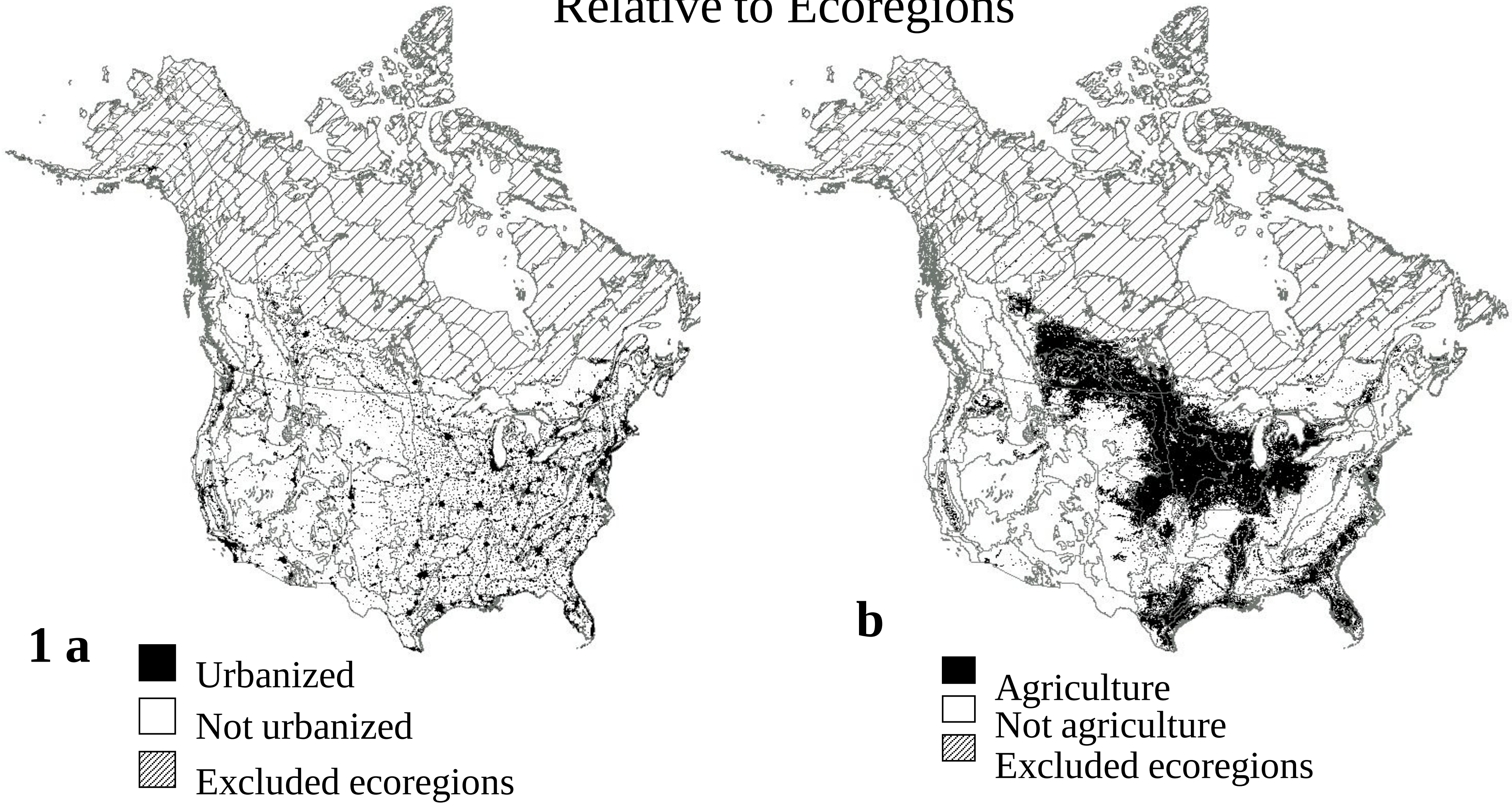
- Define ecoregions and compile species distributions map.
- Create satellite- derived urban maps and identify land cover based on use & disturbance frequency and severity.
- Quantify NPP of the landscape and create carbon “balance sheet” for ecosystems.
- Combine in a GIS to generate comparative analyses.


A. DMSP Urban Map
Geo-spatial
Data
Fusion
B. Land Cover Map
GIS
Queries
Analyses
Results
C. NDVI/MVI/NPP
D. Ecoregions Map

Biodiversity

- Ecoregions Map (Stanford CCB/WWF)
  - 110 Ecoregions for US
    - Broadly similar environmental conditions and natural communities.
  - 20,000 species across 8 taxa:
    - Birds, mammals, butterflies, amphibians, reptiles, land snails, tiger beetles, vascular plants.

Distribution of Urban & Agricultural Land Use Relative to Ecoregions



Diversity Indices

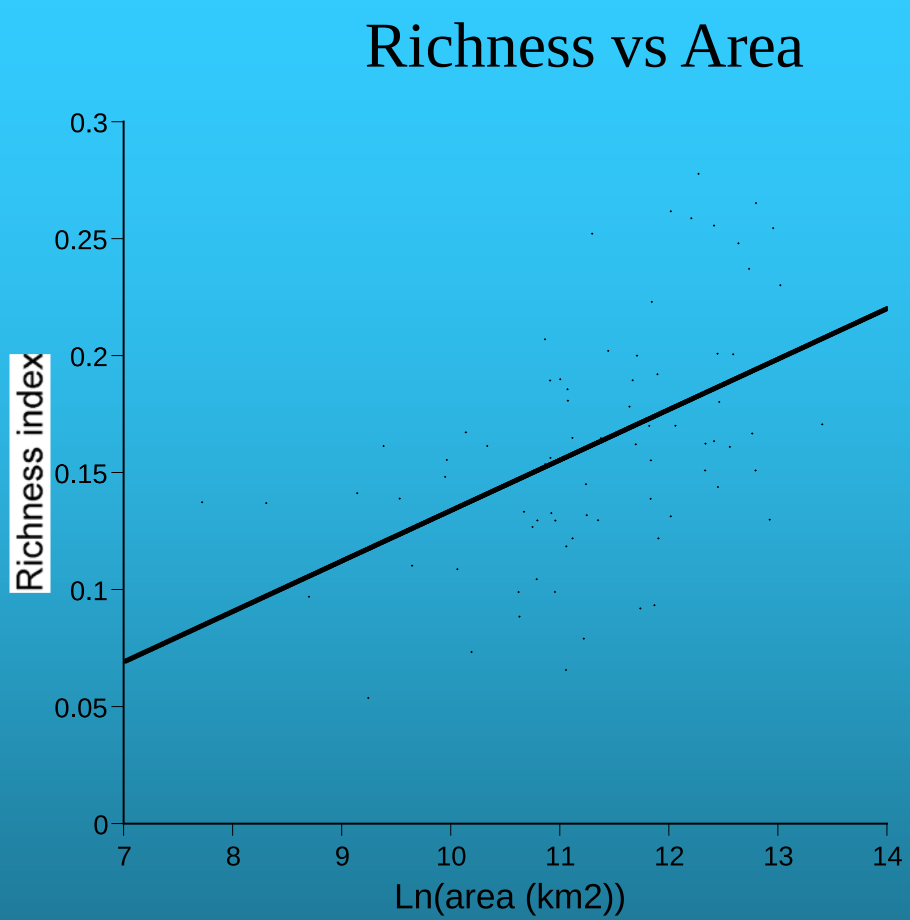
- Richness Index
  - 1/8 Σ Ri/Ti   Ri=Richness taxon i
    T =Total # species taxon I

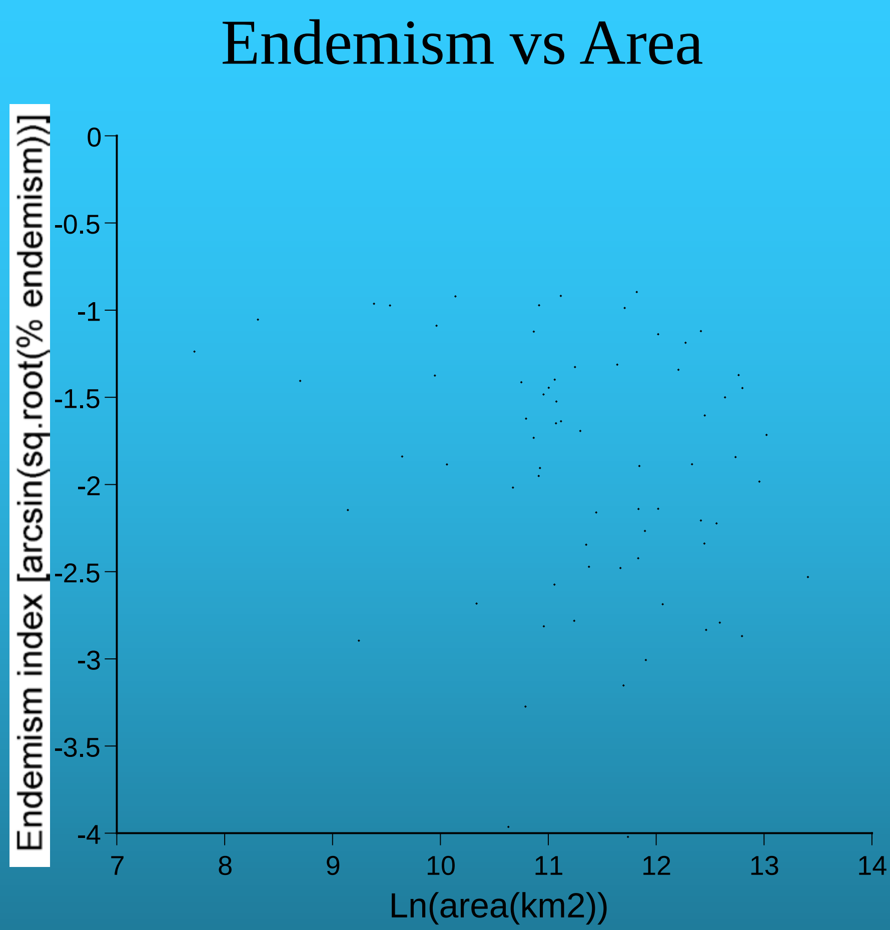
    Normally distributed.

Endemism Index (normalize for richness)

1/8 Σ Ei/Ri Ei = endemism taxon i

Endemic species – not found in any other ecoregion or occupy range less than 50,000 km2.

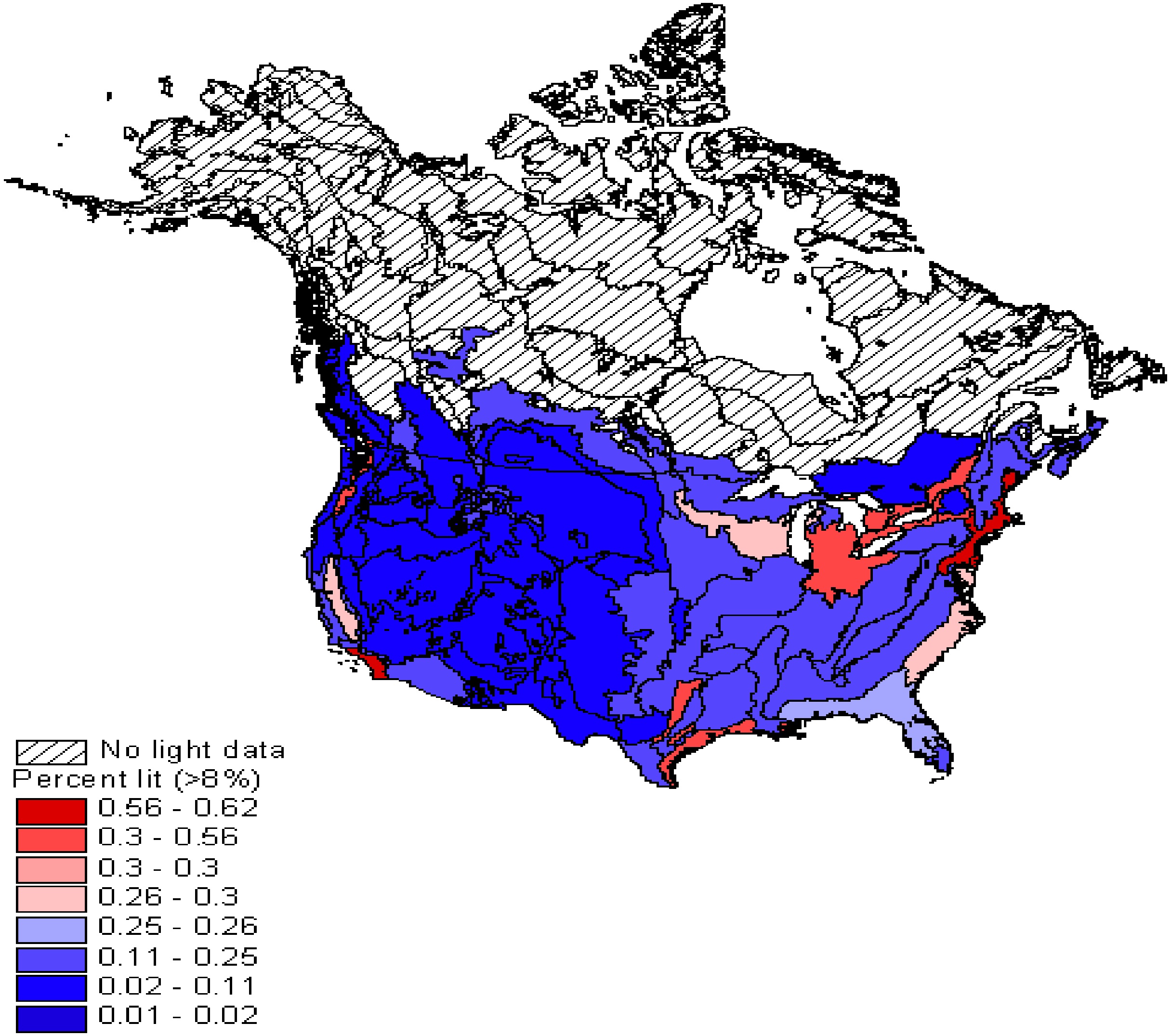




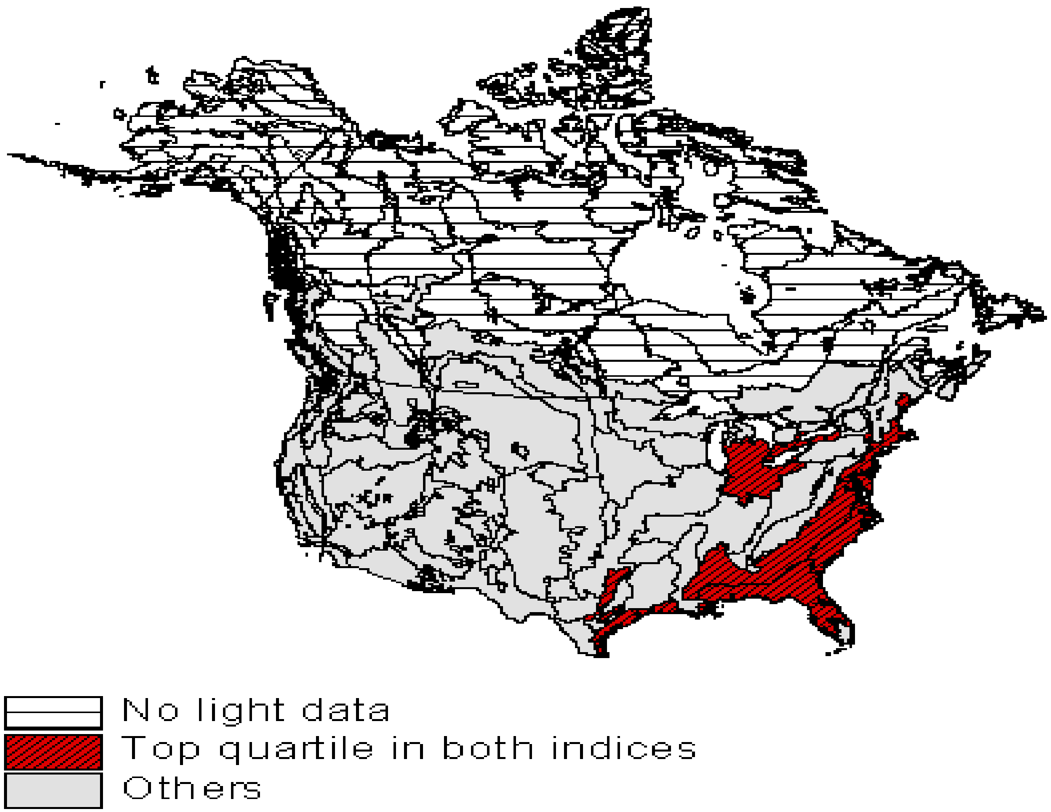
Richness and endemism indices versus ecoregion area.

A. Richness [$r^2=0.24$, $p<0.0001$] B. Endemism [ns]

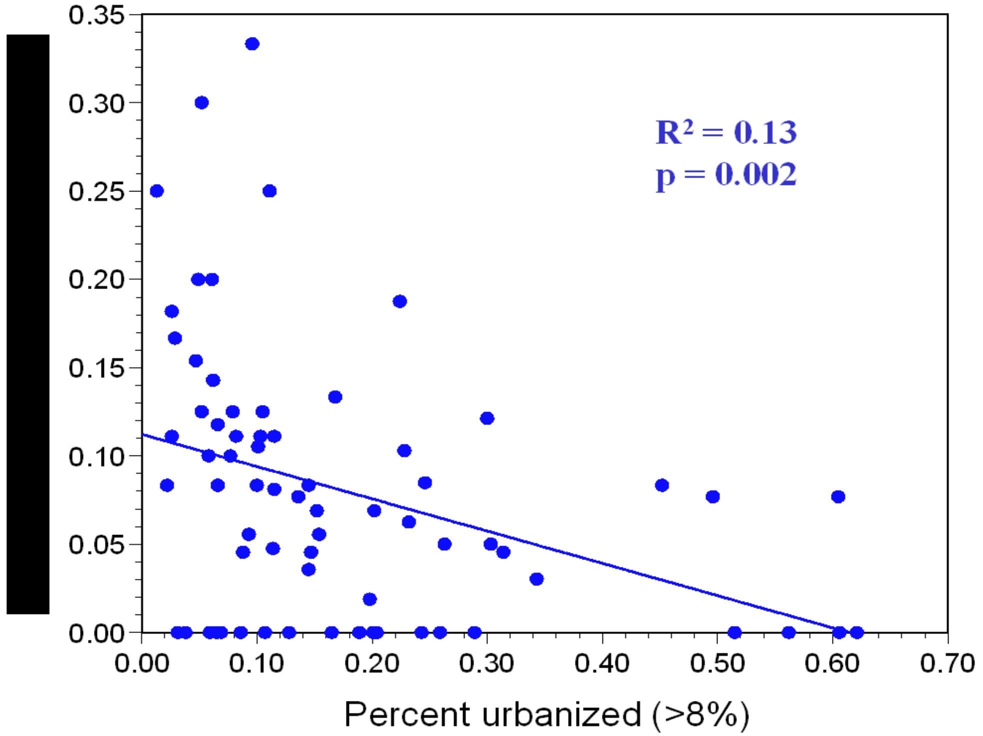
Percent illumination by human lights (>8% threshold)



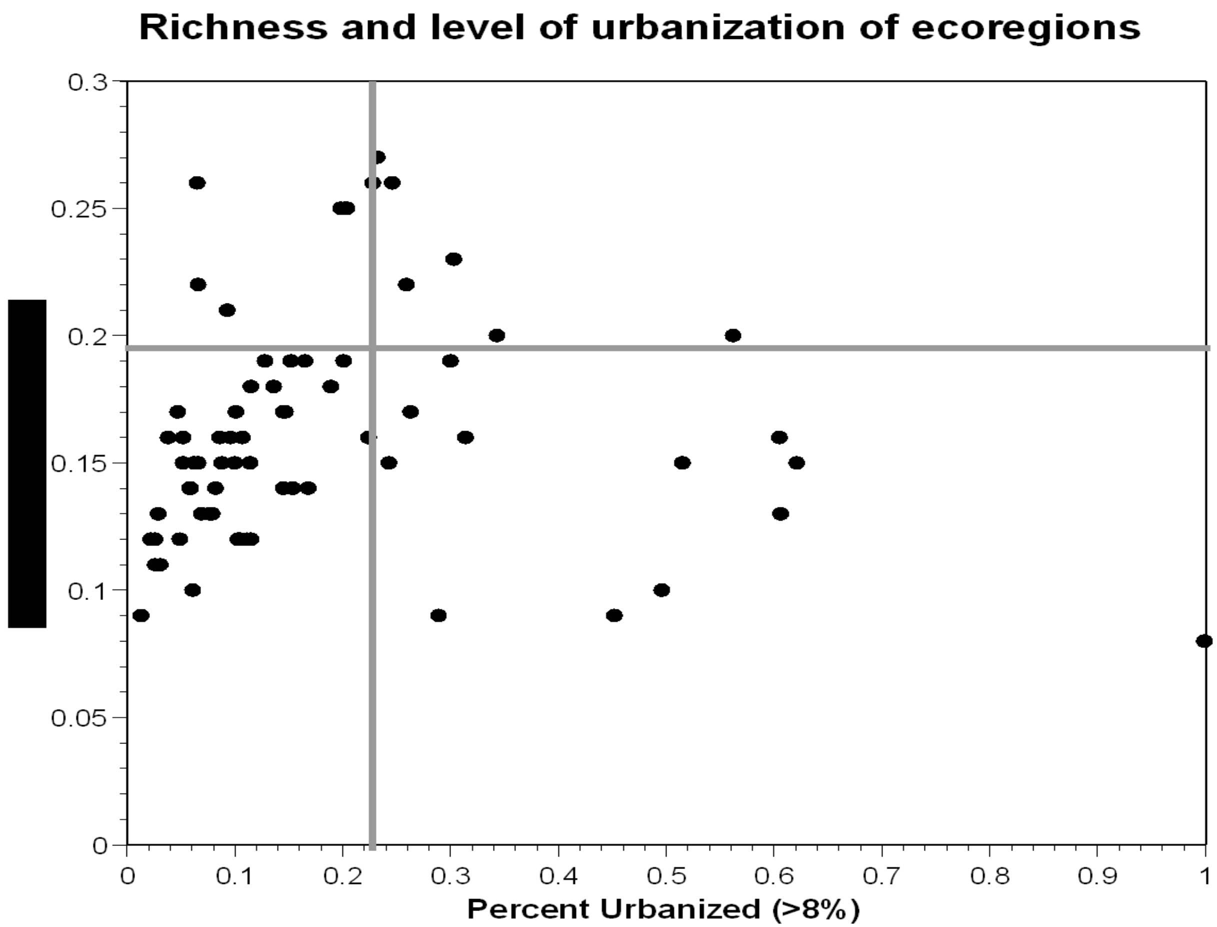
Ecoregions in top quartile in both Richness and Urbanization Indices



Relationship between urbanization and imperilment: amphibians

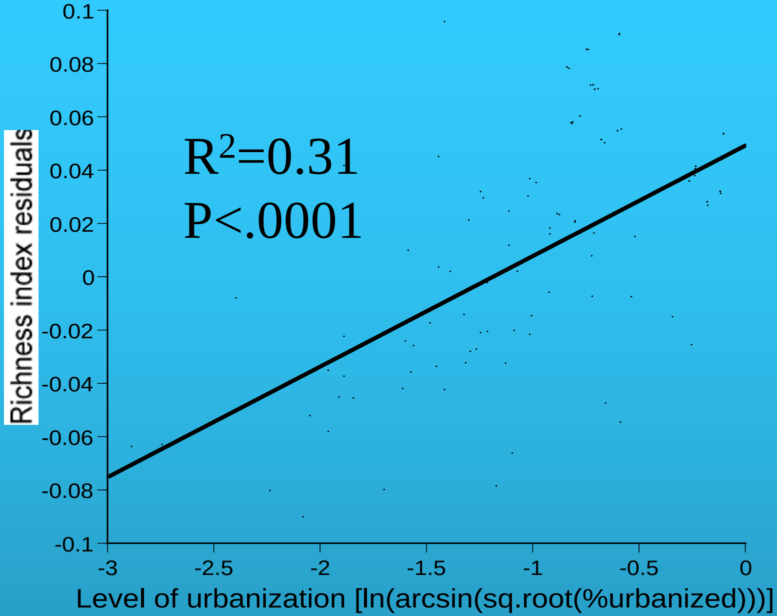


X-axis = % of ecoregion urbanized (each dot is an ecoregion).
Y- axis is fraction of total amphibian species in that ecoregion that are ranked either G1 or G2 by the nature conservancy. These ranks denote the species of highest concern on a global level (the scale goes down to 5:not of concern). They are therefore the most imperiled species.

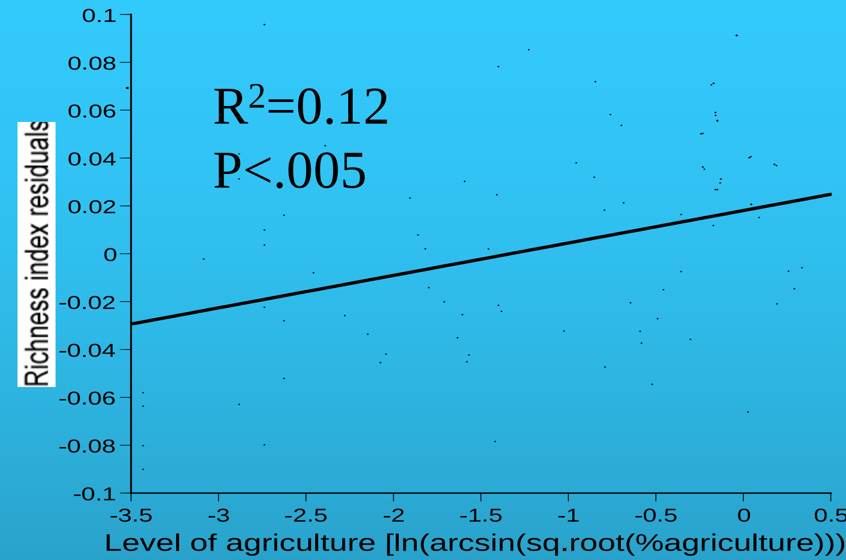


Each point is an ecoregion. Percent of each ecoregion urbanized is on x-axis overall richness index on y-axis: it is an index of species richness over 9 taxa:
birds, butterflies, mammals, trees, vascular plants, reptiles, amphibians, tiger beetles, and land snails. Taxa weighted equally in index. Index is described in Ricketts, et al (Bioscience).
Grey lines represent upper quartiles along each axis.
Points in upper right area therefore rank highly in each, and are of concern.

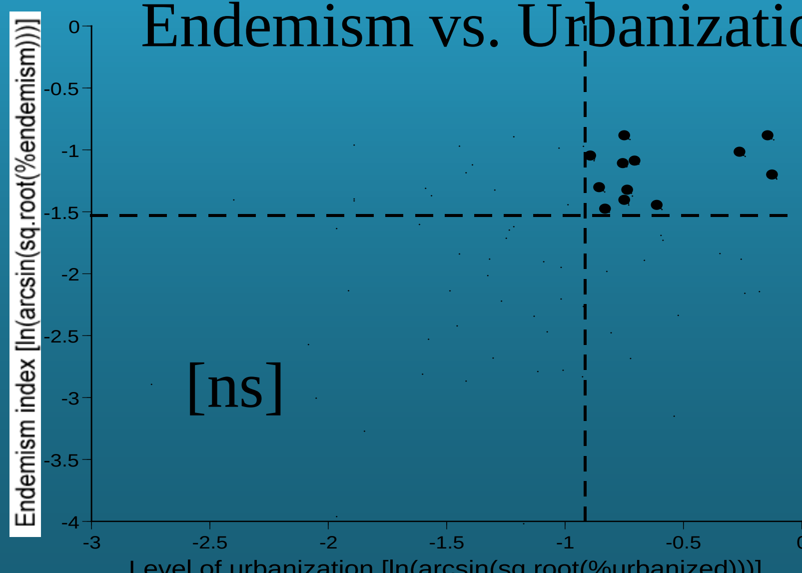
Richness vs. Urbanization



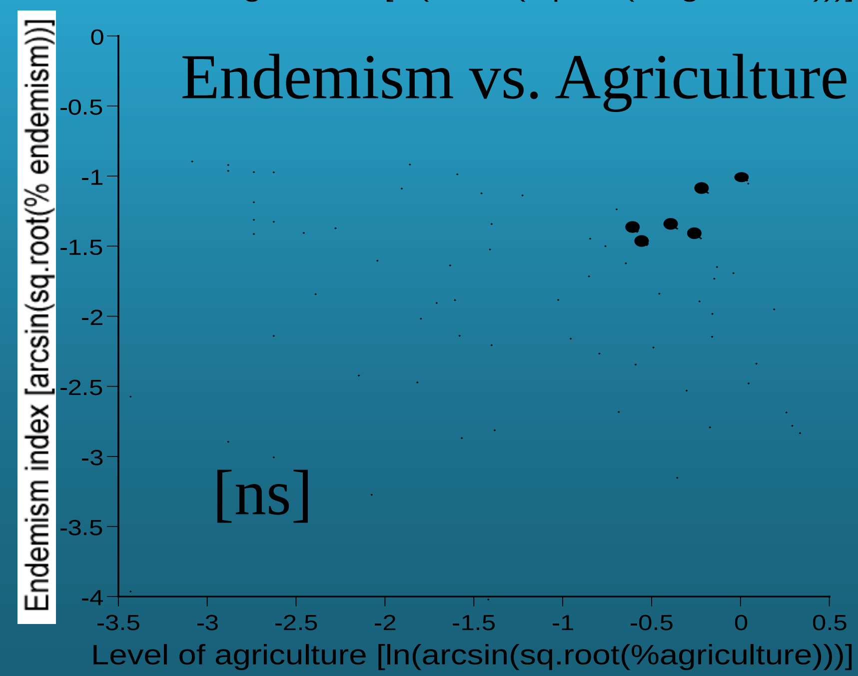
Richness vs. Agriculture



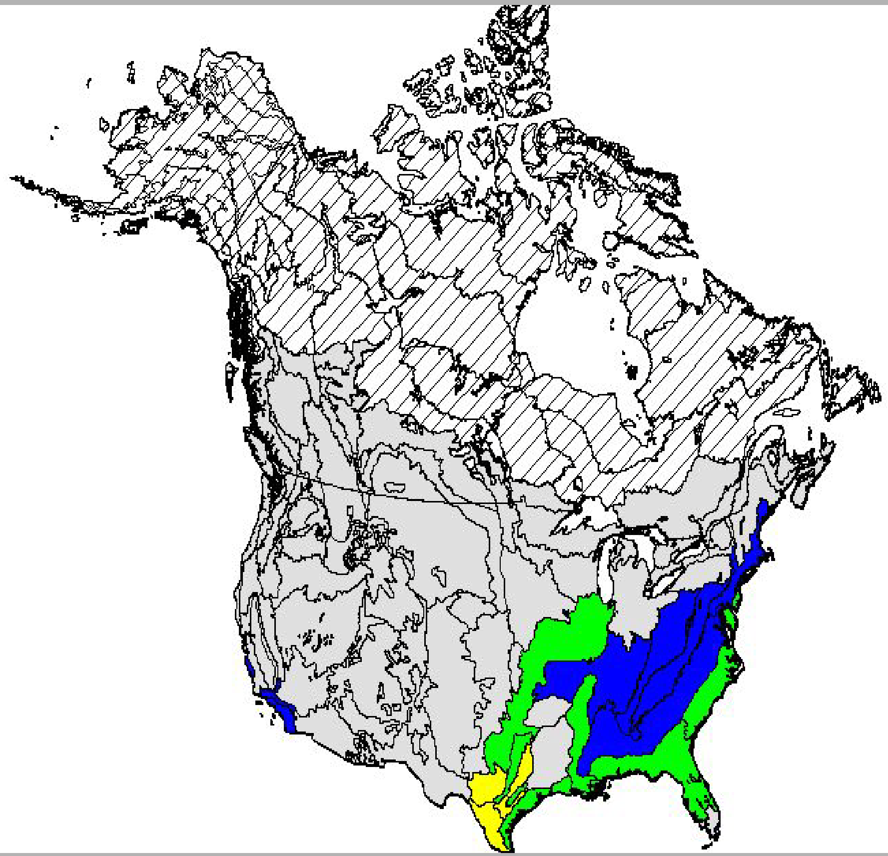
Endemism vs. Urbanization



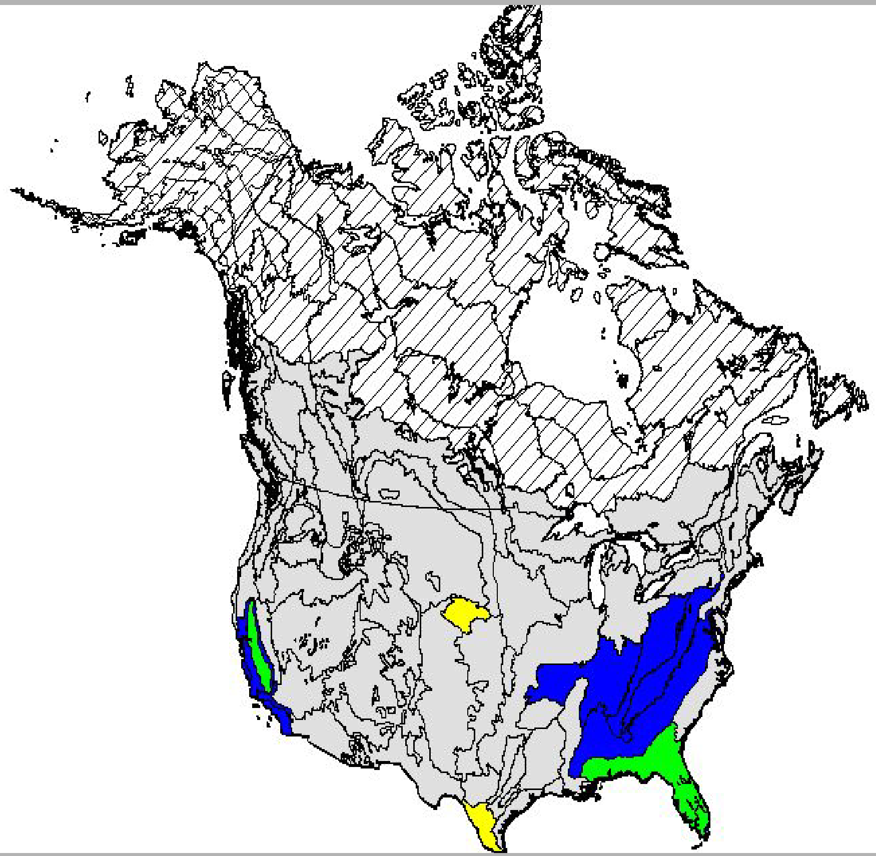
Endemism vs. Agriculture



Richness vs Land Use



Endemism vs Land Use



Ecoregions in the top 66% quantile

- **Urbanization**
- **Agriculture**
- **Both**
- **Excluded ecoregions**

- **Urbanization**
- **Agriculture**
- **Both**
- **Excluded ecoregions**

Ecoregions in top quartiles of urbanization and species richness indices

Code	% urban	Species index	Ecoregion Name
22	**0.23**	**0.27**	**Southeastern Mixed Forests**
51	**0.25**	**0.26**	**Southeastern Conifer Forests**
68	**0.30**	**0.23**	**Western Gulf Coastal Grasslands**
50	**0.26**	**0.22**	**Middle Atlantic Coastal Forests**
14	**0.56**	**0.20**	**Northeastern Coastal Forests**
10	**0.34**	**0.20**	**Southern Great Lakes Forests**
67	**0.30**	**0.19**	**Texas Blackland Prairies**
9	0.26	0.17	Upper Midwest Forest/Savanna Transition Zone
72	0.61	0.16	California Coastal Sage and Chaparral
11	0.31	0.16	Eastern Great Lakes Lowland Forests
2	0.62	0.15	South Florida Rocklands
52	0.52	0.15	Florida Sand Pine Scrub
69	0.24	0.15	Everglades
49	0.61	0.13	Atlantic Coastal Pine Barrens
35	0.50	0.10	Puget Lowland Forests
6	0.45	0.09	Willamette Valley Forests
54	0.29	0.09	California Central Valley Grasslands

These are the ecoregions (above the double line) which are in upper quartile for each axis in previous slide. Some other high-ranking ecoregions are shown below the line just to see which came close to making it.

Conclusions

- Urban land transformation important for understanding carbon dynamics on land.
  - Impacts on photosynthetic production variable but generally negative.
- Extent of urban and agricultural land use widely varies among ecoregions
  - (0 – 60% Urban, 0.5 – 95% Ag)
- 7 ecosystems identified that rank in top quartile for both biodiversity and human impacts.
  - Allows for definition of priorities.

Locating Human Risks to Biodiversity: A Carbon Balance Approach

- Marc Imhoff – PI
- Lahouari Bounoua (UMD)
- Colby Loucks (WWF)
- William Lawrence (Bowie State)

Carbon:

The "Common Currency" for Ecological-Economic Assessment

- Life on Earth is "carbon based"
- Biologically available forms of carbon are the result of photosynthesis. This is called "Primary Production".
- Primary production represents all available food, fiber, and fuel (other than fossil and nuclear).
- The balance of carbon in the atmosphere and biosphere is a primary driver of climate change (global warming) and the subject of international treaties e.g. The Kyoto Protocol.
- Humans now consume approximately 40% of all the products of photosynthesis.
- Sustainabilty may be best assessed by comparing the rate of the human consumption of photosynthetic carbon vs the rate of natural production.

NPP Analyses

How does urbanization affect NPP on land?

Examine NPP rates inside and outside urbanized areas.

- **Generate NPP maps for US at 1km resolution using AVHRR data and the CME/CASA Model.**
- **Overlay DMSP Urban Map on NPP maps & calculate NPP rates inside and outside urbanized areas.**
  - **3 Classes of “Urban” Land**
    - **1) Urbanized = 4.5 HU/ha & 10.6 PERS/ha**
    - **2) Peri-Urban = 0.4 HU/ha & 1.0 PERS/ha**
    - **3) Non-Urbanized = 0.05 HU/ha & 0.14 PERS/ha**

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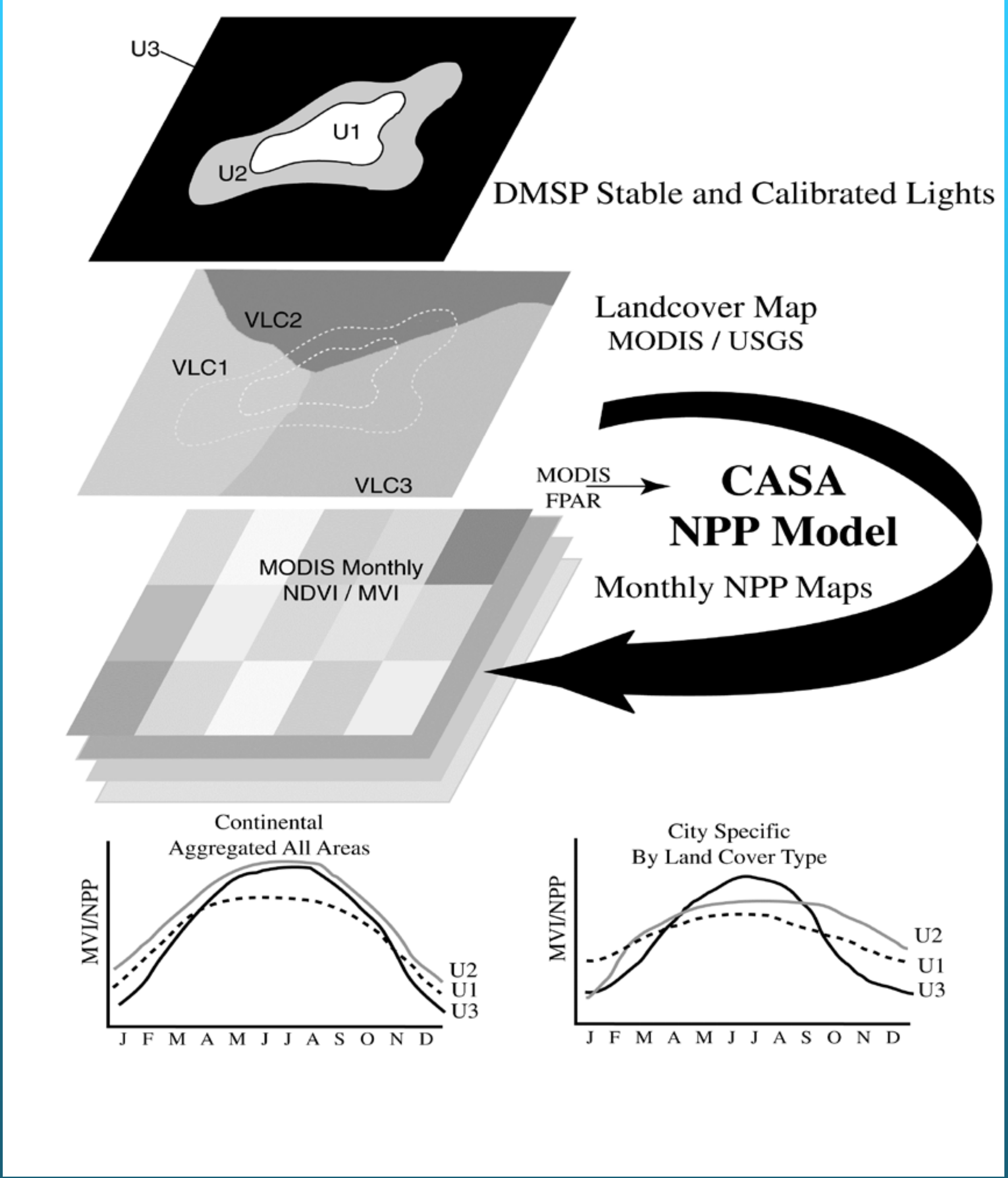
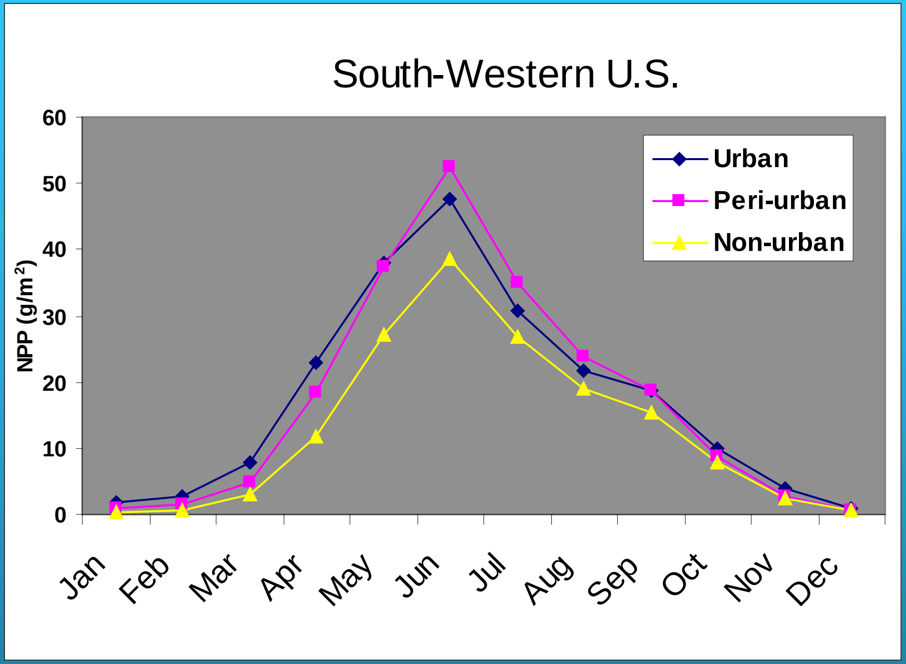
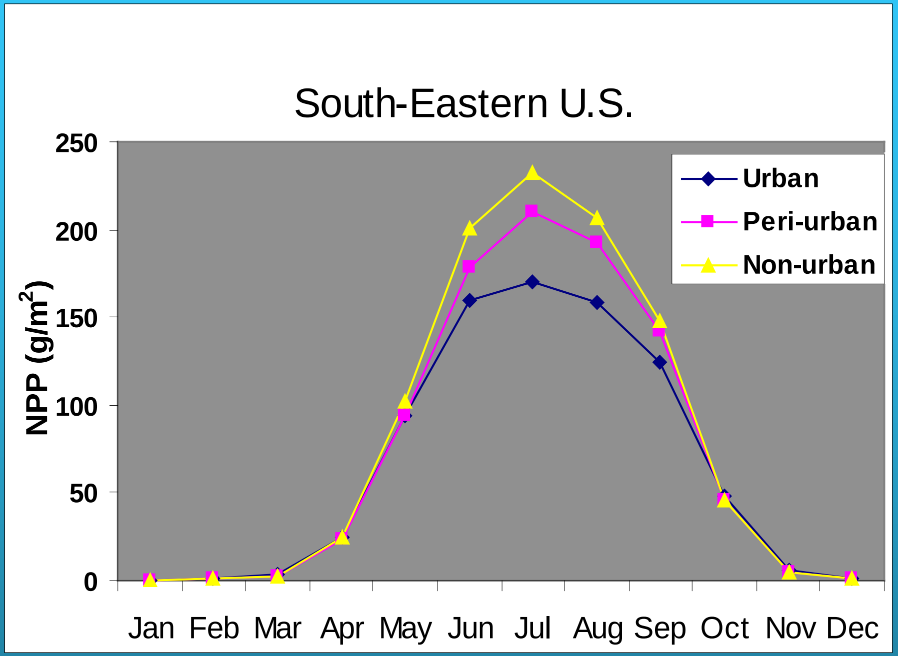
Determining the NPP – Urban Signal



Impact of Urban/Suburban Sprawl on Carbon Fixation (NPP)

Impacts are different due to climate, culture, and population density





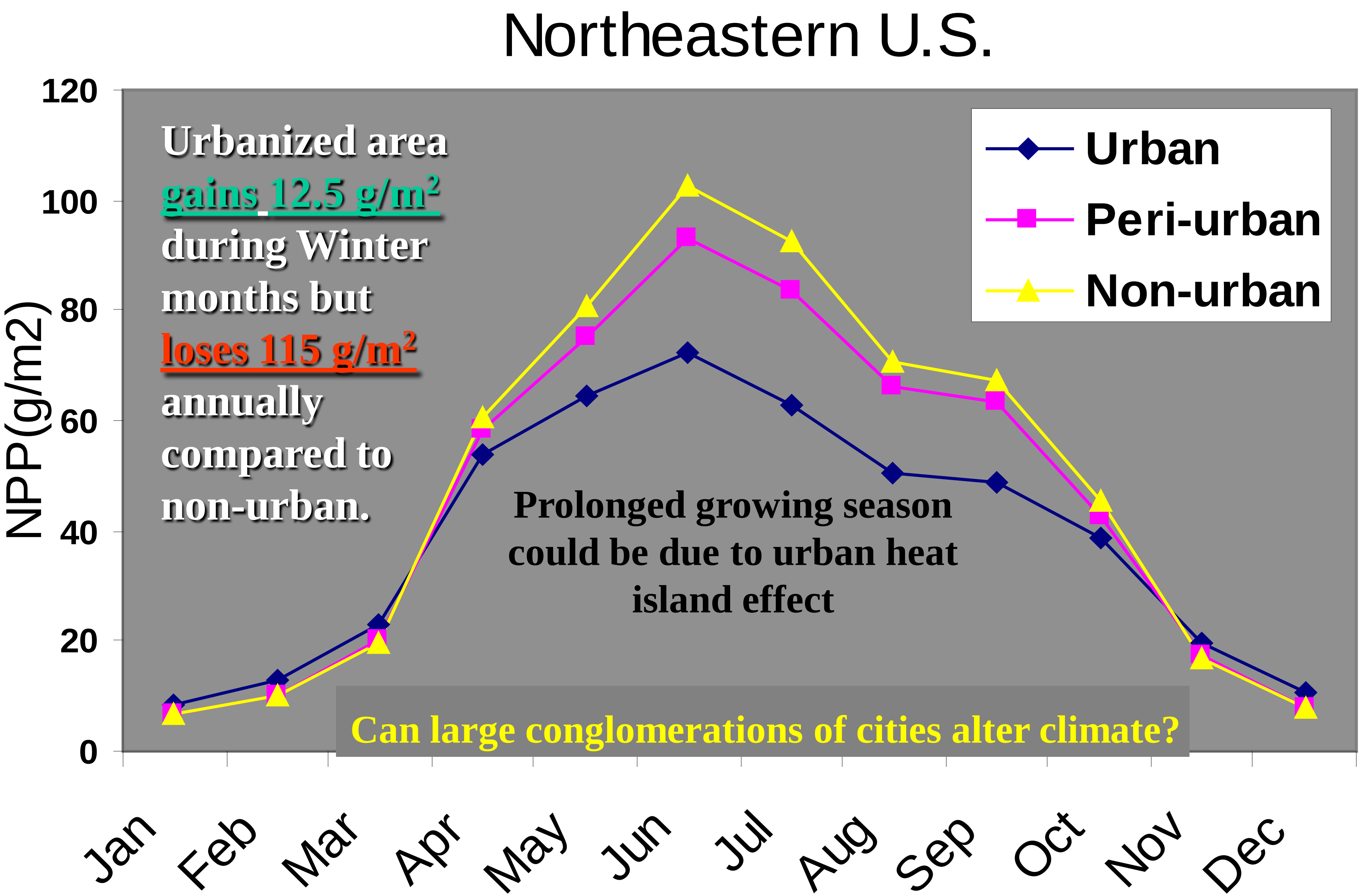
South<u>western</u> US

Urban and Peri-urban lands gain 53 g/m^2 annually over Non-urban lands due to irrigation and introduction of exotic species.

South**eastern** US

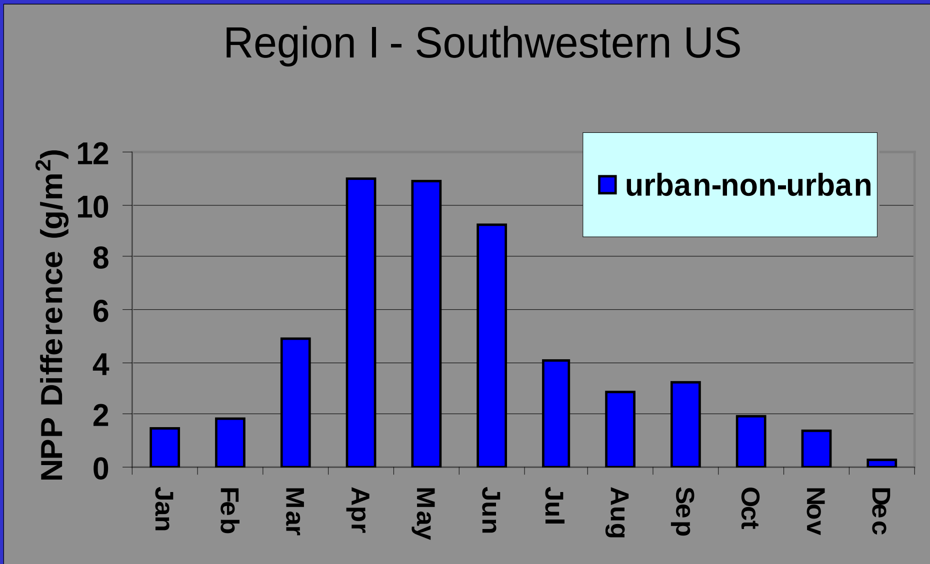
Urban and Peri-urban lands gain 4.2 g/m^2 during the winter months but loose 180 g/m^2 annually compared to Non-urban lands.

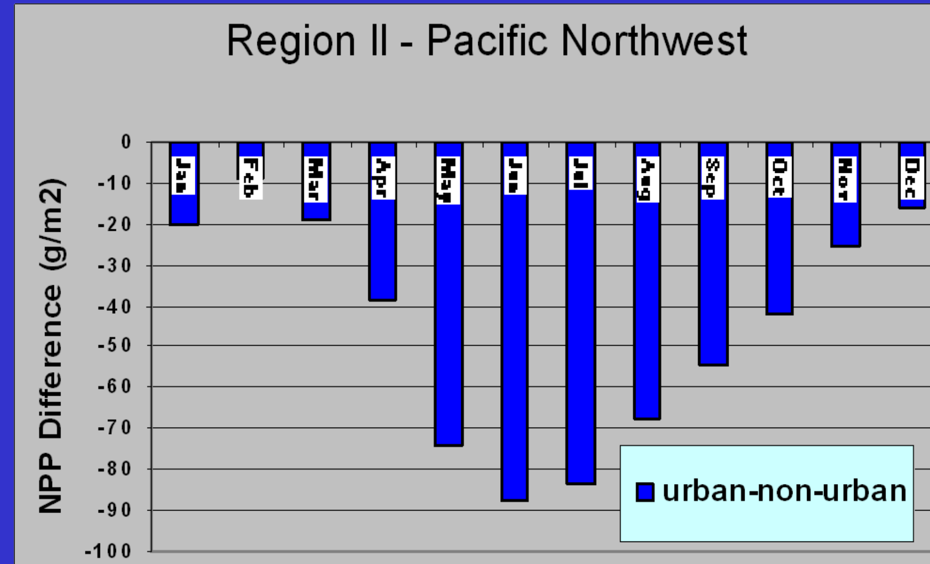
Impact of Urban/Suburban Sprawl on Carbon Fixation (NPP)

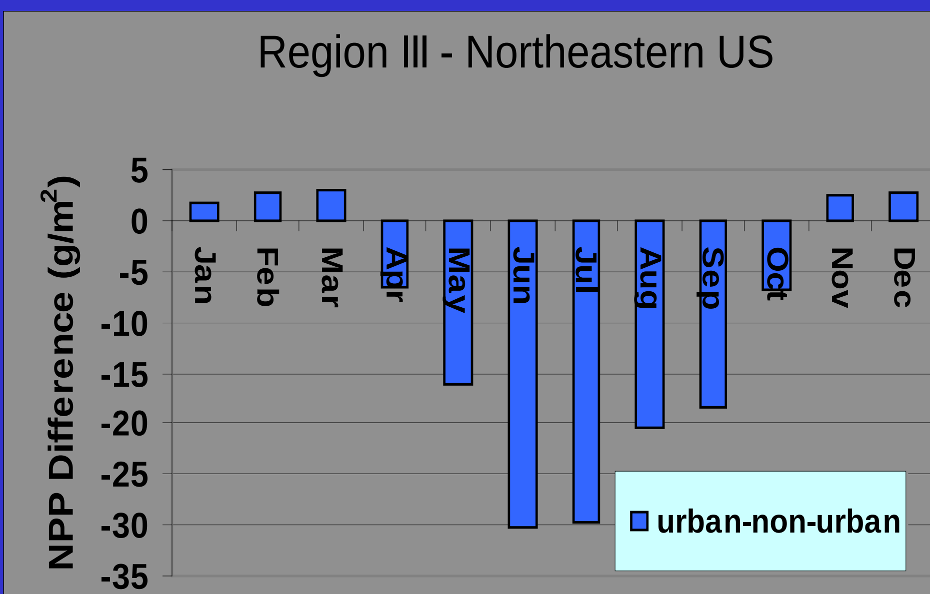


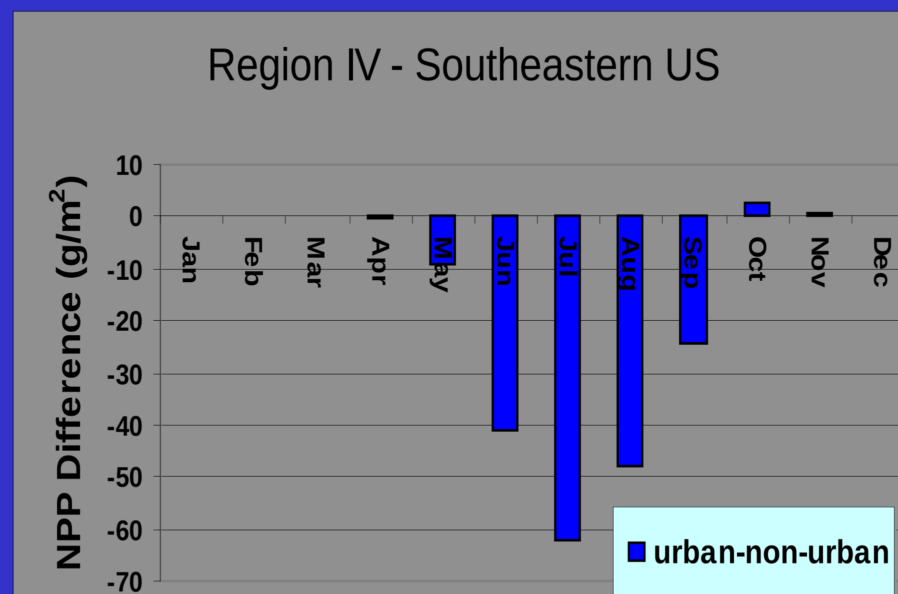
Variation in Seasonal Response of NPP to Urbanization

(Urban NPP minus Non-Urban NPP)



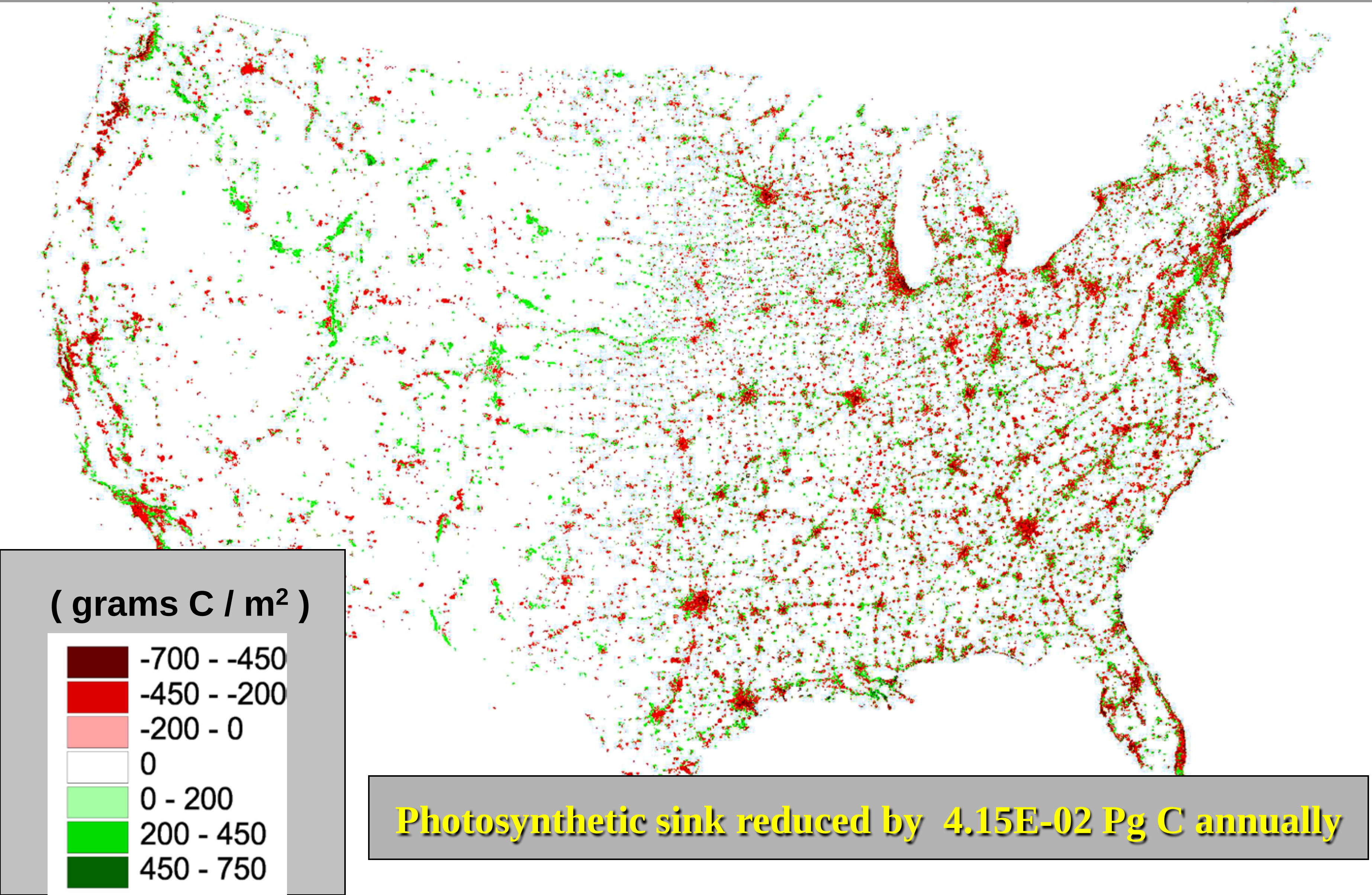






Loss / Gain of NPP Due to Urbanization

Annual Difference: POST-Urban minus PRE-Urban



Photosynthetic sink reduced by 4.15E-02 Pg C annually