Can Earth’s Plants Keep Up With Us?

Satellite View of Global Demand on Products of Photosynthesis

Marc Lee Imhoff NASA’s Goddard Space Flight Center
The Great Transformation

The current land surface little resembles what existed 10,000 or even only 3,000 years ago

Human Quest for Food, Fiber, and Fuel

- Fire for ecosystem management
- Grazing
- Deforestation
  Building material, and Fuel for heating, cooking, salt production, metal smelting
- Agriculture
- Urbanization
Global Land Cover
Pre-Agriculture
Approx. 10,000 BCE

% of Land Area
Transformed for Agriculture
(Negligible)

World Population
6-10 Million
Global Land Cover

43% of Land Area
Dominated by Agriculture

World Population
6.5 Billion
Urbanization:
One phenomenon, many processes

- Urban population, per capita consumption, and land transformation are all increasing simultaneously.
- How will we - as a species - deal with our own success?
- Can we recognize our impact on the environment and learn from it?
- Can we act in the general best interest?
- Will we use the incredible tools we have to address challenges before us?

OR...
Malthus’s Dismal Theorem:

Thomas Malthus, a 19th Century economist, postulated that since human populations increase geometrically and food supplies grow arithmetically, human populations will undergo a cycle of growth and catastrophic decline.
1998-1999
“Malthus might be right”

2002-2004
“Malthus is wrong”

2005
“Malthus might not be wrong - but we don’t want to know”
In the 200 years for which we have reliable data, overall growth of consumption has outpaced increased efficiencies in production processes.

Economic growth tends to increase consumption and the projected growth in the next 45 years is 200 - 400%.
Demand for food is projected to grow by 70-80% and water by 30-85%.

Food security is not achieved under any of the MA scenarios by 2050.
Closing the Earth System: We’ve Come A Long Way

Blue Marble
EOS Terra/Aqua 2000

TIROS
April 1, 1960
700 km Altitude

Apollo 17
Dec. 7, 1972, 45,000 km from Earth,
70mm Hasselblad, 80mm lens

World Community - Earth Observation satellite datasets
land, ocean, sea-ice, clouds, urban lights, topography

Credits: Reto Stöckli, Rob Simmon and MODIS science team
Measuring the Energy
Local to Regional Scale:
Multispectral View of San Francisco

<table>
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<tr>
<th>TM Band</th>
<th>Wavelength (μm)</th>
<th>Color</th>
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<td>7</td>
<td>2.08 - 2.35</td>
<td>Shortwave Infrared</td>
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<td>5</td>
<td>1.55 - 1.75</td>
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<td>4</td>
<td>0.76 - 0.90</td>
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Nighttime Lights of the World
Global Scale Urban Assessment: Defense Meteorological Satellite

Operational Linescan System (OLS)

Relationship between urbanization and energy production, use, and carbon emissions

- 833 km, sun-synchronous, near circular, polar orbit.
- Nighttime data (PMT)
  - 0.47 - 0.95 um
  - $10^{-5}$ to $10^{-9}$ Watts per cm$^2$ per sterradian.
- Pixel resolution:
  - 2.7 km at low resolution (smooth mode).

DMSP/OLS

Area of Lighting vs Power Consumption and Carbon Emissions for 200 Countries

Elvidge et al. ISPRS, 2001
Urbanization and Productivity

Landcover change, consumption, and food and fiber production
Earth’s “Bio-Engine”
Net Primary Production (NPP)

NPP is the amount plant material produced on Earth.
   It is the primary fuel for Earth's food web.
   Represents all available food and fiber.

NPP can be measured in terms of Carbon
   (photosynthesis - CO2 exchange between atmosphere and biosphere (global climate change).

Land use strongly impacts NPP
   Humans require almost 20% of Earth's NPP capacity on land

NPP is the “Common Currency” for Climate Change, Ecological, & Economic Assessment.
Earth's Breath of Life
Global Biological Productivity Land and Ocean
MODIS (Terra and Aqua Satellites)
Urbanization and NPP: US Examples

Satellite Observations

DMSP/OLS Urban Map
Urban, Peri-urban, Non-urban

AVHRR/MODIS
Monthly NPP (g Cm\(^{-2}\))

NPP and Local Climate:
Urban Heating Extends Length of growing season locally in cold climates.

North East
Winter NPP gain negated in peak season by reduced vegetation and heat stress.

Mid-Atlantic

South West
In semi-arid regions cities enhance NPP relative to surrounding areas

South East
Seasonal Offset diminishes in tropics

Imhoff et al., RSE, 89, 2004
Human Consumption of NPP: Can the Earth Keep Up?

NPP Carbon Balance (annual)

AVHRR (1982-1998)
CASA (land)

20 yr average - NPP (Supply) = 56.8 Pg C

UN/FAO + Models

NPP Required (Demand) = 11.5 Pg C

NPP Balance
NPP Demand as % of Supply

Global NPP Demand is 20% of Total Supply (land)
There are large regional and local variations

How HANPP Changes as a Function of: Population, Affluence, and Technology

\[ I = PAT \]

- The ecological impact \( I \) of human activities involves population size \( P \), consumption levels \( A \), for “affluence”, and the technologies employed \( T \) (Holdren and Ehrlich, 1976).

<table>
<thead>
<tr>
<th>Scenario</th>
<th>P*</th>
<th>A**</th>
<th>T***</th>
<th>HANPP (PgC)</th>
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↑(increase), – (no change from the baseline 1995 intermediate estimate).

* Population increase from 5.69 Billion (global population in 1995) to 8.92 Billion (estimated global population in 2050; Ref 18).

** Affluence increase applies average per capita consumption of industrialized countries (in 1995) for all countries.

*** Technology increase applies technological efficiencies of industrialized countries (in 1995) to all countries.

† Per capita fuel wood use in developing countries reduced to average for industrialized countries in 1995.
Conclusions

The placement, structure, and style of development of urban places impact biological resources (food and fiber production), hydrology, and the thermal environment.

Earth’s production capacity in the form of NPP-Carbon is a useful ‘common currency’ for environmental and economic assessment.

As urbanization increases so does consumption. Human NPP-C Demand is between 10% and 20% of planetary supply with large regional and local variation.

Technology, affluence, and population can interact in surprising ways.

Green technologies can reduce energy consumption, heat, and aerosol pollution to create livable cities.

Conservation does work to ameliorate impacts.
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- **Robert Harriss** - Houston Advanced Research Center.
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