This map shows total carbon stored in biomass in New Guinea, a heavily forested island just north of Australia. (NASA map by Robert Simmon, using data from Saatchi et al., 2011.) Working with 14 colleagues from 10 institutions around the world (including Michael Lefsky), Sassan Saatchi set about compiling and analyzing measurements from four space-based instruments—the GLAS lidar on ICESat, MODIS, the QuikSCAT scatterometer, and the Shuttle Radar Topography Mission—and from 4,079 ground-based forest plots. The team mapped more than three million measurements of tree heights and correlated them to measurements of trees from the ground. They calculated the amount of carbon stored above ground and in the roots. And they extrapolated their results over forest areas where there is less ground sampling but some known characteristics.

The result, released in May 2011, was a benchmark map of biomass carbon stocks covering 2.5 billion hectares (9.65 million square miles) of forest in 75 countries on three continents. Though previous efforts have mapped tropical forests on regional or local scales, the new map is “the first effort to quantify the distribution of forest carbon systematically over the entire tropical region,” Saatchi says.
Systematic land cover mapping missions
Global: growth form mapping
(AVHRR, MODIS, SPOT Vegetation)

Regional land cover, cover type
(Landsat, SPOT, IRS)

Local land cover: spatial patterns and scales (plant, patch, stand)
(IKONOS, Worldview-2, airborne)

Fragmentation, corridors
Humboldt’s “Map of the Kingdom of New Spain” was a remarkable cartographic achievement. According to Carl Wheat, as quoted in his *Mapping the Transmississippi West*, Humboldt’s map “was undoubtedly the most important and most accurate published map that had yet appeared.” Important enough that Humboldt’s great map of New Spain found its way into the hands of Zebulon Pike prior to his 1806 expedition to the Great Plains and Rocky Mountains. Humboldt would later complain bitterly to Thomas Jefferson when he saw his work reproduced, at least to a degree, in Pike’s maps of 1810.

Of particular interest was Humboldt’s recognition that the “Stoney Mountains” of the north as noted by Mackenzie was a continuation of the Cordilleras of New Spain. What are now referred to as the Rocky Mountains begin to show themselves as the very backbone of the continent, with their imposing east-to-west width drawn with much more accuracy and detail than found on earlier maps. Humboldt also advanced the science of cartography by drawing his mountains with the hachure technique of shading as opposed to the less satisfactory method of showing mountains in profile. While admitting that the hachure system “forces the drawer to say more than he knows, more than it is even possible to know of the geological constitution of a vast extent of territory,” Humboldt felt the newer system outweighed this disadvantage. This technique was soon adopted universally, not to be replaced until the contour method of displaying mountains became popular many years in the future.
Global systematic land cover mapping missions have a long history

Sekai Chizu, 1874
Vahl & Hatt: "Jorden og Menneskelivet" (The Earth and Human Life) (I-IV, Copenhagen 1922—27).
Climate Based Terrestrial Biome Map
Recent Land Cover Maps Based on Ground Data
Satellite-based Maps Started to be produced in 1990s

Matthews Vegetation Types - NPP

Mathews 1983 used map to compare to flux tower data

Recent Land Cover Maps Based on Ground data
Olson et al. 1983 also used to compare to flux tower data

Olson World Ecosystem Complexes - NPP

Comparison of 3 Global Land Based Land Cover Maps

For land Agreement
Red (26%) ALL
Yellow (46%) 2 of 3
Black (28%) none

Remote sensing based comparison of forest area to 3 ground based maps (2000 data)

Forest area agreement for the GLC2000-NCA minus IGBP, UMD and BU maps.

79% agreement

GLC2000-NCA - The GLC 2000-NCA land cover map is provided as a regional product with 28 land cover classes based on modified Federal Geographic Data Committee/Vegetation Classification Standard (FGDC NVCS) classification system, and as part of a global product with 22 land cover classes based on Land Cover Classification System (LCCS) of the Food and Agriculture Organisation.

The map was compared on both areal and per-pixel bases over North and Central America to the International Geosphere–Biosphere Programme (IGBP) global land cover classification, the University of Maryland global land cover classification (UMd) and the Moderate Resolution Imaging spectroradiometer (MODIS) Global land cover classification produced by Boston University (BU). There was good agreement (79%) on the spatial distribution and areal extent of forest between GLC 2000-NCA and the other maps, however, GLC 2000- NCA provides additional information on the spatial distribution of forest types. The GLC 2000-NCA map was produced at the continental level incorporating specific needs of the region.
Plant Functional Types

Existing Global Land Cover Maps are Based on Biome Distribution from Climate Relationships (not actual vegetation type distribution)

Coarse Spatial Resolution

Satellite Based Plant Functional Type Maps are higher Spatial Resolution and Derived from Actual Measurements

Maps today are based on remote sensing of **actual** land cover types (not just climate potential), often in combination with other database information.

IGBP Vegetation Map Classes, USGS "**Global Land Cover Characteristics Data Base (GLCC World)**" at a 30 arc second resolution using 17 clutter categories.

How do we go about mapping landcover?
- define classes
- determine the extent and resolution
  - Extent
    - continental, regional, local
  - Resolution
    - spatial (minimum mapping unit)
    - temporal (multidate needed to classify?)
    - spectral (class spectral features)
Global Systematic Land Cover Mapping
(AVHRR, MODIS, SPOT-VEGETATION)

**Define Classes**

Map limit is defined by your scientific questions
The actual landscape units to be mapped
Classified 9-Class Map of Land Cover
Global Systematic Land Cover Mapping (AVHRR, MODIS, SPOT-VEGETATION)

*How to define Class composition?*

What information to use in your creating your map?

A world map of the potential species diversity of terrestrial vascular plants based on the evaluation of approximately 1400 records from literature is presented. The evaluation of data from approximately 1400 floras, floristic studies, biogeographical essays and vegetation studies, regional to continental in scope, provides the mainstay for our map. The species numbers of the areas covered (predominantly political units) is calculated for a standard area of 10 000 sq. km. by a benchmark formula. Ten diversity zones in categories within the spectrum of less than 100 species and more than 5000 species per 10 000 sq. km. have been considered and mapped by ten colour indicators. Because political, and not natural, units constituted the data utilized, zonation boundaries of those areas with equal taxa density (isotaxas) are inferred on the basis of climatic and other data.

In the context of the elaboration of the map, it became clear that certain terminological and methodological issues need to be clarified. Based on the existing literature, a terminology for the classification of plants according to the mode and time of their first occurrence in the study area, and for the respective diversities, is introduced. It is particularly important to distinguish between the autodiversity, i.e. the diversity of indigenous plants (autophytes), and the allodiversity, i.e. the diversity of plants introduced by man (allophytes). In addition, for other purposes it is more important to distinguish between the eudiversity, i.e. the diversity of autophytes and plants introduced with the former continuous migration of man (archaeophytes), and the neodiversity, i.e. the diversity of plants dispersed by man over large distances, usually resulting in distribution gaps (neophytes). Neodiversity is increased tremendously by neoterodiversity, i.e. the diversity of plants dispersed in the context of motorised mass transportation since the end of the last century (neoterophytes, "invaders").

This world map diverges in significant details from hitherto acknowledged concepts of the distribution of diversity (e.g. the Cameroon-Gabon Centre is identified as a diversity maximum for Africa for the first time). We recognize six global species maxima: 1. Chocó-Costa Rica Centre, 2. Tropical Eastern Andes Centre, 3. Atlantic Brazil Centre, 4. Eastern Himalaya-Yunnan Centre, 5. Northern Borneo Centre, 6. New Guinea Centre.

The results are elucidated by explanatory comments and critical discussion. Inevitably, a number of terminological issues must be clarified (e.g. isotaxas - isoporia, diversity maxima, diversity centres, criteria governing the quality of diversity, landscape diversity - geodiversity - ecodiversity, etc.). As is to be expected, the biodiversity of an area does not depend solely on its history (climatic and floristic history, palaeogeography and evolutionary availability of genetic diversity) or its position (degree of isolation and zonobiom), but also on the whole variety of its abiotic parameters (geodiversity). In this context, a connection becomes apparent between tropical diversity maxima and oceanic surface temperatures of more than 27°C. With reference to and in the context of the well documented interdependent ecosystem of primary producers (vascular plants) with consumers and decomposers, we suppose that the map reflects quite accurately the global distribution of terrestrial biodiversity in its entirety.
Examples of trait-based biogeography for macroorganisms. (A) Covariation in leaf traits [leaf life span (LL) and leaf mass per area (LMA)] as a function of climate [mean annual rainfall (MAR)]. Data plotted for species sampled worldwide [modified from (10)]. (B) Variation in community-aggregated plant traits over successional time. Data sampled from vineyards in France after abandonment [modified from (15)]. (C) Variation in community-aggregated wood density with latitude. Data plotted for mean wood density of all species in 1° grid cells [modified from (14)].

Microbial Biogeography: From Taxonomy to Traits

Jessica L. Green,
Brendan J. M. Bohannan and
PV = photosynthetic vegetation
NPV = non-photosynthetic vegetation (all the non-green parts of plants and dead plant material)
Global Systematic Land Cover Mapping
(AVHRR, MODIS, SPOT-VEGETATION)

- determine the extent and resolution
  - Extent = continental
  - Resolution
    - spatial
    - temporal
    - spectral
TOOLS FOR OBSERVING THE LAND
Resolution and coverage for different needs....

VIIRS
- 3300 km swath
- spatial resolution, 400/800m (nadir (Vis,IR))
- global coverage, 2x/day/satellite

AVHRR/
MODIS
- 2048 km swath
- spatial resolution, 250m, 500m, 1000m
- global coverage, 2 days

MISR
- spatial resolution, 275m, 550m, 1100m
- global coverage, 9 days

Landsat
- spatial resolution, 15m, 30m, 60m
- 16 day orbital repeat
- seasonal global coverage
- 2-3 day repeat coverage
- seasonal repeat coverage
- 45-60 day orbital repeat
- global coverage, years

SPOT spatial resolution, 10m 20m
- 60 km

ASTER
- spatial resolution 15m, 30m, 90m
- 60 km

Commercial Systems
- spatial resolution < 5m
- global coverage, decades, if ever

PLUS RADAR, MAGNETICS, MICROWAVE, ETC., plus airborne and in situ methods
Global and Regional Satellites: Spatial Resolution

**Regional:**
- Landsat
- SPOT
- ASTER
- IRS

**Global:**
- AVHRR
- MODIS
- SPOT Vegetation
Spatial resolution (pixel)

Ikonos has 1m pan and 4m 4-band VNIR
Worldview-2 has 46cm pan, 1.85m 8-band VNIR

Qbird pan = 0.6m
Green circles in the desert frequently indicate tracts of agriculture supported by center-pivot irrigation. The Al Khufra Oasis in southeastern Libya (near the Egyptian border) is one of Libya’s largest agricultural projects, and is an easy-to-recognize landmark for orbiting astronauts aboard the International Space Station. Because only about 2 percent of Libya’s land receives enough rainfall to be cultivated, this project uses fossil water from a large underground aquifer. The Libyan government also has a plan called the Great Man Made River to pump and transport these groundwater reserves to the coast to support Libya’s growing population and industrial development.

The center-pivot irrigation system pumps water under pressure into a gantry or tubular arm from a central source. Anchored by a central pivot, the gantry slowly rotates over the area to be irrigated, thereby producing the circular patterns. Although the field diameters vary, these fields are approximately 0.6 mile (1 kilometer) in diameter. Darker colors indicate fields where such crops as wheat and alfalfa are grown. Lighter colors can indicate a variety of agricultural processes: fields that have been harvested recently; fields that are lying fallow; fields that have just been planted; or fields that have been taken out of production.

Astronaut photograph ISS010-E-5266 was acquired October 28, 2004 with a Kodak 760C digital camera with a 180 mm lens, and is provided by the ISS Crew Earth Observations experiment and the Image Science & Analysis Group, Johnson Space Center. The International Space Station Program supports the laboratory to help astronauts take pictures of Earth that will be of the greatest value to scientists and the public, and to make those images freely available on the Internet. Additional images taken by astronauts and cosmonauts can be viewed at the NASA/JSC Gateway to Astronaut Photography of Earth.
### AVHRR/3 Channel Characteristics

<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Resolution at Nadir</th>
<th>Wavelength (μm)</th>
<th>Typical Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.09 km</td>
<td>0.58 - 0.68</td>
<td>Daytime cloud and surface mapping</td>
</tr>
<tr>
<td>2</td>
<td>1.09 km</td>
<td>0.725 - 1.00</td>
<td>Land-water boundaries</td>
</tr>
<tr>
<td>3A</td>
<td>1.09 km</td>
<td>1.58 - 1.64</td>
<td>Snow and ice detection</td>
</tr>
<tr>
<td>3B</td>
<td>1.09 km</td>
<td>3.55 - 3.93</td>
<td>Night cloud mapping, sea surface temperature</td>
</tr>
<tr>
<td>4</td>
<td>1.09 km</td>
<td>10.30 - 11.30</td>
<td>Night cloud mapping, sea surface temperature</td>
</tr>
<tr>
<td>5</td>
<td>1.09 km</td>
<td>11.50 - 12.50</td>
<td>Sea surface temperature</td>
</tr>
</tbody>
</table>

250m pixels for red, NIR bands; 500m pixel for (3A) SWIR band
8km pixels for TIR bands
### Global systematic land cover mapping

<table>
<thead>
<tr>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land/Cloud/Aerosols</td>
<td>1</td>
<td>620 - 670</td>
</tr>
<tr>
<td>Boundaries</td>
<td>2</td>
<td>841 - 876</td>
</tr>
<tr>
<td>Land/Cloud/Aerosols</td>
<td>3</td>
<td>459 - 479</td>
</tr>
<tr>
<td>Properties</td>
<td>4</td>
<td>545 - 565</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1230 - 1250</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1628 - 1652</td>
</tr>
<tr>
<td>Ocean Color/</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Phytoplankton/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogeochemistry</td>
<td>10</td>
<td>483 - 493</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>526 - 536</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>546 - 556</td>
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<tr>
<td></td>
<td>13</td>
<td>662 - 672</td>
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<tr>
<td></td>
<td>14</td>
<td>673 - 683</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>743 - 753</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>862 - 877</td>
</tr>
<tr>
<td>Atmospheric</td>
<td>17</td>
<td>890 - 920</td>
</tr>
<tr>
<td>Water Vapor</td>
<td>18</td>
<td>931 - 941</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>915 - 965</td>
</tr>
</tbody>
</table>

**NDVI** = \[
\frac{B2 - B1}{B2 + B1}
\]

MODIS

[Link](http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf)

36 bands
Use just visible
Spectral resolution (# bands, band location, bandwidth)

Spatial and Spectral Resolution of Landsat Multispectral Scanner, Landsat Thematic Mappers, and SPOT Sensor Systems

- SPOT 5 High Resolution Visible Infrared (HRVIR)
- SPOT 4 High Resolution Visible Infrared (HRVIR)
- SPOT 1, 2, and 3 High Resolution Visible (HRV)
- Landsat 7 Enhanced Thematic Mapper Plus (ETM+)
- Landsat Thematic Mappers (TM) 4 and 5
- Landsat Multispectral Scanner (MSS) 1, 2, 3, 4, and 5

Jensen, 2007
used AVHRR NDVI maps, and a “fuzzy neural network” (a self-learning algorithm that uses indeterminant class boundaries based on statistical tests) classifier to classify global ecosystems. Note how general the classes are.
Temporal resolution (revisit times)
What do you think about these two images and what you can interpret from them?
Global Systematic Land Cover Mapping

Why do we care?

Ecoregions

Ecoregions are large areas of similar climate where ecosystems recur in predictable patterns. We provide resources and education on the origins of these patterns and their relevance to sustainable design and planning.

Who’s Using Ecoregions

Many federal agencies and private organizations use a system of land classification based on the ecoregion concept. Some of these include USDA Forest Service, U.S. Geological Survey, U.S. Fish and Wildlife Service, The Nature Conservancy, and The Sierra Club. Projects include biodiversity analysis, landscape and regional level forest planning, and the study of mechanisms of forest disease.

- USDA UV-E Monitoring and Research Program
- The Committee on Earth Observing Satellites
- Sierra Club Critical Ecoregions Program
- NEARCTICA - The Natural World of North America
- National Geographic and World Wildlife Fund
- Applications of Baleys Ecoregions to Military Lands
- Ecoregional Planning – The Nature Conservancy
- Wild Ones - Guidelines for Selecting Native Plants

http://www.fs.fed.us/rm/ecoregions/

Ecoregions

Biodiversity ignores national and other political boundaries, so a more relevant conservation planning unit is required. WWF addresses this need with ecoregions.
The Nature Conservancy. "Major Habitat Types" are groupings of ecoregions; they share similar environmental conditions, habitat structure, natural communities and patterns of biological complexity. Globally there are about 30 major habitat types: 13 terrestrial, about 10 freshwater and about 10 marine. The marine and freshwater major habitat types are in the process of being refined. To do this, our scientists are working with their counterparts at the World Wildlife Fund, World Resources Institute and other organizations to ensure scientific credibility and buy-in so that all our organizations can adopt consistent definitions and perspectives on the global-scale organization of biodiversity. We adopted outright the World Wildlife Fund’s 13 terrestrial major habitat types, which are widely accepted by the scientific community. The major habitat type (also know as biome) framework was published some time ago by World Wildlife Fund scientists.
By using the data fusion method, the study was able to characterize the world’s cultivated lands in a continuous fashion, depicting the percentage of each pixel that is in croplands.
determine the extent and resolution
  Extent = regional
  Resolution
    spatial
    temporal
    spectral
WRS with > 10% forest cover

- > 1200 Landsat images
- More than 480 images with greater than 10% forest cover
- > 800 MHa mapped
- circa 2000 imagery
- Completed 2006
- Hyperclustering and labeling: 6 optical channels+intra-pixel pan variance
4 Taiga Plains  11 Taiga Cordillera
5 Taiga Shield  12 Boreal Cordillera
6 Boreal Shield 13 Pacific Maritime
7 Atlantic Maritime 14 Montane Cordillera
9 Boreal Plains  15 Hudson Plains
Local land cover mapping

determine the extent and resolution
  Extent = regional
  Resolution
    spatial
    temporal
    spectral
Local land cover mapping

Quickbird View of Copper Mountain Ski Resort, Colorado

QuickBird
Local land cover mapping

Logging in the Tropics Observed from Weather Satellites
Local land cover mapping

Effect of sensor data

Xu, B., and Gong, P. 2002
MESMA: vegetation mapping of the Santa Barbara Front Range

Dar Roberts UCSB

Adenostoma fasciculatum  Ceanothus megacarpus  Arctostaphylos spp.  Quercus agrifolia

Accuracy: 90%
How to measure fragmentation

- The conversion of a single patch of habitat into smaller disconnected patches.

Yasuni National Park, Ecuador,
LANDSAT
1996
**How to measure fragmentation**

**Metrics** can be derived for each category:
- Patch: area, distance to nearest patch, edge effects, etc.
- Habitat Type: area of each habitat

From these, landscape level metrics can be derived: patch count, total patch area, etc.
How to measure fragmentation

**EDGES:**
- Boundaries may impact habitat quality.
- Edges are functions of both the *area* of the patch as well as the *shape*.

**AREA:**
- Patch size can be related to habitat quality
- Smaller patches are more likely to go extinct than larger patches

**DISTANCE:**
- May preclude migration, further threatening extinction in a single patch.
- Corridors effectively connect two separate patches, allow migration to occur unimpeded.
What you should know from this lecture

1. Analyzing Patterns: **how landscape patterns may have developed** (using spatial, spectral and temporal patterns)

2. Data analysis and interpretation range from **visual evaluation** and **simple band comparison** (techniques with roots in photogrammetry)

3. Classifications from only **single date image data** (trained or unsupervised), **multiple datasets** (capturing phenological separation), or **multiple types of data** (field, various image datasets, etc.)

4. Greater differentiation of land cover with hyperspectral alone and with lidar at smallest **scales**