How open access to the Landsat archive is changing how we map and monitor ecosystem dynamics: Case studies from Southern New England

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Free Access to Landsat Imagery

WE ARE ENTERING A NEW ERA IN THE LANDSAT Program, the oldest and most venerable of our Earth-observing satellite programs. With little fanfare, the U.S. Geological Survey (USGS) has begun providing imagery for free over the Internet. Throughout the history of the Landsat Program, the cost and access to imagery has always limited our ability to study our planet and the way it is changing. Beginning with a pilot program to provide “Web-enabled” access to Landsat 7 images of the United States that were collected between 2003 and this year, the USGS now plans to provide top-quality image products for free upon request for the entire U.S. archive, including over 2 million images back to Landsat 1 (1972) (for details and schedules, see (/)). The release by NASA and the USGS in January 2008 of a new Landsat Data Distribution Policy (2) was a key step to this goal. Free imagery will enable reconstruction of the history of Earth’s surface back to 1972, chronicling both anthropogenic and natural changes during a time when our population doubled and the impacts of climate change became noticeable.

THE LANDSAT SCIENCE TEAM: CURTIS E. WOODCOCK,1 RICHARD ALLEN,2 MARTHA ANDERSON,3 ALAN BELWARD,4 ROBERT BINDSCHADLER,2 WARREN COHEN,4 FENG GAO,5 SAMUEL N. GOWARD,6 DENNIS HELDER,7 EILEEN HELMER,7 RAMA NEMANI,8 LAZAROS OREOPoulos,9 JOHN SCHOTT,9 PRASAD S. THENKABAIL,10 ERIC F. VERMOTE,11 JAMES VOGELMANN,11 MICHAEL A. WULDER,12 RANDOLPH WYNNE12

Free image. This Landsat 5 image of the southeastern corner of the Black Sea is part of the general U.S. archive that will be accessible for free under the new USGS policy.
Landsat Scenes Visible in EarthExplorer

- L8 (Pre and on WRS 2): 1,150,516
- L7 (SLC On & Off): 2,410,018
- L4-S TM: 2,410,305
- L1-S MSS: 1,319,873

Millions of Landsat Images Downloaded since December 2008

http://landsat.usgs.gov/Landsat_Project_Statistics.php
Landsat 101:
Spatial, Spectral, Temporal
30 m spatial resolution

30 centimeters
(high res. imagery)

30 meters
(Landsat)
Broad multi-spectral bands

<table>
<thead>
<tr>
<th>TM Band</th>
<th>Wavelength (μm)</th>
<th>Thermal Infrared</th>
<th>Shortwave Infrared</th>
<th>Near Infrared</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>10.4 - 12.5</td>
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<td></td>
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<tr>
<td>7</td>
<td>2.08 - 2.35</td>
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<tr>
<td>5</td>
<td>1.55 - 1.75</td>
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<tr>
<td>4</td>
<td>0.76 - 0.90</td>
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<tr>
<td>3</td>
<td>0.63 - 0.68</td>
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<tr>
<td>2</td>
<td>0.52 - 0.60</td>
<td></td>
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<tr>
<td>1</td>
<td>0.45 - 0.50</td>
<td></td>
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</tr>
</tbody>
</table>

**Band designations**

- L8 OLI/TIRS
- L7 ETM+
- L4-5 TM
- L4-5 MSS*
- L1-3 MSS*

**Landsat band wavelength comparisons**

- All bands 36-meter resolution unless noted.

- Coastal/Aerosol
- Blue
- Panchromatic
- Green
- Near-Infrared
- Shortwave Infrared-1
- Shortwave Infrared-2
- Thermal
- Thermal

**Band numbers**

- Band 1
- Band 2
- Band 3
- Band 4
- Band 5
- Band 6
- Band 7
- Band 10 T1
- Band 11 T1

**Acquired at**

- 79 meters, resampled to 60 meters
- 15-meter (panchromatic)
- 100 meters, resampled to 30 meters
- 120 meters, resampled to 30 meters

https://svs.gsfc.nasa.gov/vis/a000000/a000900/a000936/landsat_bands_all.jpg
16-day revisit
(8-day with two)
1. Example time series
2. Gypsy moth defoliation monitoring
3. Forest composition mapping
4. Future work
1. Example time series
2. Gypsy moth defoliation monitoring
3. Forest composition mapping
4. Future work
“Spectral-temporal responses”
Abrupt Change

State 1

State 2
Disturbance-Recovery

State 1

State 2

Recovers to same state

time
Clearing and forest succession/recovery
Disturbance-Recovery

State 1

State 2

State 3

Recovers to new state
Beaver-impacted wetland (Wachusett Meadow)
Gradual Change

State 1

Vegetation Growth

State 2

time
Forest succession/recovery

Un-development (Boston State Hospital)
Shift from high marsh to low marsh/mud flat (Smith 2015)
Cyclic Change

State 1

State 2

time
Allens Pond tidal inlet
Example time series

- Conventional single date and multi-date approaches have been missing the full range of ecosystem dynamics
- Different bands capture different processes
- Same basic data, many possibilities
Example time series

Gypsy moth defoliation monitoring

Forest composition mapping

Future work
Figure 26. Defoliation of a mixed broadleaf forest by *gypsy moth*. Bear Brook State Park, NH.

Long history of using satellite remote sensing to map defoliation...
“Greenness” time series (for one pixel)
Use historical observations to estimate **baseline**

“Greenness” time series (for one pixel)
“Greenness” time series (for one pixel)

Use historical observations to estimate baseline

\[
\text{Condition} = \frac{\text{obs} - \text{pred}}{\text{RMSE}}
\]
“Greenness” time series (for one pixel)

Use historical observations to estimate baseline

\[ \text{Condition} = \frac{\text{obs} - \text{pred}}{\text{RMSE}} \]
2016
Total number of observations
mid-May – September, n = 16
2016
Mean condition score

Non-forest (masked)
Near normal
Slight change
Moderate change
Large change
Very large change
I. Modeling

Fit model to stable base period

II. Monitoring

New image

Predicted image

Find potential changes in condition

Near-real-time products (per scene)

Targeted field/aerial surveys (attribution)

III. Assessment

Season-integrated metric of change in condition

Annual disturbance map (larger swath)
2017
Total number of observations
mid-May – September, n = 18
2017
Mean condition score
Gypsy moth defoliation monitoring

• New Landsat time series approach for monitoring gypsy moth outbreaks
• Historical assessments enable comparisons across years
• Could be modified for other defoliators
• Integration with aerial/ground surveys is key!
1. Example time series
2. Gypsy moth defoliation monitoring
3. Forest composition mapping
4. Future work
• Higher spatial resolution
• Locally accurate


Spectral-temporal features (STFs):
Features derived from time series data that characterize temporal variability in spectral reflectance

- Seamless coverage
- Can be generated for any date/year
- Relatively stable
Harmonic features
Annual variability in reflectance
CCDC (Zhu et al. 2014)

Phenological features
Change in timing of seasonal events

Relative to y-axis (reflectance)

Deciduous forest
MA, USA

Relative to x-axis (time)
Harmonic Tasseled Cap Brightness (TCB)

* Non-forest masked in black
Harmonic
Tasseled Cap Greenness (TCG)

* Non-forest masked in black
Harmonic
Tasseled Cap Wetness (TCW)

* Non-forest masked in black
Phenology
Long-term means

* Non-forest masked in black

Peak Enhanced Veg. Index (EVI)
Growing season length
Model r
Harmonic
Landsat Brightness Temperature

* Non-forest masked in black
Harmonic PRISM Mean Temperature

* Non-forest masked in black
Harmonic
PRISM Monthly Precipitation

* Non-forest masked in black
Ancillary
Topography + Wetlands

- Elevation
- Slope
- Aspect
- Topographic Position Index
- Terrain Roughness Index

NOAA C-CAP Wetlands Probability

* Non-forest masked in black
FIA/RS
“Data Cube”

- RF Classification
- RF Regression
- GNN Imputation
Assigning class labels:

Tree-level data

% Total Basal Area (TBA) by species

Dominant Species

Minimum TBA Criteria

Most recent survey year

Training/Testing Data

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Number of plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulmus rubra (slippery elm)</td>
<td>300</td>
</tr>
<tr>
<td>Ulmus americana (American elm)</td>
<td>250</td>
</tr>
<tr>
<td>Tsuga canadensis (eastern hemlock)</td>
<td>200</td>
</tr>
<tr>
<td>Tilia americana (American basswood)</td>
<td>150</td>
</tr>
<tr>
<td>Thuja occidentalis (northern white cedar)</td>
<td>100</td>
</tr>
<tr>
<td>Sassafras albidum (sassafras)</td>
<td>150</td>
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<tr>
<td>Robinia pseudoacacia (black locust)</td>
<td>100</td>
</tr>
<tr>
<td>Quercus velutina (black oak)</td>
<td>200</td>
</tr>
<tr>
<td>Quercus rubra (northern red oak)</td>
<td>150</td>
</tr>
<tr>
<td>Quercus prinus (chestnut oak)</td>
<td>100</td>
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<tr>
<td>Quercus macrocarpa (bur oak)</td>
<td>50</td>
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<tr>
<td>Quercus coccinea (scarlet oak)</td>
<td>50</td>
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<td>Quercus alba (white oak)</td>
<td>200</td>
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<td>Prunus serotina (black cherry)</td>
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<tr>
<td>Prunus pensylvanica (pin cherry)</td>
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<td>Populus tremuloides (quaking aspen)</td>
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<td>Populus grandidentata (bigtooth aspen)</td>
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<td>Pinus strobus (eastern white pine)</td>
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<td>Pinus rigida (pitch pine)</td>
<td>50</td>
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<tr>
<td>Pinus resinosa (red pine)</td>
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<tr>
<td>Picea rubens (red spruce)</td>
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<tr>
<td>Picea abies (Norway spruce)</td>
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<tr>
<td>Ostrya virginiana (eastern hophornbeam)</td>
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<tr>
<td>Nyssa sylvatica (blackgum)</td>
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<tr>
<td>Liriodendron tulipfera (yellow poplar)</td>
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<tr>
<td>Juniperus virginiana (eastern redcedar)</td>
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<tr>
<td>Fraxinus pennsylvanica (green ash)</td>
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<tr>
<td>Fraxinus nigra (black ash)</td>
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<td>Fraxinus americana (white ash)</td>
<td>50</td>
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<tr>
<td>Fagus grandifolia (American beech)</td>
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<tr>
<td>Carya ovata (shagbark hickory)</td>
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<tr>
<td>Carya glabra (pignut hickory)</td>
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<tr>
<td>Betula populifolia (gray birch)</td>
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<tr>
<td>Betula papyrifera (paper birch)</td>
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<td>Betula lenta (black birch)</td>
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<tr>
<td>Betula alleghaniensis (yellow birch)</td>
<td>50</td>
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<tr>
<td>Acer saccharum (sugar maple)</td>
<td>200</td>
</tr>
<tr>
<td>Acer rubrum (red maple)</td>
<td>150</td>
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<tr>
<td>Abies balsamea (balsam fir)</td>
<td>100</td>
</tr>
</tbody>
</table>
Rare species > 30% TBA
Common species > 50% TBA

- Tsuga canadensis (eastern hemlock)
- Quercus velutina (black oak)
- Quercus rubra (northern red oak)
- Quercus coccinea (scarlet oak)
- Quercus alba (white oak)
- Pinus strobus (eastern white pine)
- Pinus rigida (pitch pine)
- Picea rubens (red spruce)
- Fraxinus (ash spp.)
- Fagus grandifolia (American beech)
- Betula papyrifera (paper birch)
- Betula lenta (black birch)
- Betula alleghaniensis (yellow birch)
- Acer saccharum (sugar maple)
- Acer rubrum (red maple)
- Abies balsamea (balsam fir)
Rare species > 30% TBA
Hemlock >50% TBA
Common species > 70% TBA
So, which map is right?
All species > 30% TBA
Rare species > 30% TBA
Common species > 50% TBA
Rare species > 30% TBA
Hemlock >50% TBA
Common species > 70% TBA
Different definitions of dominance ➔ Different maps
FIA/RS
“Data Cube”

RF Classification

RF Regression

GNN Imputation
3 Forest composition mapping

• Spectral-temporal features and FIA plot data are a powerful combination

• All maps are wrong, some maps are useful

• Need to consider both statistical assessments and more qualitative expert review
  • Stakeholder feedback is critical!
1. Example time series
2. Gypsy moth defoliation monitoring
3. Forest composition mapping
4. Future work
Species Composition + Vegetation Structure

Development

Harvest & Management

Natural Disturbances

Climate Change

Invasive Species & Forest Pests
Acknowledgements:

Bethany Bradley, NE CSC

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Jonathan Thompson, Luca Morreale
Questions?

valpasq@umass.edu
Red maple

RF Probability

0 1 - 5 5 - 25 25 - 50 50 - 75 75 - 100

Acer rubrum (red maple)

RF Probability

FIA % TBA

Inset: Red maple tree in autumn.