



Application of Landsat Imagery for Landscape-Scale Change Detection and Trend Analysis in the Northern Colorado Plateau Network

Protocol Narrative and Standard Operating Procedures, Version 1.0

Natural Resource Report NPS/NCPN/NRR—2016/1216



ON THE COVER

The Colorado River flows between the city of Grand Junction, Colorado, and Colorado National Monument in this Landsat 7 Enhanced Thematic Mapper true color image. NASA photo.

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Previous version #	Revision date	Author	Changes made	Reason for change	New version #
1.00	4/24/2016	A.W. Biel	Editorial, revision history log added	Preparation for NRR publication	1.01

Introduction

Landsat-based detection of Trends in Disturbance and Recovery (LandTrendr) and TimeSync are a set of tools that extract spectral trajectories of land-surface change from yearly Landsat time-series image stacks (LTS). Developed by Oregon State University (OSU) and the Pacific Northwest Research Station, LandTrendr identifies important features in time-series signatures by minimizing the influence of noise caused by changes in illumination, phenology, atmosphere, and geometric registration (Kennedy et al. 2010). Temporal trends in reflectance are evaluated on a pixel-by-pixel basis by regression-based and point-to-point fitting.

LandTrendr is accompanied by TimeSync to help interpret temporal patterns in reflectance by allowing analysts to visually compare segmentation and fitted functions with yearly spectral values (Cohen et al. 2010). The combination of algorithms embodied in LandTrendr and TimeSync enable quantitative description of change at pixel and landscape scales. Specifically, these tools allow the Northern Colorado Plateau Network (NCPN) to determine the start, end, duration, and rate of disturbance, as well as the magnitude of disturbance and recovery. The evolution of project work leading to implementation of LandTrendr and TimeSync in NCPN applications informs the appropriate application of these tools and the kind of interpretation that can be made.

Pilot studies

Over the course of several years, collaborators at OSU worked with staff from the National Park Service (NPS) Northern Colorado Plateau Network and Southern Colorado Plateau Network (SCPN) on a multi-stage

project to evaluate the potential utility of Landsat imagery for monitoring vegetation on the Colorado Plateau. The initial stage of the project focused on baseline and single-time-frame mapping. Because of the difficulties encountered at this stage, later work focused on detection and interpretation of change, using increasingly sophisticated methods that incorporated longer time-series of imagery.

Baseline mapping

Identification of change requires information about both the starting condition and the creation of models to identify vegetation types from the Landsat imagery. Thus, substantial effort was initially aimed at baseline mapping. Baseline maps from the NPS Vegetation Mapping (NPSVM) Project are both extremely rich in information and generally high in spatial detail, but are limited to the parks proper and their immediate vicinity, and to a single occasion. Expanding the temporal and spatial scope with Landsat imagery would provide context for monitoring within the parks. Work focused on Mesa Verde and Canyonlands national parks, which had no NPSVM products at the time of the studies, and at Zion National Park, which did have a completed NPSVM map.

Key conclusions from this stage of the project included:

- As expected from the initial literature review, the soil signal dominates the spectral response in most of NCPN and SCPN areas, making vegetation discrimination difficult under any circumstance when Landsat data are used. This is a limitation inherent to the data, regardless of the spectral indices used or the data-analysis method employed.

- Mapping vegetation components with Landsat is done most robustly for forest and woodland vegetation cover. When thematic maps are available, such as those from the NPSVM program, aggregation to simpler, spectrally separable classes is feasible and relatively accurate.
- Available reference data are generally inadequate for the purposes of training and testing maps with Landsat data. New airphoto interpretation can fill some gaps but is costly, and even airphoto interpretation lacks the separability needed to go beyond aggregated class labels with confidence.
- Reference data are an even greater bottleneck for many change-detection approaches than they are for single-date mapping, as reference data must be both appropriate for remotely sensed models and consistent across time. Such data are rarely available. Validation of change results is thus particularly challenging.
- Detection of landscape change is possible using either continuous-variable maps or the POM approach originally envisioned for these projects. The former approach is primarily limited to forest and woodland cover types. Land-cover classes in the POM-change approach were limited to fairly broad labels that may not be useful for some NCPN and SCPN goals.
- Any map of change using only two dates of imagery is suspect in these ecosystems because vegetation phenology and year-to-year variance in precipitation cause many potential false-positive spectral changes.

Because of these challenges, the NCPN, SCPN, and OSU groups determined that the potential utility of Landsat data for baseline mapping alone was lower than that desired by the parks but that some of the methods explored for baseline mapping may be relevant when used in the context of change detection.

Two-date change detection

Detection of landscape change was thus the next major focus. Change-detection studies focused on Mesa Verde and Zion national parks and Wupatki National Monument. At the onset of the project, the NCPN and SCPN (aka “the networks”) were interested in the potential to apply the method known as “POM” (probability of membership) change detection that OSU had developed for the parks of the North Coast and Cascades Network (NCCN). However, unlike the NCCN situation, existing land-cover maps were available for the NCPN and SCPN parks; thus, new methods to aggregate and merge the existing land-cover maps with the spectral strategies of the POM were developed. Also, because of the different ecosystem properties of the two networks and the expected difficulties of working in soil-dominated systems, OSU also examined other change detection approaches based on statistical models between the imagery and airphoto-interpreted estimates of component cover characteristics.

Key conclusions from this stage of the project included:

As was the case with baseline mapping, these results showed that the methods tested were appropriate for some uses, but the level of detail needed by the networks was greater than was generally feasible. Thus, on both of the primary efforts of the initial agreement between OSU and the parks, the potential utility of monitoring with Landsat imagery was inconclusive at best.

Many-date change detection

Rather than map landscape change by comparison of two dates of imagery, OSU developed methods to detect trends across time-series of many years of imagery. A primary benefit of this approach is that year-to-year changes caused by phenology, sun angle, or ephemeral weather events can fade to noise around longer-term trends. Also, change is defined for each pixel relative to its own spectral trajectory, not relative to other pixels. In theory, the influence of cross-pixel variation in soil brightness would become less of an impediment than for more traditional methods. Additionally, the availability of stacks of imagery allows for more robust interpretation of the satellite imagery itself for valida-

tion using tools developed in-house at OSU (known as “TimeSync”). If these interpretation tools were applicable on the Colorado Plateau, many of the potential problems with reference data could potentially be avoided. Because of these potential advantages, a small pilot project was funded under a new agreement between OSU and the networks to investigate the potential utility of the new method (termed “LandTrendr”) in the parks.

Key conclusions from this stage of the project included:

- LandTrendr segmentation captured many of the key disturbance processes of interest, including fire, insect mortality, and apparent drought disturbance, as well as growth/recovery processes.
- Change mapping in herbaceous areas would likely require new rules to link spectral change to increase or decrease in cover, but these new rules would likely be generally applicable once found.
- Linking POM labeling to LandTrendr was technically successful, resulting in yearly land-cover maps with potentially large information content.
- However, POM labeling required aggregation of classes that altered the detailed class labels.
- Additionally, the spectral conditions present directly after a change result in labels that often do not make ecological sense; true labeling will require significant effort to develop post-disturbance spectral class labels that are different from those applicable to the rest of the landscape.
- TimeSync interpretation was much more challenging in the non-forest and non-woodland areas of the Colorado Plateau than expected, suggesting that this validation approach is still not sufficient to replace inadequate reference data from existing sources.

At a teleconference in August 2009, OSU and the networks made progress toward evaluating which of the methods might be useful for actual implementation in the parks of the Colorado Plateau. The LandTrendr change

maps appear to be the best balance of cost and utility, and the POM approaches (with two-date and LandTrendr + POM) are likely too costly to justify the further research needed to fully understand and implement them.

Focused studies

LandTrendr and TimeSync are “one size fits all, wall-to-wall” processing algorithms, in the sense that they work everywhere at the pixel scale. Thus, in one sense, they are an implementable protocol that can be applied in all NCPN parks to detect long-term change that cannot be detected at broad scales any other way. However, these are sophisticated, resource-intensive tools that require “tuning” for optimum change detection, depending on the change of interest (e.g., slow, abrupt, disturbance, recovery). Furthermore, long-term change assessments at broad scales are unlikely to be necessary in every park every year. For these reasons, the NCPN plans to implement LandTrendr on a project basis to address management-relevant questions appropriate to the tools, as described below.

Based on the potential demonstrated in the many-date change detection pilot study, the NCPN contracted with OSU to investigate management-driven questions at Dinosaur National Monument and Capitol Reef National Park. Relevant questions at Dinosaur National Monument center on understanding dynamics of pinyon/juniper, sage, and vegetation condition of the river corridor. At Capitol Reef National Park, change in vegetation condition in grazing allotments and along the Fremont River are of interest. In all of these cases, either parks or the NCPN have ancillary data to help interpret the cause of observed change and its magnitude as measured on the ground. As learning and analytical approaches for using both LandTrendr output and ancillary data together mature, we expect the techniques to be transferable to other park units.

Literature Cited

- Cohen, W.B., Z. Yang, and R. Kennedy. 2010. Detecting trends in forest disturbance and recovery using yearly Landsat time series: 2. TimeSync—Tools for calibration and

validation. *Remote Sensing of Environment*, 114(12):2911–2924. Elsevier B.V.
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Landscape Dynamics Monitoring Protocol for Park Units in the Northern Colorado Plateau Network

Standard Operating Procedures

Most of the standard operating procedures associated with this protocol consist of the LandTrendr Version 3.0 Users Guide, Version 0.1, known here as SOP #1. An electronic copy of this document is attached to this document and may also be found at <https://irma.nps.gov/DataStore/Reference/Profile/2229776> and <https://irma.nps.gov/DataStore/DownloadFile/549483>.

SOP #2, with instructions on revising the protocol, may be found on the following page.

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Landscape Dynamics Monitoring Protocol for Park Units in the Northern Colorado Plateau Network

Standard Operating Procedure #2 Revising the Protocol Narrative and SOPs

Version 1.01
April 2016

Revision History Log

Previous version #	Revision date	Author	Changes made	Reason for change	New version #
1.00	4/24/2016	A.W. Biel	Minor editorial	Publication preparation	1.01

This Standard Operating Procedure (SOP) explains how to make and track changes to the narrative and standard operating procedures for the Northern Colorado Plateau Network (NCPN) landscape dynamics monitoring protocol. Individuals editing the protocol narrative or SOPs need to follow these procedures in order to eliminate confusion on how data are collected and analyzed. The procedures in this SOP are based on the NCPN Protocol Versioning Guidance Document (NCPN 2009).

Procedures

1. Modifications must be reviewed for clarity and technical soundness. Small changes or additions to existing methods will be reviewed in-house by NCPN staff. An outside review is required for substantive changes in methods.
2. Record all changes to a protocol document (narrative or SOP) in the document's revision history log—even minor edits, such as fixing typos or formatting changes. It is not necessary to record the specific edits made; rather, just the fact that typos were fixed or formatting changes were made. For minor edits, record the same document version number in the revision history log. For actual protocol changes (e.g., changes in methods), assign a new version number in the revision history log. Depending on the significance of the changes, it may be okay to combine multiple changes in the same entry in the revision history log. Version numbers increase incrementally by hundredths (e.g., version 1.01, version 1.02) for minor changes. Major revisions should be designated with the next whole number (e.g., version 2.0, 3.0, 4.0). Record the previous version number, date of revision, author of the revision, and the reason for the changes along with the new version number (if applicable).
3. Narrative and SOP updates may occur independently. That is, a change in one SOP will not necessarily invoke changes in other SOPs; a narrative update may not require SOP modifications. The NCPN tracks the narrative and SOP version numbers in a Master Version Table (MVT), which is maintained in this document (SOP #2). Any time a narrative or an SOP version change occurs, a new Version Key number (VK#) must be created and recorded in the MVT, along with the date of the change and the versions of the narrative and SOPs in effect. The VK number increments increase by whole integers (e.g., 1, 2, 3, 4, 5). Updates to the MVT also must be provided to the NCPN data manager for inclusion in the master version table database. *The protocol narrative, SOPs, and data should not be distributed independently of this table.*
4. New versions of the protocol narrative and SOPs must be posted on the NCPN web page. Older versions of the protocol narrative and SOPs must be archived in the NCPN protocol library: (R:\Monitoring_Archive\Land_Use_Cover\Protocol).

References

Northern Colorado Plateau Network (NCPN). 2009.
Protocol versioning guidance document, Version

1.0. National Park Service, Inventory and Monitoring Program, Northern Colorado Plateau Network, Moab, Utah.

Landscape Dynamics Monitoring Protocol for Park Units in the Northern Colorado Plateau Network

Master Version Table

Version Key #	Date of change	Narrative	SOP 1	SOP 2
VK1	4/12/12	1.00	1.00	1.00
VK2	4/24/2016	1.01	1.00	1.01

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