REPORT:
LANDTRENDR & TIMESYNC WORKSHOP FOR NPS I&M

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Authors: Robert E. Kennedy[1], Peder V. Nelson[1], Maureen Duane[1], Zhiqiang Yang[1], Justin Braaten[1], Warren Cohen[2]

1. Department of Forest Ecosystems and Society, Oregon State University
2. PNW Research Station, USDA Forest Service

Executive summary

This report summarizes a workshop held by the Laboratory for Applications of Remote Sensing in Ecology (LARSE) at Oregon State University (OSU) on February 1 – 3, 2011. Sponsored by the National Park Service (NPS) Inventory and Monitoring (I&M) program, the workshop had three purposes:

1. Provide NPS participants with enough knowledge of the details of implementing LandTrendr ("Landsat based detectiong of trends in disturbance and recovery"), the specific needs for validation with TimeSync ("Syncing algorithm and human interpretations of Landsat time-series) and ground-truthing, and the steps involved in interpreting maps for networks to assess final utility for monitoring.

2. Assess whether a cross-park structure to carry out LandTrendr processing may be more efficient for long-term monitoring, and whether common divisions of effort across networks could create economies of scale.

3. Facilitate cross-network contacts and spur new uses of remote sensing imagery for monitoring.

Evaluating responses from a pre-workshop survey of participants, LARSE developed a workshop agenda of breadth rather than depth. Agenda topics covered the entire arc of the LandTrendr workflow, with priority given to interpretation and conceptual underpinnings of all topics. Topics moved from pre-processing (image acquisition, normalization and cloud screening) through the core temporal segmentation algorithms of the LandTrendr approach to map making, evaluation, and value-adding. For all of these steps, LARSE developed fully processed datasets for each participant to follow through the entire processing flow in an area familiar to them.

Participants reported in end-of-day surveys that they gained enough knowledge of the process to evaluate where the LandTrendr and TimeSync tools could be used, but also gained an appreciation of the technical difficulty of implementing the approach that could cause challenges for in-house implementation of many of the steps in the workflow.

LARSE suggests four primary recommendations for moving forward: 1. Leverage what has been done to greater effect; 2. Continue building foundations with existing networks; 3. Expand the work by proposing new science proposals, and 4. Communicate the utility of methods more clearly within and outside the core group of LandTrendr users in the NPS. To aid in evaluating and communicating the potential utility of the method, a conceptual framework evolved in workshop discussions that is summarized and expanded upon within this report.

1. 0 Introduction

As part of the NPS's larger goal of developing long-term monitoring programs in response to the Natural Resource Challenge of 2000, several NPS Inventory & Monitoring (I&M) Networks have identified landscape patterns and dynamics as important vital signs for monitoring ecosystem health. Landscape dynamics refers to a suite of ecological, geomorphological and anthropogenic processes that occur across broad spatial and temporal scales. Many landscape dynamics include large-scale ecosystem disturbances to dominant vegetation, such as fire, insect outbreaks, landslides, windthrow, grazing, and drought.

Over the past several years, six NPS I&M networks have been collaborating with the Laboratory for Applications of Remote Sensing in Ecology (LARSE) at Oregon State University (OSU) in developing and testing protocols to monitor landscape dynamics. These networks are from several NPS regions including: the Southwest Alaska Network (SWAN), the North Coast and Cascades Network (NCCN), the Sierra Nevada Network (SIEN), the Northern Colorado Plateau Network (NCPN), the Southern Colorado Plateau Network (SCPN), and the Great Lakes Network (GLKN). These networks have been investigating using Landsat remote sensing imagery as the base data source for landscape monitoring. LARSE has responded to the monitoring needs of NPS and other federal agencies by testing various image processing techniques using Landsat data to identify and capture important landscape changes. As a result of this work, LARSE recently developed tools called LandTrendr and TimeSync, which are automated and manual tools, respectively, that tap the Landsat image archive to identify and understand landscape change (Cohen et al. 2010; Kennedy et al. 2010).

Recently, these six I&M networks have conducted initial applications of the LandTrendr and TimeSync tools, and these pilot efforts have generated a series of new issues, needs, and questions. These include:

- What is the sensitivity and accuracy of LandTrendr in non-wooded ecosystem types?
- What are the best approaches in attributing a change agent to mapped change?
- How best to deal with data gaps and persistent clouds?
- What is the degree to which manual post-processing of change maps is needed?
- What is the overall interpretation of change trajectories when change is not obvious?

In addition to these methodological questions, I&M networks have requested more general guidance on logistical implementation of these tools. In the pilot studies, many networks determined that the methodological complexity of the LandTrendr and TimeSync tools may exceed the expertise available locally. Thus, networks expressed a desire to determine possible overlaps in either processing or goals across networks that would allow for economies of scale.

As a means of addressing these goals, NPS funded a training workshop hosted by LARSE in February 2011. This report summarizes that workshop.

1.1 Objectives

NPS and LARSE developed three overall objectives to meet the methodological, strategic, and cultural goals of users of LandTrendr within NPS.

Primary Objective: Provide NPS participants with enough knowledge of the details of implementing LandTrendr, the specific needs for validation with Timesync and with ground-truthing, and the steps involved in interpreting maps for networks to assess final utility for monitoring.

This technical objective was focused on addressing the issues, needs, and questions raised during the pilot studies.

Secondary Objective: Assess whether a cross-park structure to carry on LandTrendr processing may be more efficient for long-term monitoring, and whether common divisions of effort across networks could create economies of scale

This strategic objective was focused on addressing potential gaps in expertise at individual networks, allowing continuation of monitoring by pooling resources.

Tertiary Objective: Facilitate cross-network contacts and spur new uses of remote sensing imagery for monitoring.

This cultural objective was aimed at developing a community of practice within the NPS.

1.2 Methodological underpinnings

Because of the strong methodological focus of the workshop, many of the components described in this report are structured around the LandTrendr workflow. Therefore, to aid in interpreting the remainder of the report, we provide a brief overview of the method.

The typical arc of a LandTrendr-based project has five successive phases (Figure 1). Phases grade from those requiring substantial knowledge of remote sensing science and processing software at the beginning of the process to those requiring substantial knowledge of site-specific processes at the end. Pre-processing involves ordering and downloading imagery from the USGS archive, correcting one image for atmospheric effects, normalizing all other images to that image, and cloud screening all images, as well as defining a study area to constrain all pre-processing steps. The entire process is founded on finding patterns in spectral data, which refer to the measurements of different colors of light recorded by the Landsat sensor. During the segmentation phase, algorithms are applied to a time-series of Landsat spectral data to define time periods when consistent processes are occurring. For example, growth processes would be captured as a steady increase in vegetative-related signals over many years, while a forest fire would be detected as an abrupt loss in vegetation from one year to the next. The outputs from segmentation are files that are spatial in nature, but the rich information content is not organized in a manner that is easily accessible to most users. Therefore, the next phase, change label mapping, imposes user-defined rules to convert the segmentation outputs into maps that highlight particular processes of growth and loss of vegetation. The resultant maps describe the timing and conditions at the onset of a growth or loss process, as well as the character of the change that occurred as the process evolved, as well as the time period over which the change occurred. For example, a growth process would be described both by the relative absence of vegetation at the onset of growth and by a characteristic spectral change from bare ground to vegetation. Conversely, a fire would be described by the conditions of the forest before the fire and the amount of spectral change associated with the fire, which would provide a proxy for the amount or type of vegetation lost during the fire.

These maps, while beginning to be interpretable to most ecological users, typically require more processing to be directly useful. Thus far, information is only mapped at the pixel level (pixels are square, 30 by 30m), while most ecological users prefer to work with patch-level phenomena. Moreover, the initial maps also typically include single-pixel noise ("speckle") that is too small to either validate or interpret. Therefore, the next critical phase is one of spatial filtering, where adjacent pixels experiencing similar processes are grouped together into patches, and pixels in tiny patches are removed. Finally, these patch-based maps must then be evaluated for accuracy. Additionally, it is often critical for many ecological users to add a label for the agent causing a change. To continue using fire as an example, a fire would thus far only be described using the spectral change that occurred during the fire, and the pixels in the fire would have no label to distinguish them from other pixels that had experienced, for example, clearcutting or development. Thus, the final phase of validation and attribution involves viewing maps to determine if changes were adequately captured and, if so, what agent caused the change.

Figure 1. The typical arc of the LandTrendr workflow. During preprocessing, annual (or super-annual) Landsat images from approximately 1985 to present are acquired, normalized, and masked for clouds. In the segmentation phase, algorithms simplify the noisy time series of imagery into time periods in every pixel's "life history" when vegetation cover is either increasing, decreasing, or remaining stable. These time periods are then expressed in map form during change label mapping, allowing description of landscapes by the different processes of interest: slow mortality, abrupt mortality, growth, or sequences thereof. Pixels in these maps are grouped into patches and isolated pixels removed during the spatial filtering phase, leading to final maps that can be expressed as either raster or vector (patch) attributes. Finally, these maps must be compared against other reference data to determine their robustness.

2.0. Implementation

Project activities occurred in two phases: Pre-workshop activities and the workshop itself.

2.1 Pre-Workshop activities

2.1.1 Participants

During the fall of 2010, NPS worked internally to identify likely participants from the networks that had developed working relationships with LARSE using LandTrendr. The following participants were confirmed:

GLKN:
  Al Kirschbaum, Remote Sensing Specialist - I&M Program, Great Lakes Network
NCCN:
  Mark Huff, I&M Program Manager, North Coast and Cascades Network
  Catharine Thompson, Botanist - Olympic NP
NCPN:
  David Thoma, Northern Colorado Plateau Network
PNW CESU:
  Chris Lauver, Pacific Northwest CESU NPS Research Coordinator, Acting Great Basin CESU NPS Research Coordinator Co-leader, Pacific Northwest CESU
SCPN:
  Jodi Norris, Southern Colorado Plateau Network
SWAN:
  Amy Miller, Ecologist - I&M Program, Southwest Alaska Network

Additionally, three participants from the USDA Forest Service were confirmed to join the workshop: Demetrios Gatziolis (PNW Research Station); Ian Housman, Robert Chastain (Remote Sensing Applications Center, Salt Lake City, UT).

2.1.2 Pre-workshop needs assessment survey

Before the workshop, LARSE surveyed likely participants to gain a sense of their relative priorities to guide agenda creation. The survey, summarized in Table 1 and detailed, along with responses, in Appendix 1, was structured around the five phases of a LandTrendr project (Figure 1), as well as background information on remote sensing imagery and software. These topics corresponded to the Primary Objective of the workshop. Additionally, one topic focused on implementation issues, including the amount of work needed to conduct such analyses and the management structures that could be envisioned (Secondary Objective). For each topical category, participants were asked to select their level of knowledge or interest using descriptive phrases (Table 1). After participant responses, LARSE then assigned relative interest scores to these phrases to distinguish among categories that should receive greater or lesser emphasis in the workshop.

Table 1. Overview of topic interest survey sent to likely workshop participants. Each topical category had between three and six sub-topics that respondents addressed using the rating system to capture their level of knowledge or interest in the topic. Interest was then scored on a relative "interest score" scale to quantify overall group interest in each topic.

Topical category	***Related Workshop Objective***
Background for change detection approaches	Primary
Software	"
Pre-processing	"
Temporal segmentation with LandTrendr	"
Post-processing for maps	"
Working with tasseled-cap images	"
Validation-attribution of change	"
Other remote sensing technologies	"
Implementation	Secondary
Level of knowledge or interest	***Interest score***
Need to know a lot more about this	3
I know nothing about it but really need to	3
I know some but could use a bit more	2
Need a better understanding for interpretation	1
I don't care about this (don't need to spend a lot of time or this is less important to me)	0
Do I need to know about this? What is this?	0
Already now a lot about this	0

The pre-workshop survey also included the opportunity for participants to characterize the landscape processes of most interest for monitoring in their networks. Respondents were asked to cast their processes of interest in terms that could be used to assess the appropriateness for monitoring with remote sensing, including both the type of transition caused by the process and the temporal and spatial grains and extent needed to adequately detect it (Table 2).

Table 2. Survey questions used to frame monitoring questions for remote sensing. Each respondent was asked to describe processes of interest in terms of the characteristics listed below.

Characteristic	***Example response***
Monitoring objective	Vegetation health/condition
Type of vegetation transition	Within-cover loss of vegetation density or vigor
Underlying cause	Disease, drought
Location on landscape/ecosystem type affected	Mid-elevation conifer forests
Related stressor of interest	Climate change
Temporal grain / extent	1-2 yrs / 10+ yrs
Spatial grain / extent	30m / park wide

2.1.3 Pre-workshop data and image preparation

To more fully engage workshop participants, LARSE prepared a Landsat image set relevant for each participant's geographic focus (Table 3). These datasets could be used in the workshop to apply the general lessons to a landscape with which each participant was familiar. A subset of each Landsat image 1500 by 1500 pixels (45 by 45km) was processed through the first four phases of the LandTrendr process. These data were distributed to disks that could be accessed by participants during the workshop.

Table 3. Landsat image sets processed for each participant. Landsat Path/Row refers to the unique address system of the Landsat satellites.

Path / Row	***Geographic area***	***Participant***
46/27	Mount Rainier NP	Thompson / Huff (NCCN)
70/18	Lake Clark NP	Miller (SWAN)
36/32	Dinosaur NM	Thoma (NCPN)
37/35	Grand Canyon NP, Wupatki NM	Norris (SCPN)

2.1.4. Agenda development

Based on responses from participants, LARSE developed an agenda spanning three full days (Tuesday, February 1 through Thursday, February 3rd, 2011), reserved computer lab space in the College of Forestry Richardson Hall building, and handled logistics for coffee breaks and snacks during the workshop. LARSE also set up a workshop area on the LandTrendr website (http://landtrendr.forestry.oregonstate.edu/content/workshop-information) to keep track of logistics and to provide initial agenda plans.

3.0 Results

3.1 Pre-workshop activities

3.1.1 Pre-workshop survey

Participant interest scores were tabulated by sub-topic and then averaged by topic to provide a relative measure of interest across topics (Figure 2). Interest was distributed widely, but a broad pattern emerged: participants were more interested in topics related to implementation and mapping with LandTrendr than with general background and low-order technical details.

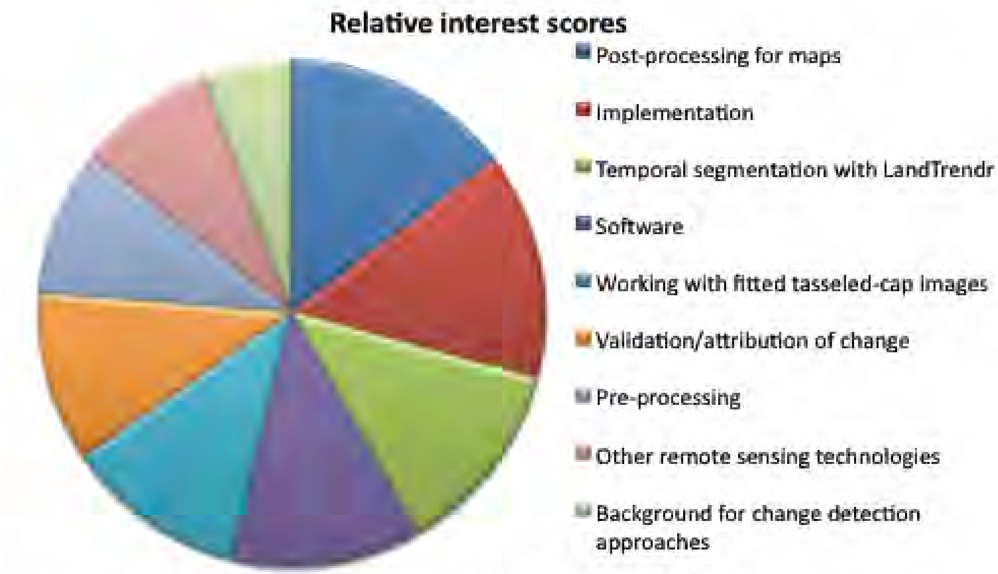


Figure 2. Pre-workshop relative interest of participants in proposed topics. Interest scores (Table 1) were averaged across all participant responses within each sub-topic, then an average score calculated for all sub-topics within a topic. While the score has no absolute meaning, these relative scores provide means of comparing interest among topics, as shown in the pie chart above.

The vegetative processes of interest to participants were also wide-ranging (Table 4). Although total counts in each category or across categories do not account for variation in the level of detail among participants, general patterns can be interpreted. First, most vegetative structural types (forest, woodland, shrub, and herbaceous) were represented, as well as many landscape positions or types (riparian, wetlands, high elevation and low elevation). Second, both loss and growth processes were of interest, as were abrupt and gradual processes. No single process or speed of change was uniquely relevant in all cases. And finally, abrupt changes were more often of general interest across all park ecosystems or in forest, but slow changes appeared to be more tightly coupled with specific vegetative communities.

3.1.2 Agenda

The agenda was designed to meet all three objectives (See Appendix 3). Given the interests of the respondents to the survey, LARSE chose a balance of exercises and topics that would focus on providing an understanding of the full LandTrendr and TimeSync process, with less emphasis on extremely detailed understanding of any particular step in the process.

Spanning three full days, the bulk of the material focused on providing participants with working knowledge of the analysis process (Objective 1). LARSE developed 11 exercises for participants that moved them through the LandTrendr workflow, from pre-processing to labeling agents of change. Each exercise was to be preceded by a presentation describing the key concepts of the exercise, and most exercises were conducted on a common set of imagery that LARSE had already processed completely. This allowed participants the

Table 4. Changes in vegetation of interest to participants. The counts in each cell refer to the number of individual responses relevant to that cell.

		Community (ies) in which change process begins											
		All	Forest	Forest & Montane shrub	Mon-tane shrub	Montane shrub & herba-ceous	Forest & desert shrub	Desert Wood-land	Desert shrub & wood-land	Desert Herb-aceous	Riparian & Pond & Wetland	Snow & Ice	Grand Total
Vegetation loss or growth?	*Loss*	7	8	1	1					1	2		**20**
	Growth	2	2		1	3	1				1	1	**11**
	Both	1						1	1		1		**4**
	Conversion	1	2								1		**4**
Gradual or abrupt change?	*Abrupt*	5	7								2		**14**
	Both	5	1								2		**8**
	Gradual	1	4	1	2	3	1	1	1	1	1	1	**17**
	Grand Total	**11**	**12**	**1**	**2**	**3**	**1**	**1**	**1**	**1**	**5**	**1**	**39**

chance to run the code themselves, but to not rely on all steps working perfectly to allow progression to the next concept. Details of the labs and participants' responses follow in section 3.2 below.

In addition to direct training sessions, time was built into the agenda to allow discussion of key issues, particularly implementation of LandTrendr within and outside of NPS (Objective 2).

Finally, LARSE attempted to provide ample opportunity for participants to interact informally and formally to improve linkages across networks (Objective 3). All participants worked in pairs with one other participant, and after each day of the workshop, a group dinner was held at local restaurant to allow continued informal interactions.

3.2 Workshop activities

3.2.1 Workshop: Day 1. Tuesday February 1, 2011

Day 1, Morning topics

The morning of Day 1 focused on setting the stage, both logistically and conceptually, for LandTrendr and TimeSync (Table 5). Participants were set up on lab computers, and LARSE provided brief introductions to the concepts of change embodied in both LandTrendr and TimeSync, and how those could relate to core monitoring objectives. The central concept embodied in both LandTrendr and TimeSync is that change occurs all the time, and that the spectral signal from Landsat imagery over time can track trends in that change as well as times when those trends shift direction or abruptly change. These temporal trajectories are captured by the automated algorithms in LandTrendr (Figure 3) and by trained human interpreters using TimeSync. The steps embodied in the arc of the LandTrendr workflow (Figure 1) revolve around this segmentation step: Pre-processing cleans the signal to allow the segmentation algorithms to find pattern, while post-processing converts the outputs from the segmentation algorithms into maps that can then be labeled according to the timing, severity, and duration of change, and then eventually with the agent that caused the change. All of those steps, however, depend on understanding how LandTrendr captures change in the segmentation phase.

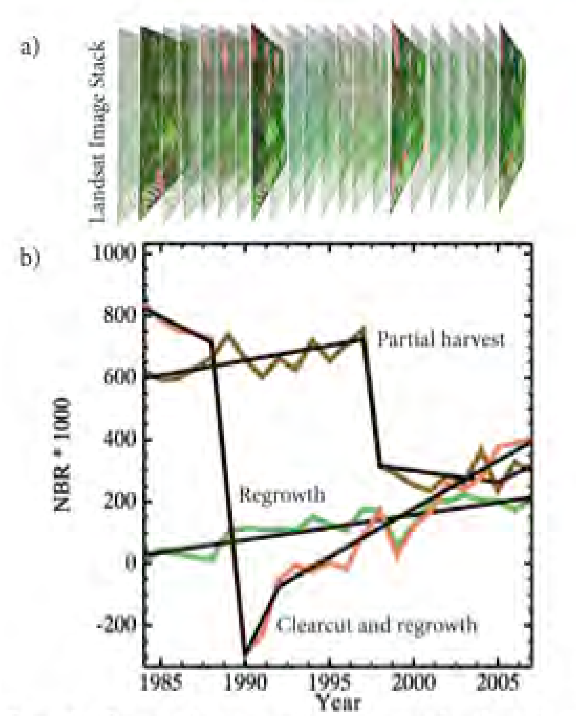


Figure 3. Temporal segmentation of spectral trajectories that capture different processes of interest in forests. a) A time series of many annual Landsat Thematic Mapper (TM) data is aligned, cleaned, and normalized. b) Statistical algorithms fit straightline representations (black lines) or cleaned pixel values (colored lines). This process is referred to as "temporal segmentation."

Additionally, several participants provided the group with presentations of work related to the workshop that had already been occurring in their networks.

Day 1, Afternoon topics

Once participants had been introduced the concepts of change, LARSE then began to guide participants through the LandTrendr workflow. Because all of the LandTrendr process occurs within the IDL software package (ITTVis Corporation), one of the core steps needed to implement the remaining sections of the workshop was to ensure that participants could run the necessary scripts in IDL to carry out the exercises throughout the workshop. With that introduction, participants were briefly shown the steps needed to conduct pre-processing: Image naming conventions and database construction, relative normalization using MADCAL (Canty et al. 2004), and cloud masking using LandTrendr-specific approaches. Finally, participants set up basic batchfiles to run segmentation on a single Landsat image stack.

Table 5. Topics on Day 1 of workshop. See Appendix 3 for full agenda

Period	Type	Topic
Morning	Presentation	Introduction and logistics
	Presentation	Core monitoring objectives
	Presentation	Concepts of change
	Presentation	Temporal trajectories
	Presentation	Participant presentations
Afternoon	Presentation	Expectations from workshop
	Presentation	Overview of LandTrendr process
	Exercise 1	Working with IDL for LandTrendr
	Presentation	Preprocessing, MADCAL, and cloud masks
	Exercise 2	Creating segmentation batchfile
	Discussion	

Day 1, Survey results

Each day, participants were provided surveys to rate how well they understood the topics presented each day. On Day 1, the questions focused on the conceptual underpinnings of LandTrendr and TimeSync change detection for monitoring (Figure 4) and on the details of setting up and implementing the initial LandTrendr steps in IDL (Figure 5). LARSE reviewed these responses each evening while planning for the next day.

In general, participants felt comfortable with the conceptual underpinnings, but faced considerable challenges as the workshop moved into its technical phase. To some extent, this was anticipated, particularly in the case of the MADCAL and cloud masking steps, which require more time than could be afforded to fully implement. However, both the use of IDL and the use of tracking variables (image_info variables) would be critical to later steps, and thus LARSE revisited these topics on Day 2 and 3 to reinforce the topics and improve participant comfort with them as topics. In this manner, the surveys proved an extremely valuable tool to adjust foci and ensure participant learning through the workshop.

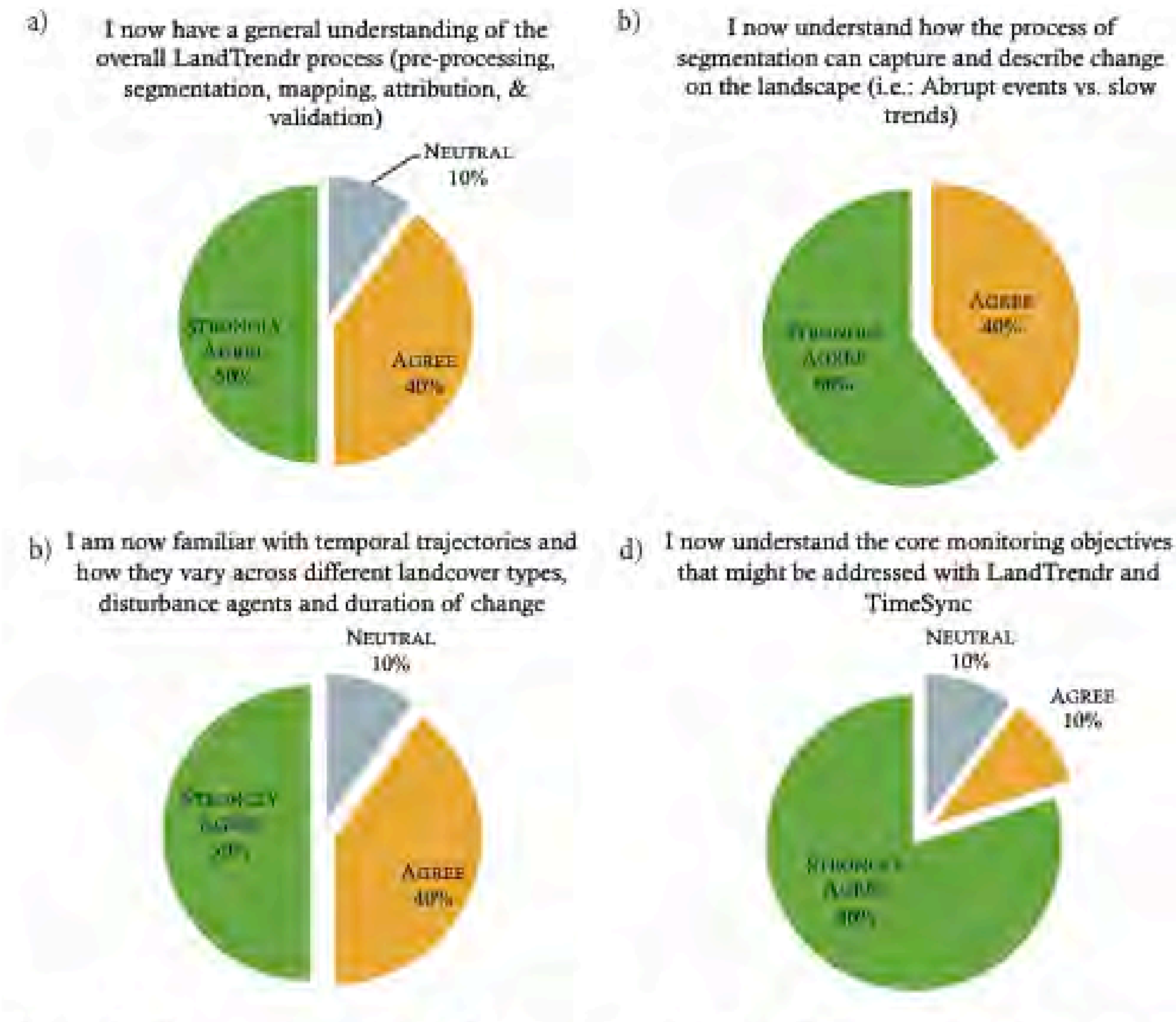


Figure 4. Participant responses to end-of-day survey questions focused on conceptual understanding. a) Conceptual steps associated with Landtrendr. b) How different changes may be captured using the LandTrendr approach. c) What temporal trajectories and how they vary. d) How monitoring may be linked the segmentation approach towards describing change.

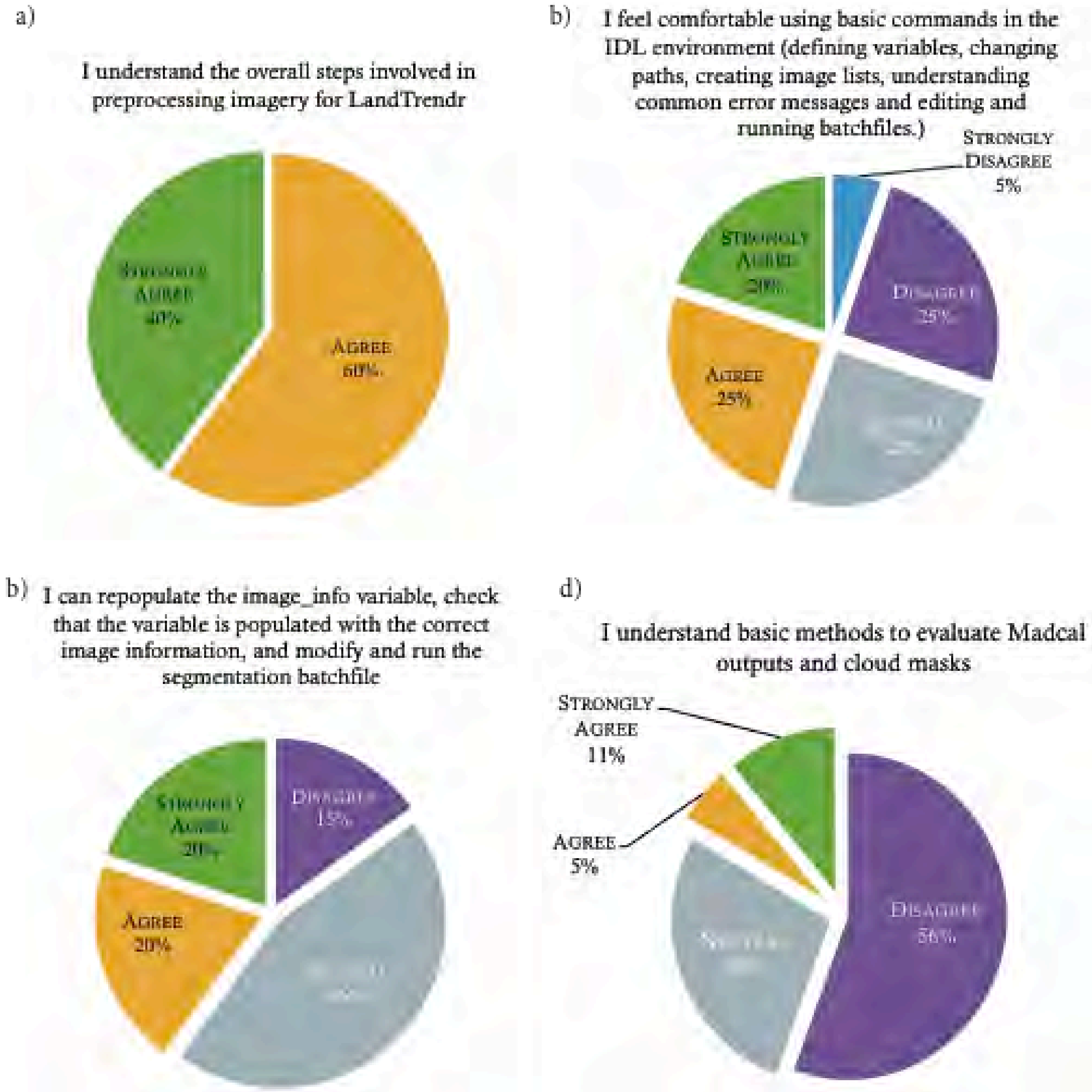


Figure 5. Participant responses to end-of-day survey questions focused on technical understanding. a) Overall understanding of work flow. b) Detailed knowledge of running IDL scripts. c) Handling the core information source used to track processing steps in LandTrendr. d) Evaluating normalization and cloud masking.

3.2.2 Workshop: Day 2. Tuesday February 2, 2011

Day 2, Morning topics

The morning of Day 2 focused on interpreting the core LandTrendr segmentation outputs, running scripts to convert those outputs into maps, and evaluating those maps from the perspective of spectral trajectories (Table 6). As one of the areas of high interest to participants from pre-workshop surveys, and one that is not immediately intuitive to new users, these topics were the focus of the entire morning.

The process of converting segmentation results to maps can be considered a further distillation of the time series data. The temporal segmentation results represent a simplification of a yearly, somewhat noisy time series, but they retain all of the features of the time series. Converting these results to maps requires focusing on only one feature of that time series, such as disturbance, and mapping its characteristics. This, in turn, requires that rules be used to define the characteristics of a time-series segment that correspond to that feature, and using rules to filter away uninteresting segments that may be caused by residual noise. It also requires bringing in other spectral data to more fully describe the change according to its starting characteristics, the change that occurred over the time of the change, and what happened after the focal change. These steps are handled through a change label script (a "batchfile") where rules are defined, filtering thresholds set, and ancillary spectral data identified.

Table 6. Topics on Day 2 of workshop. See Appendix 3 for full agenda.

Period	*Type*	*Topic*
Morning	Discussion	Review of prior day / Questions
	Exercise 3	Evaluating LandTrendr segmentation outputs
	Exercise 4	Turning spectral trajectories into maps
	Exercise 5	Evaluating change label outputs
Afternoon	Exercise 6	Moving from pixels to patches
	Discussion	Implementation, costs, networking

Day 2, afternoon topics

The afternoon of Day 2 progressed from continued evaluation of the change label outputs to the process of converting the change label maps from pixel-based into patch-based maps (Table 6). Conversion from pixels to patches is necessary for a variety of reasons. First, it facilitates further cleaning of the maps. Although segmentation and change labeling are generally effective at the pixel scale, the necessity of balancing errors requires that some false change be allowed through prior filtering steps into the maps. To the extent that this false change may be caused by random errors in processing or by noise, it often lacks spatial structure associated with real change agents, and thus appears as “speckle” noise in the maps. By associating individual pixels with their neighbors into patches, small patches most likely cause by noise can be removed. The added benefit is that the processes of interest in most monitoring programs act not on pixels, but on spatially-coherent patches of vegetation, soil type, or disturbance agent footprint. By associating pixels together that appear to be from the same agent, patch-level statistics can be accumulated that may provide clues to the type of agent, to the severity of effect, etc. As with prior steps, the filtering process was carried out using IDL-based scripts that the participants implemented in exercises in the workshop.

Although further steps in the arc of the LandTrendr workflow remained, patch conversion step is the last where remote sensing expertise dominates the work. Thus, at this point the participants had enough exposure to the process to begin a conversation about implementation of the work. For a two hour block, participants and LARSE discussed actual implementation of the LandTrendr process: costs, tasks, working between networks, and possible integration with other projects.

As the secondary objective in the workshop, understanding ways of implementing LandTrendr was a topic of substantial discussion on the afternoon of Day 2. As the only analyst in the NPS whose full time effort is devoted towards implementation of Landsat- and related change detection efforts, Al Kirschbaum (GLKN) provided the rest of the participants a sense for the scale of the effort. The disturbance work is a full time job, with as much as 80% of his time devoted to LandTrendr work, particularly getting images and handling pre-processing. He estimated that between 30 to 50% of the effort went toward pre-processing, 25% to validation, and the remainder to analysis and written summaries.

One issue of particular interest was how to handle the mapping of false positives. False positives are those areas mapped by the algorithms as change that do not appear to relate to anything real occurring on the ground. The challenge in navigating false positives is that all automated approaches involve error, and that most remote-sensing based mapping endeavors choose to balance false positives and false negatives. Yet the theme arising from the discussion was that false positives have a much greater cost in terms of monitoring and reporting than do false negatives. Given this reality, in the GLKN, Kirschbaum reviews every polygon to manually remove false positives. For abrupt disturbances whose impacts are easily discernible in airphotos or in single-visit field observation, this is laborious but is achievable. Thompson (NCCN) noted that this is not always possible: the parks in the NCCN include substantial areas mapped as having experience long-duration disturbance, such as that associated with insect-related mortality in forests. In some cases, these changes can be confirmed, but when the magnitude of this long change is low, it is difficult to know if the change is indeed falsely mapped, or perhaps real but difficult to interpret with a single observation.

Another topic of high interest was how to manage actual implementation of the processing, and where in the arc of the LandTrendr process it would make the most sense for networks or parks to begin working with the data. Given the challenges the participants found engaging with the technical aspects of the LandTrendr processing, the theme arose that it would make the most sense to handle much of the pre-processing and initial segmentation outside of the parks, and to have the networks engage when the first phase of maps have been produced. A model that had been considered in informal discussions among networks and with LARSE was that of centralized processing for distributed parks. Under this model, LARSE or a similar agency would handle most of the core remote sensing tasks, and then hand off maps to the networks.

The key question here is at what point to conduct the “handoff.” Both Kirschbaum (GLKN) and Thompson (NCCN) expressed a desire to retain as much control over the processing flow as possible to ensure that site-level knowledge is put to greatest use and to ensure timely progression of maps. Amy Miller noted that the SWAN network had just begun advertising for a position to act as a remote sensing liaison to improve technical remote sensing capacity within the network. Although not yet covered by Day 2 of the workshop, accuracy assessment was another component to the work that was of concern to Thoma (NCPN). For the arid regions that dominate the parks of the SCPN (represented by Norris), it was unclear the degree to which LandTrendr signals had been proven to be useful for the monitoring questions of interest, and thus it was difficult to envision committing more to the LandTrendr process until it was clearer that some signals were unambiguously useful. In the end, it appeared that each network may desire different levels of processing, but that handling at least some of the pre-processing and initial segmentation would make sense for most cases.

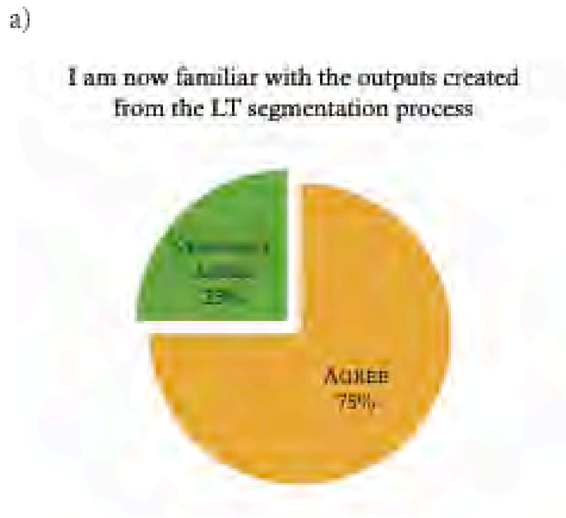
This led naturally to a discussion of cost. The centralized model described above still requires commitment from the networks, and with all budgets under substantial strain, it seemed unlikely that new allocations could be envisioned. Thus, the most likely route for current progression with LandTrendr is through grant-based processing focusing on questions of interest, but this was noted as a non-sustainable option. There are possible ties to questions of climate change, for example, but given the uncertainty in any thematically-funded source within the NPS, particularly climate change, this would likely also be non-sustainable.

Mark Huff (NCCN) then noted that the key goal would be to succinctly communicate the utility of the methods to any relevant decision makers. A particular challenge in achieving this, however, is generalizing when and where the approaches make sense and provide unambiguous results, and where noise and other factors make results more uncertain. To understand utility to a network, the degree of difficulty making maps then needs to be linked with availability of reference data and, ultimately, to the degree of interest the parks have in a particular process or ecological setting. He proposed a simple tabular organizing structure framed by ecological setting (forest, high elevation vegetation, etc.) and change processes of interest (slow disturbance or mortality, fast disturbance, and growth). This structure was a useful framework for most of the participants, and thus will be used later in this workshop report to summarize findings and set the stage for recommendations.

Day 2, Survey Results

Survey questions from Day 2 focused on interpreting segmentation outputs and converting them to maps and on spatial filtering of those maps. Additionally, because the participants had experienced the LandTrendr process through to the creation of maps, one question focused on whether participants had a better sense for how those maps could be used in monitoring (Figures 6-8).

A pattern of response emerged that was similar to that from Day 1. Participants tended to report that they gained much better conceptual understanding of the process and largely how to interpret results (examples in Figure 6a, 7c, and 8a), but that many had not yet reached the point of feeling technically capable to implement the process themselves (examples in Figure 7b and 8b).



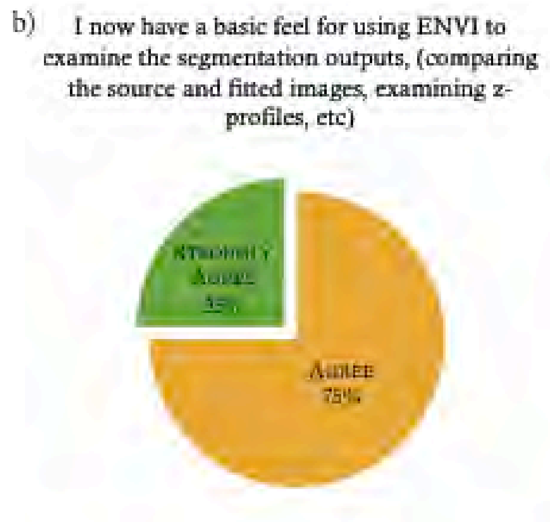
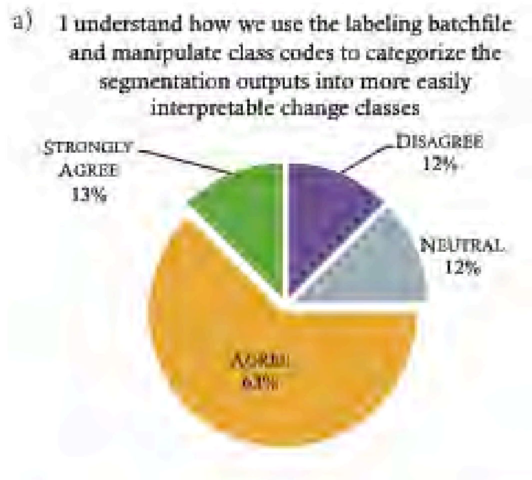
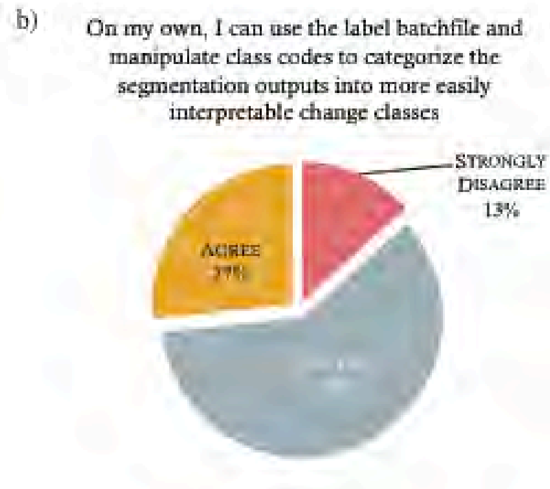


Figure 6. Participant responses to Day 2's end-of-day survey questions focused on technical understanding. a) General understanding of the products of segmentation. b) Understanding how to visualize those outputs. c) Evaluating pre-processing errors.





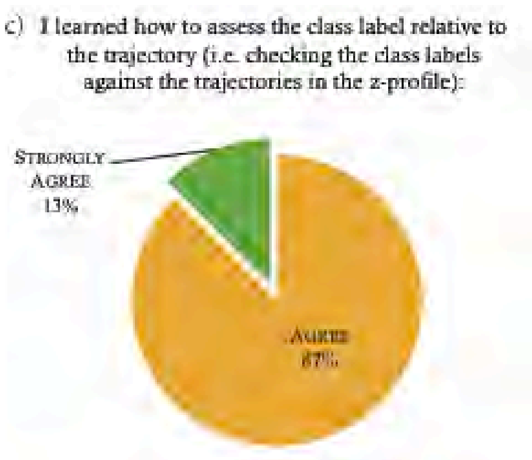
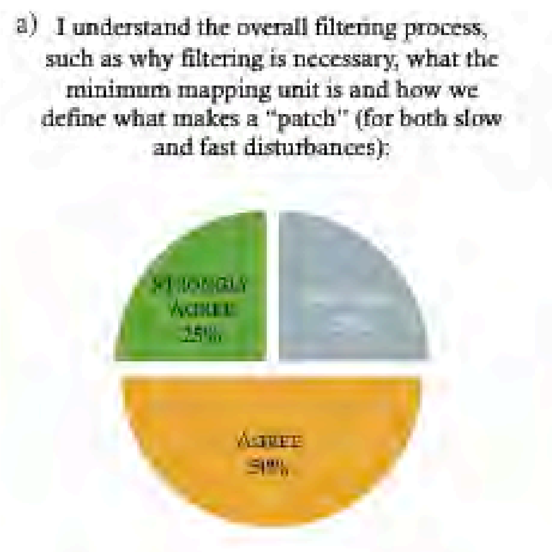


Figure 7. Participant responses to Day 2's end-of-day survey questions focused on converting segmentation outputs to maps. a) Understanding how class codes convert segmentation results to maps. b) Setting up a batchfile to implementat that information. c) Assessing maps to ensure that the maps accurately capture the desired sequence of landscape processes.



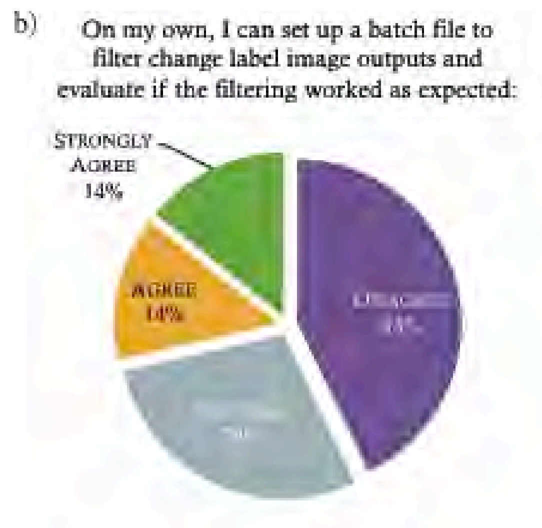


Figure 8. Participant responses to Day 2's end-of-day survey questions focused on spatial filtering of maps and on overall understanding of LandTrendr outputs. a) General understanding why spatial filtering is necessary. b) Detailed knowledge of how to implement the filtering. c) Overall sense with how LandTrendr outputs could be relevant to monitoring.

3.2.3 Workshop: Day 2. Tuesday February 2, 2011

Day 3, Morning topics

Where Days 1 and 2 had focused on creating maps, Day 3 involved summarizing, evaluating, and adding value to those maps (Table 7). After a brief "housekeeping" presentation to clarify a key step in the prior day's work, exercises moved further from remote sensing expertise towards incorporation of ecological knowledge in the process.

When maps are used for monitoring, one of the key requirements is a means of summarizing the maps across park areas or within certain sub-regions (e.g. vegetative community types, elevation bands, etc.) of a park. While this is a common need that is frequently addressed in GIS analysis, the time-series nature of the LandTrendr outputs adds a dimension that sometimes requires tedious repetition of normal tasks. Therefore, LARSE provided participants with tools to aggregate and summarize the LandTrendr map outputs.

The next important topic was a formal introduction to TimeSync, a validation and interpretation tool developed alongside LandTrendr. Because satellite-based maps provide information about changes over large areas every year, no single external reference dataset can be used to evaluate the robustness of those maps. Therefore, the paradigm used with these datasets is a two-tiered approach: The first tier is TimeSync evaluation of the satellite imagery itself, bringing to bear an expert's knowledge of the spectral signal, the spatial and temporal context of the landscape, and the ecological realities of a given study area; in the second tier, any available ground based reference data can then be used to evaluate the sensitivity bounds of TimeSync. For this workshop, the focus was entirely on the ensuring participants' familiarity with the new tool TimeSync. Additionally, participants were introduced to the special issues that must be considered when attempting to match TimeSync interpretation databses with LandTrendr-based maps for accuracy assessment.

The last major topic to be covered was change agent attribution. For most monitoring goals, it is necessary to know only know that something has changed, but also what caused that change. For example, disturbances in forests could be caused by fires, landslides, floods, or insects, and distinguishing among them is critical to track both long-term driving forces of change and potential cumulative impacts of change. In the LandTrendr paradigm, agent attribution is assigned at the patch level rather than the pixel level, and uses the statistical technique known as "random forest" to predict change agents using a sample of polygons labeled by an expert interpreter. Exercises covered the extraction of other variables to increase statistical power, attribution by the interpreter, and the actual modeling process in the statistical package "R".

Table 7. Topics on Day 3 of workshop. See Appendix 3 for full agenda.

Period	***Type***	***Topic***
Morning	Presentation	Recalibrating percent cover models
	Exercise 7	Summarizing LandTrendr map results
	Discussion	Review of prior day and questions
	Exercise 8	TimeSync
	Exercise 9	Making accuracy matrices
	Exercise 10	Attributing change agents
	Presentation	Extracting other variables for attribution
	Exercise 11	Modeling disturbance agent
Afternoon	Exploration	Using LandTrendr and TimeSync tools to ask a question at your park or area of interest
	Discussion	Unresolved topics, general discussion

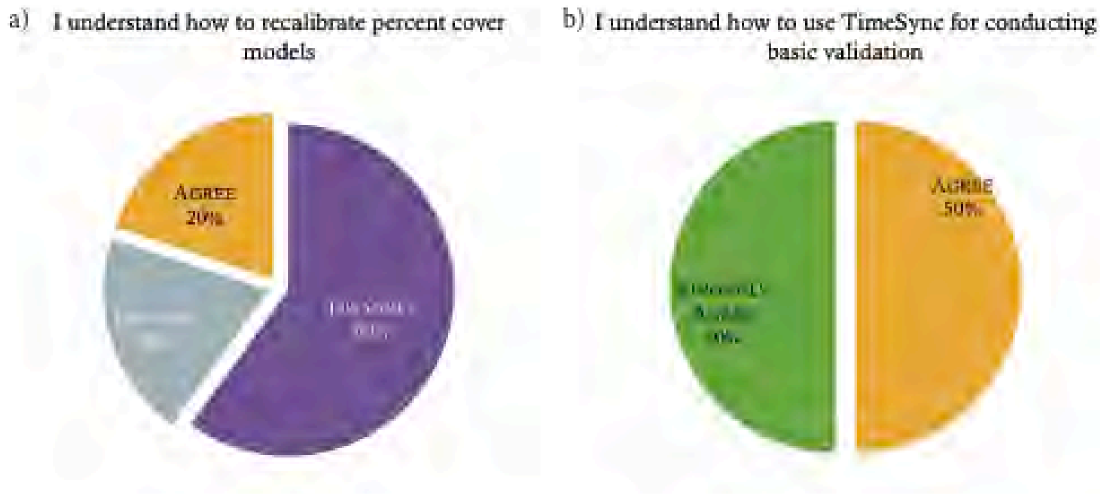
Day 3, Afternoon topics

In the afternoon of Day 3, participants were given the opportunity to take what they had learned and apply it to a park or area of interest to them, and then to report to the rest of the group on their analysis.

Day 3, Survey results

Survey questions on Day 3 focused largely on TimeSync and on change agent attribution, with one question focused on the calibration of percent cover models (Figure 9 and 10). The percent cover model was only covered as a brief presentation, and thus participants did not gain enough detailed knowledge of the topic to feel comfortable with it. Because this topic is less critical than the others covered in detail, future workshops should omit this topic as a presentation and simply provide the guidelines in a written format for participants to approach at their own speed.

Understanding was generally high both for TimeSync interpretation and for the change agent attribution.



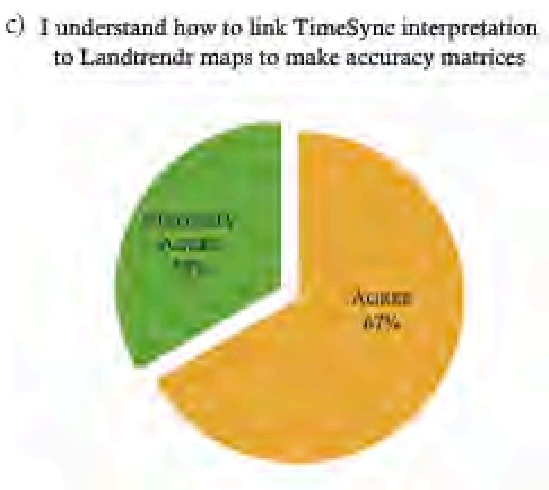
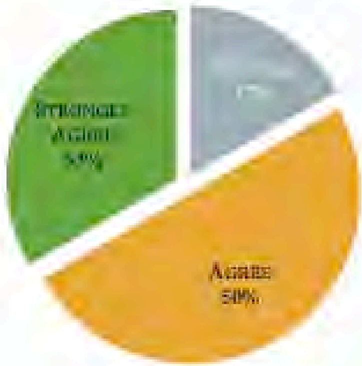
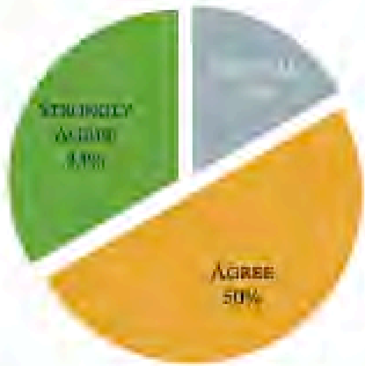


Figure 9. Participant responses to Day 3's end-of-day survey questions focused on percent cover and TimeSync validation. a) Understanding how percent cover models are built and updated. b) Working with TimeSync to conduct interpretation of changes using expert knowledge. c) Bringing the results of TimeSync interpretation into a form for standard accuracy assessment.

a) I understand how to extract other explanatory variables for attributing disturbance polygons



b) I understand how to attribute disturbance polygons with their change agents



c) I understand how to model disturbance polygons with their change agents

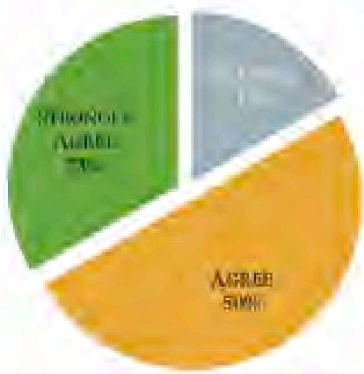


Figure 10. Participant responses to Day 3's end-of-day survey questions focused on change agent attribution. a) Using batchfiles to link change-label maps to other explanatory variables to increase predictive variables in attribution modeling. b) Intepreting disturbance polygons to assign agent type. c) Bringing that interpreted information into a random forest model to statistically predict agent for non-intepreted polygons.

4.0. Summary, discussion and recommendations

4.1 Summary

The LandTrendr and TimeSync workshop held February 2011 at Oregon State University was designed to meet three broad objectives.

1. Provide NPS participants with enough knowledge of the details of implementing LandTrendr, the specific needs for validation and ground-truthing, and the steps involved in interpreting maps for networks to assess final utility for monitoring.

2. Assess whether a cross-park structure to carry on LandTrendr processing may be more efficient for long-term monitoring, and whether common divisions of effort across networks could create economies of scale.

3. Facilitate cross-network contacts and spur new uses of remote sensing imagery for monitoring.

After NPS identified likely participants, LARSE sent a survey to assess which components of the LandTrendr and TimeSync processes were of most interest. The arc of processing runs from highly technical pre-processing through steps that successively add requirements for ecological knowledge and diminish the need for technical remote sensing expertise. Although interest was distributed across all topics, interest tended toward topics that would allow participants to better judge the costs and benefits of using LandTrendr and TimeSync for monitoring, rather than topics delving into deep technical detail on methods, particularly those more technical methods nearer the onset of the process. Therefore, LARSE sought to create an agenda that would touch on all topics but allow more time for interpretation and use of products. To facilitate this approach, LARSE developed fully-processed datasets for areas of interest to all participants so that success in interpretation at later stages was not dependent on detailed technical knowledge in earlier stages.

The workshop progressed from February 1st through 3rd, 2011 in a computer lab in the College of Forestry, Oregon State University campus in Corvallis, Oregon. On Day 1, users were introduced to the general topics underlying the techniques and to the software package in which all scripts were to be run, and briefly to the pre-processing steps involving radiometric normalization and cloud screening. They then began the steps needed to run temporal segmentation of a time-series of Landsat Thematic Mapper images, which is the core step in the entire LandTrendr workflow. On Day 2, the morning was spent interpreting outputs from the segmentation and learning some of the many ways that these outputs can be converted to maps that track vegetative growth and mortality, both as abrupt events and as longer trends. The afternoon was spent on concepts associated spatial filtering to group pixels into patches, which represented the last step in the process that requires substantial remote sensing expertise. At that point, participants engaged in a discussion of limitations and implementation of the method. On Day 3, the morning was devoted to concepts associated with summarizing and interpreting the maps produced on Day 2, including summarizing changes over time, assessing accuracy, and using statistical models to assign an agent of change to each mapped patch. In the afternoon, participants were given the opportunity to develop their own analysis in a park or protected area relevant to them, using the tools learned during the workshop. Additionally, the group engaged in larger discussions

End of day surveys across all three days suggested general themes. Participants gained a greater understanding of the overall process of LandTrendr processing, how to work with TimeSync to interpret the results of LandTrendr maps, and under what conditions the process is best suited for monitoring. They developed a better sense of how the richness of LandTrendr outputs could be tailored to meet a diversity of monitoring goals, but also how the richness of outputs could make interpretation challenging. Finally, they found it difficult to gain mastery of the more detailed technical steps in the short time of the workshop, and through those challenges gained an appreciation of the complexity of process and the likely technical expertise needed if the process were to be taken on within any given network.

4.2. Discussion and recommendations

By most accounts, the workshop was successful in providing participants with a much better sense of how Landsat-based monitoring with LandTrendr and TimeSync could be achieved. This heightened understanding led to greater appreciation of the challenges towards implementation. The technical expertise needed to conduct much of the pre-processing was considered by most to be beyond the scope realistically achievable in all but a few networks (for example, GLKN). Given this acute sense of the cost of implementation, the core unresolved issue of the workshop was how to best assess and communicate to policy and decision makers within the NPS the possible benefits of the approach. While considering communication to others, Chris Lauver (PNW CESU) reminded the group that the change detection processes covered in the workshop work well in many situations, and that focusing only where the results are questionable would provide a false sense of negative outcomes. Rather, he suggested that the focus be on describing results in terms of relative certainties.

Taken together with Huff's (NCCN) framework suggestion from Day 2, we propose as a starting point the following heuristic to help guide assessment of the use of LandTrendr in the NPS (Table 8). We follow Huff's recommendation and group change processes from the perspective of remote sensing signals: growth, abrupt disturbance, or long disturbance, and group ecological settings for those typical of many parks (but note that any of these could be further specified for a particular network). We then consider both the likely certainty of maps claiming change and the certainty in making assessments of those maps. Certainties in map making diminish when the target process has a spectral manifestation similar to background noise, or when background noise rises relative to the target process. In the case of treeline mapping, for example, abrupt changes could be caused by real events, but because treeline is by definition an edge between two contrasting spectral signals, an apparent change could also be caused by geometric problems in imagery and/or by phenological variability on the non-tree side of the boundary. Certainties in validation diminish when reference data appropriate to the process of interest are typically sparse, or when any reference data, even if available, would poorly resolve the process of interest. Limitations on availability of reference data are common, and this issue has been a constant theme in LARSE's reports to the NPS over the years. Often it is difficult to find reference data measured consistently over time, and thus much validation must occur with single-observation reference data. In these cases, many slowly evolving processes are extremely difficult to assess. Even in those situations where historical field data exist, they are rarely at a spatial grain appropriate for remote sensing. Finally, in locations with historical and recent airphotos, which represent reasonably consistent multi-date reference sources, many slow changes of interest (such as encroachment) are very difficult to resolve unambiguously.

Table 8. Characterizing degree of certainty (high, medium, low) of mapping and validating different change processes in a variety of ecological settings. The degree of certainty is subjective and based on experiences of LandTrendr producers working in these settings. Certainty in mapping decreases as sources of noise and falses signals rise relative to the strength of the ecological signal in the spectral data. Certainty in validation depends both on availability of appropriate reference data, particularly multiplec consistent measurements over time at the appropriate grain size, and on the degree to which data, even if available, can actually resolve the process of interest.

		Forest	Treeline	Arid woodland	Herbaceous (both alpine and desert)	Riparian	Margins of snow and ice
Mapping	*Abrupt disturbance*	High	Low	Medium-High	Low-Medium	Medium	Low
	Slow disturbance	High	Low-Medium	Medium-High	Low-Medium	Medium	Low-Medium
	Growth	High	Low-Medium	Low-Medium	Low	Medium-High	Low
Validating	*Abrupt disturbance*	High	Low	Medium-High	Low	Medium	Low
	Slow disturbance	Medium	Low-Medium	Low-Medium	Low	Low	Low
	Growth	Medium	Low-Medium	Low	Low	Medium	Low

The heuristic above (Table 8) must then be linked with the monitoring goals of each network to determine if the high-value processes are those that are most difficult to monitor with certainty. For both mapping and validating, slowly-evolving processes are challenging to monitor with high degrees of certainty. Yet many changes hypothesized to occur under climate change involve slowly evolving processes, such as increased susceptibility to insects and disease, changes in competitive advantage caused by changes in precipitation or temperature regimes, etc. To the extent that these occur in areas where change is difficult to map or validate, the Landsat-based approach may not appear attractive.

However, it is critical in these deliberations to contrast the satellite-based approach to any other available approaches. Satellite data from Landsat Thematic Mapper extend back to 1984, and from the prior sensors (the Multispectral Scanner, or MSS) to the early 1970s. Although the information content in satellite data is coarser than that obtained from most field measurements, it is unique in being spatially exhaustive and temporally consistent. If we presume that understanding baseline conditions (i.e. historical conditions) is critical to future monitoring, such data may be a critical tool in monitoring to complement other sparser historical measurements made in the field. As we outlined in LARSE's original protocol for the NCCN (Kennedy et al. 2007), low or moderate certainty may still provide significant utility if there are no other sources of information to capture a particular process.

In assessing the potential utility of LandTrendr or other similar times-series based approaches to monitoring, two ongoing developments merit consideration by the NPS. First, since the workshop, LARSE has continued to develop and improve the workflow for LandTrendr to the point where much of the pre-processing is nearly full automated. While an updated version of the LandTrendr code is still being tested, it appears likely that the cost of pre-processing will be considerably lower in the future than it has been. This increases the attractiveness of a centralized processing system, where LARSE or a similar entity handles the phases of the workflow that are highly specialized, and then hands off maps that then require validation and attribution. Second, efforts within the USDA Forest Service and the USGS towards a national Landsat-based change monitoring system have continued to progress. During the LandTrendr workshop, representatives from the Forest Service provided a background presentation on this work. While the details of this effort are still evolving and the project would not reach operational phase for several years, its continued progression suggests a general move among agencies towards time-series analysis that could facilitate the kind of hand-off of maps envisioned for the NPS.

Thus, we see four overarching recommendations:

1. Leverage what is done.

We advocate continued use of existing LandTrendr-based maps in the networks where they already exist. Many of the later steps in the workflow, particularly attribution, have been only cursorily investigated. We hope that the participants in the workshop gained enough expertise with the maps to help them see potential in the existing maps.

2. Lay foundations.

We will continue to work with NCCN, NCPN, and GLKN to publish methods and results and establish foundations. These should lead to greater articulation of possible benefits.

3. Propose science

The monitoring questions of interest to the parks involve science questions relevant to host of other agencies and funding sources. It makes sense to propose science-question work to these agencies using Landsat change detection as its base. LARSE has begun this process, with a short proposal to the North Pacific LCC earlier in the spring of 2011. While not successful, it is an example of the kind of funding source that may be relevant. Participants are encouraged to suggest other such examples to us.

4. Communicate.

Finally, we propose that participants in the workshop act as an informal working group to help LARSE articulate in a succinct format where and how LandTrendr monitoring may occur. A suggestion during the workshop was the development of a two-page or similar fact sheet to illustrate the current and potential uses of the approach. This could be augmented with the conceptual table proposed above (Table 8), or with other communication tools proposed by the group. At a minimum, we hope that we can continue to receive feedback from the participants on such a summary effort to ensure that we are clearly articulating goals and possibilities.

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Appendices (Separate files)

Appendix 1: Pre-workshop survey questions, with tallies of the number of respondents answering in each cell.

Appendix 2: Pre-workshop responses to areas and topics of interest for monitoring.

Appendix 3: Agenda.