Leveraging temporal variation in climate and management across national parks in the western U.S. to characterize three decades of landscape vegetation dynamics

A proposal to NASA's New Investigator Program

Short title: Characterizing vegetation dynamics in western national parks

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Overview

Spatial patterns of vegetation reflect a history of interacting biotic and abiotic factors, including competition, dispersal, climatic effects, topographic position, nutrient and soil status, disturbance, and management by humans. Several of these driving factors are thought to be changing under human influence (Cook et al. 2004; 2005; Program] 2000; Schimel et al. 1997; Seastedt et al. 2004; Vitousek et al. 1997; Wimberly and Spies 2001), and as they change the spatial patterns of vegetation type and condition are likely to change as well (Bachelet et al. 2000; Floyd et al. 2000; Graham et al. 1990; Lewis et al. 2004; Logan et al. 2003; Mast and Wolf 2004; Walther et al. 2002). Because changes in vegetation dynamics can adversely affect ecological and socioeconomic systems, understanding vegetation dynamics and the processes that drive them is critical for long-term management and health of those systems, and, by extension, of the Earth system as a whole. The overarching science goal of the project is to develop satellite-based maps of changes in vegetation dynamics over time, and to test the extent to which spatial and temporal patterns of change can be used to infer the relative importance of human management and climate change on those vegetative dynamics.

The approach to mapping vegetation dynamics will be based on a recent strategy developed by the PI that captures change in vegetative cover through analysis of temporal trajectories of spectral data from satellites (Kennedy et al. 2007b), in this case from the Landsat Thematic Mapper family of sensors. The "trajectory-based change detection" (TBCD) algorithms are generic and self-normalizing, requiring minimal alteration for application in new ecosystems. Examples provided in the text of this proposal (Figures 1 – 3) illustrate the power of the approach for mapping not just the abrupt transitions in vegetative cover that have been captured with most existing satellite-based approaches, but also the subtle processes of change that anticipate or follow abrupt transitions. In the first two years of the project, this method will be applied in its current form; in the third year, the method will be extended and generalized. The maps produced will then be used to investigate the relative importance of management and climate on changing vegetation dynamics.

Although ascribing causation to climate or management is essentially impossible without large manipulative experiments, appropriate study design can improve correlative inferences and reduce chances of spurious correlations. The design of this project will leverage spatial and temporal contrasts in climate and management to test whether useful inference can be drawn about these two potential drivers of vegetation dynamics. The project will develop maps of 30+ years of landscape dynamics for a suite of national parks in the western U.S. Because of their size, vegetative diversity, and history of minimal human development, large national parks provide an excellent baseline condition to contrast with conditions on adjacent lands that have greater human management but similar climates and vegetative types. By examining these contrasts over more than three decades, several modulations of important climate cycles will be captured (McCabe et al. 2004), potentially improving inference by allowing tests of "sign-change" in climate drivers (Parmesan and Yohe 2003). Finally, any potential sign-change signal will be amplified by examining parks in climate regions whose sign-change responses to cyclic oscillations are opposed (Kitzberger et al. 2007; McCabe et al. 2004).

Conducting this research at national parks also provides an excellent means of communicating the importance of space-based research to the public. National parks receive millions of visitors every year across a diverse swath of backgrounds, one-third to one-half of whom interact in some form with park interpretive and education specialist programs and materials (Forist, 2003). The PI has assembled a core team of national park service (NPS) interpreters and education specialists (see collaborators) to help build an education/outreach plan whose central strategy is *train the trainers*: Through a series of focused professional develop trainings and workshops, the PI will help NPS staff build the expertise needed to integrate the products of this research into existing programs and to build new programs and materials from the research. A trained, independent evaluator (Coble, consultant) will provide front-end, formative, and summative evaluations of the plan and of key workshops as they develop. The plan has the support of, and will use the best practices developed by, the Landsat education and public outreach program and NASA's Earth-to-Sky program (through Co-Investigator Davis).

There are three components to the strategy for meeting project goals. First, image processing will rely on methods the PI and collaborators have established and used (Kennedy et al. 2007a) in the Laboratory for Applications of Remote Sensing in Ecology (LARSE, www.fsl.orst.edu/~larse), where he is Co-Director. Second, access to data and to institutional knowledge in the parks will be built on connections the PI has already developed with the parks under study. All parks in the proposed study are associated with networks of parks in the National Park System's (NPS) Inventory & Monitoring (I&M) program with which the PI has or will be conducting remote-sensing based research. Finally, the PI will rely on the expertise of a large group of collaborating scientists and education/outreach specialists to interpret results and relay them to the public.

The work described in this proposal has relevance to NASA, to the NPS, and to other groups. Addressing the overall science goal is the first step toward better modeling and prediction of vegetation dynamics under future climates and variable management strategies(Keane et al. 2003), both of which will be needed as society makes resource management choices in the future. As such, this research feeds directly into NASA's Earth Science Research Program's goal of understanding how the Earth system responds to natural and human-induced changes, and specifically contributes to research objectives of quantifying land cover change and expanding societal benefits from Earth system science. Understanding recent historical changes in vegetation dynamics is useful not only for NPS interpreters, who can use the information to better tell the story of their parks, but also to the managers of parks and to the NPS I&M program, which is charged with monitoring the condition of parks over time. A recent perspective of vegetative conditions is critical in determining contemporary status and the degree to which existing vegetative conditions exceed or fall below perceived management thresholds. The difference between contemporary and threshold conditions, in turn, determine the level of change a monitoring design should be capable of achieving. Finally, the methods of characterizing changing vegetation dynamics are relevant to other public agencies and programs. For example, recognizing the potential utility of the semi-automated TBCD approach for describing both current vegetation conditions and potential future trends, the multi-agency Landfire project (Rollins and Frame 2006; Zhu et al. 2006) has pledged to work with the PI to acquire the significant Landsat imagery needed for the project to facilitate exploration of the research goals in this project (collaborator Zhu).

Science plan

The science goals of the project are to develop satellite-based maps of changes in vegetation dynamics over time, and to test the extent to which spatial and temporal patterns of change can be used to infer the relative importance of human management and climate change on changing vegetative dynamics. The focus will be on national parks within five monitoring networks defined by the NPS I&M program (Table 1; http://science.nature.nps.gov/im/). The PI has worked with or is working with all of these monitoring networks to develop protocols to incorporate remote sensing into their future monitoring efforts. *[Note:* Except for isolated cases of testing in support of developing methodologies, park protocols are to be applied for the current era forward, not for the historical era proposed here. Additionally, methods used in protocols are not based on the TBCD. Thus, requested funds in this proposal do not duplicate funding from the NPS. *]*

Table 1. NPS I&M Monitoring networks involved in the proposed study	
Network	*Acronym*
Southwest Alaska Network	SWAN
North Coast and Cascades Network	NCCN
Sierra Nevada Network	SIEN
Northern Colorado Plateau Network	NCPN
Southern Colorado Plateau Network	SCPN

Working with these parks, the PI has noted a set of questions related to vegetation dynamics, climate change, and management that occur repeatedly across networks (Table 2). These "key questions" are relevant not only for the parks themselves, but for many natural resource managers and for society at large. Focused at the parks, they form the focus for the exploring the science goals of the project.

Table 2. Key science questions
1. What types and magnitudes of human-mediated vegetation clearing and conversion are occurring around the margins of national parks?
2. Are abiotic disturbance events (drought, fire, flood, wind) changing in frequency or severity because of past management and/or climate change? Are certain parts of the landscape in or around the parks more susceptible to these events?
3. Are rates and types of vegetative regrowth after disturbance related to factors expected to change under climate change?
4. Is climate change causing changes in vegetative community composition, especially for vegetation types at the margins of their ecological range?
4. Are climate change and fire suppression increasing susceptibility to insect and disease-related mortality in forests? If so, do management options alter that susceptibility?

Need: New approaches to mapping vegetation dynamics

The first step in addressing the key science questions in Table 2 is to build accurate maps of what, when, where, and how fast vegetation changes are occurring, at temporal and spatial scales relevant for the questions of interest. Earth system sensors are fundamental to this mapping process.

The Landsat family of sensors represents the best means of tracking change in land cover in a relatively consistent, frequent fashion over large areas. Moreover, the 30+ year archive of Landsat imagery captures a period of intense human-mediated change in global vegetation (Cohen and Goward 2004). With pixels <80m on a side and image extents of approximately 180km, the Landsat sensors (Multispectral Scanner [MSS], Thematic Mapper [TM], and Enhanced Thematic Mapper Plus [ETM+]) have proven to be of fine enough grain to track land cover at scales commensurate with key processes, yet coarse enough to allow a broad landscape perspective needed as societal demands for resource management move to broader scales (Franklin et al. 2002).

Although a variety of well-known projects currently use Landsat imagery to map vegetation and land cover, their products will be inadequate to address many of the questions listed in Table 2. Projects such as the Multi-resolution Landcover (MRLC) consortium's National land cover database (NLCD; http://www.epa.gov/mrlc/nlcd.html), the US Geological Survey's (USGS) Gap analysis program (GAP; http://gapanalysis.nbii.gov), and the multi-agency Landfire project (Rollins and Frame 2006; Zhu et al. 2006), will provide a range of useful one-time land cover maps relevant to vegetation, but dynamics of vegetation change can only be inferred because detection of change was not an original goal of these projects. The USGS's "Trends in Land Use and Land Cover Change" project (TLULCC) will provide essential understanding of drivers of land cover change, but only at 5-7 year intervals, only at the scale of ecological mapping regions [gallant et al], and only with generalized mapping categories that contain only a handful of descriptors for vegetation and the processes affecting it (such as "forest", "grassland/shrubland," and "mechanically disturbed"). Slow increases or decreases of vegetation within a type and changes in vegetation composition and structure cannot be distinguished. Another USGS program, "Monitoring Trends in Burn Severity" (MTBS) project (http://svinetfc4.fs.fed.us/mtbs/), will provide a more subtle characterization of change using the normalized burn ratio (NBR, van Wagtendonk et al. 2004), but will only focus on one direction of one type of vegetation process (loss due to fire), and currently has no explicit plan for characterizing pre-fire or post-fire processes with imagery.

The strategies used in these projects reflect the change detection literature in remote sensing. With some exceptions, most methods infer land cover change from change in spectral reflectance between two dates of imagery, either through direct subtraction of spectral values or through comparison of maps derived from those spectral values. Because many other factors related to sensor noise, atmospheric change, and phenological variation can cause variation in spectral reflectance between two dates of imagery, subtle changes in cover simply fall below the background noise levels of the imagery. Moreover, the rate of cover change (such as that associated with slow insect-related mortality or with regrowth of vegetation after disturbance) cannot be inferred from two dates. ***Thus, many important vegetation dynamics simply cannot be mapped.***

Background: Trajectory-based change detection

The PI has developed a trajectory-based change detection (TBCD) approach using Landsat imagery that makes significant strides toward meeting the needs of mapping vegetation dynamics. Vegetation changes are captured not by comparison against a particular threshold of change, as is typical in remote sensing change detection approaches (Lu et al. 2004), but by quantifying how well an entire temporal sequence of spectral data for each pixel can be described by simplified trajectories (Kennedy et al. 2007b). The goals of standard change detection arise from this analysis as by-products: Once a simplified trajectory is found, the parameters that describe that shape capture the onset year of a disturbance or recovery process, the intensity of that disturbance, and the rate or slope of that process in the spectral space. The method described in Kennedy et al. (2007b) focused on disturbance processes only, but the approach has been expanded to capture a full suite of fast and slow increases and decreases in vegetation.

Figure 1 illustrates the approach for a small area of ponderosa pine forest in central Oregon. In Figure 1a, a progression of Landsat TM and ETM+ images is linked to trajectories fitted to Band 5 (short-wave infrared) reflectance for three pixels within those images. These fitted trajectories capture both the abrupt changes associated with forest harvest and the variable rates of recovery of the forest after the disturbances. In Figure 1b, the parameters describing the trajectories for all pixels are displayed spatially, illustrating how an area thinned in 1986 separates itself from the area clearcut in 1986, both in terms of the intensity of disturbance and in the rate of the revegetation. <u>For the purposes of this proposal, the approach could be applied to any index (not just band 5) to track subtle as well as abrupt changes in the index.</u>

The method has several attributes making it attractive for mapping vegetation dynamics. The increased signal-to-noise ratio afforded by examining many images simultaneously allows detection of more subtle effects than standard two-date approaches, and the self-normalizing trajectory-fitting allows application to any spectral index without the need to change rules, tune the algorithm, or identify a norming population of forested pixels (Healey et al. 2005). Additionally, pixels with no coherent temporal "shape," including noisy pixels, are considered unchanged, allowing most spectrally-noisy agricultural, wetland, and similar areas to fall away without the need for masking or pre-screening. Finally, by parameterizing the temporal dimension of the spectral data, additional descriptive indices are created that can be used to distinguish among vegetation dynamics whose instantaneous spectral signatures may be otherwise indistinguishable. For example, clearcuts in managed forest often recover more quickly than cuts made for the purpose of rural or suburban development, making possible the distinction of land use from the temporal progression of land cover.

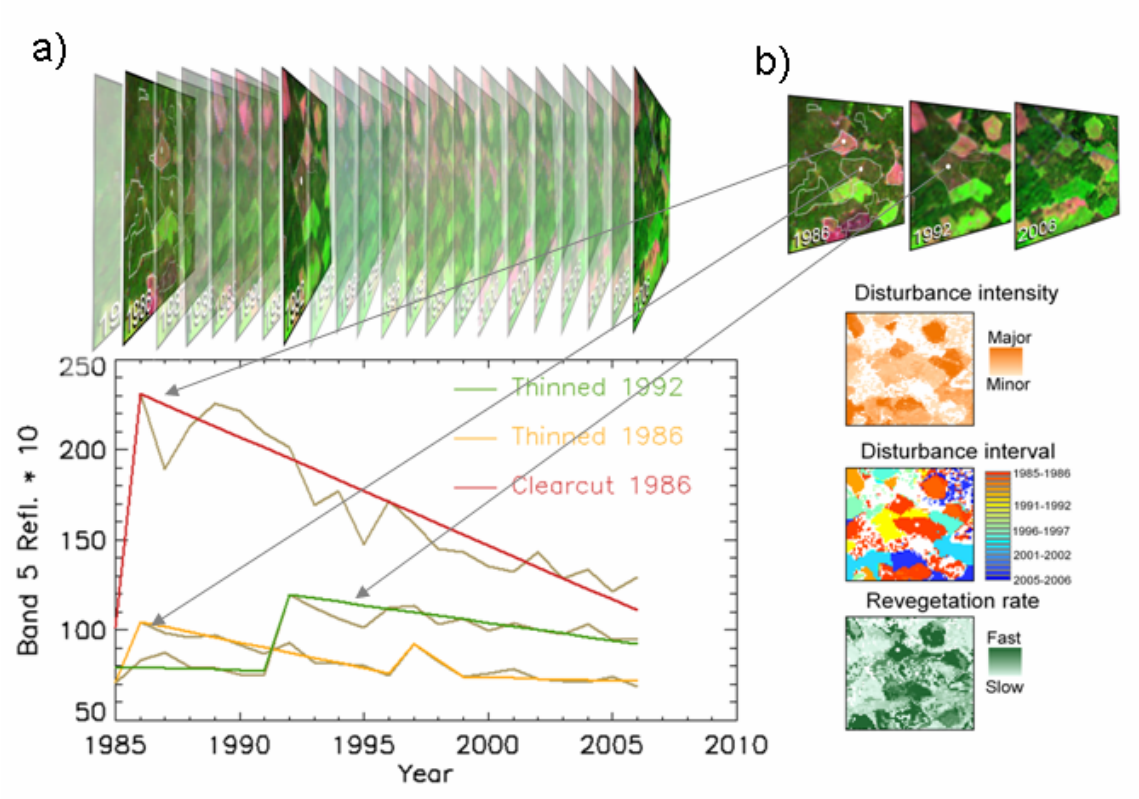

Figure 1. Examples of trajectory-based change detection. a) A temporal progression of a small subset of Landsat imagery in ponderosa pine forest in central Oregon, displayed in false color (RGB= Band 5,4,3). The graph shows trajectories of band 5 reflectance for three pixels experiencing different management effects. High values of band 5 correspond to increased reflectance from non-vegetative materials such as soil, making a disturbance of vegetation appear as an upward spike in band 5 reflectance. b) Parameters describing fits of the type shown in a) are then displayed spatially, resulting in maps of the intensity of disturbance, the time the disturbance occurred, and the rate of revegetation. Note that revegetation rate also captures infilling of pixels that were disturbed before the observation interval, meaning that much of the landscape in this particular subset shows a discernible trend toward increasing vegetation.

An important process that can now be detected is slow mortality caused by insects, drought, or disease. Figure 2 compares maps of defoliation detected using TBCD with maps of a spruce budworm outbreak in Oregon's High Cascades from the USDA Forest Service's Forest Health Monitoring (FHM) program, showing high correspondence between areas identified from low-altitude fixed-wing aircraft (Figure 2a) and areas identified using the TBCD.

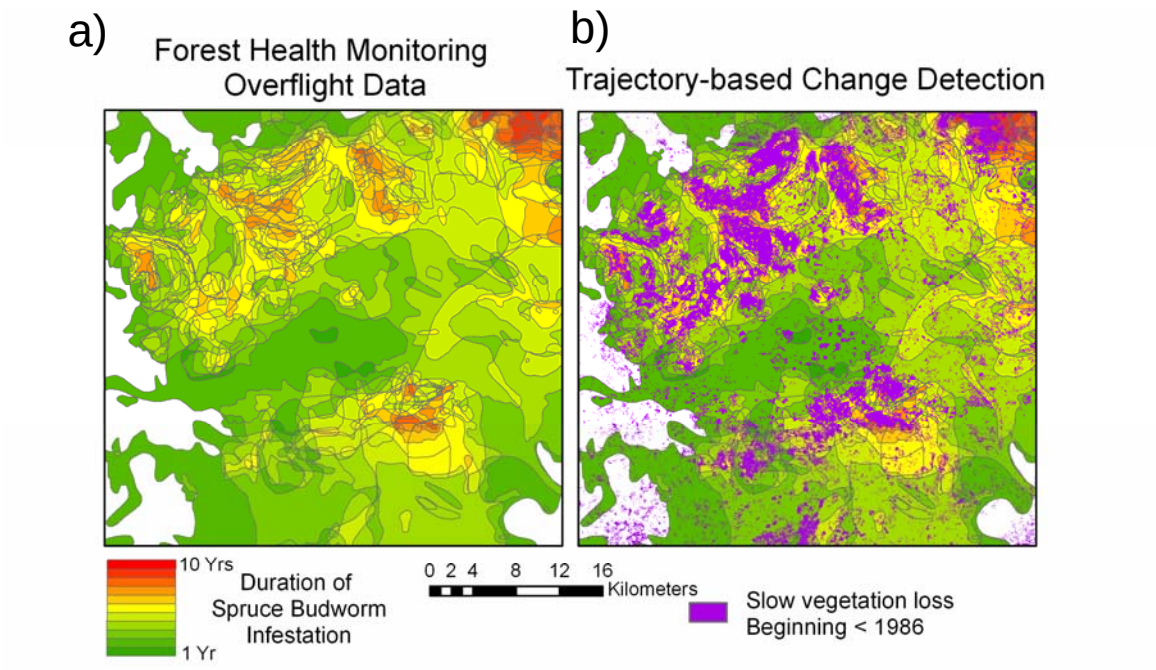

Figure 2. Comparing detection of TBCD-detected vegetation loss with maps of vegetation defoliation from spruce budworm taken produced by the Forest Health Monitoring program of the USDA Forest Service. a) Overlaid polygons where defoliation was observed over multiple years, beginning in the early 1980s, color coded according to the duration of defoliation. b) Map of areas where the TBCD detected consistent loss of vegetation that had already begun in 1986 and that continued until the peak of the insect outbreak in 1992.

The TBCD also detects sequences of vegetation processes, for example the progression from insect mortality to fire. Another spruce budworm outbreak area is shown in Figure 3a. Areas of high insect-related forest loss correspond to initiation areas of two fires that eventually burned together in 2003 to form the B&B complex fire. As the fires burned together, they killed forests that had not experienced pre-fire insect mortality (purple trajectory in Figure 3). While the fact that this large fire began in insect-killed forest is well-known, these maps provide spatially-explicit estimates of pre-fire and fire mortality mapped with a consistent tool, allowing unprecedented opportunities to explore relationships between these processes and other possible predictor variables, including slope position and aspect, vegetation type, and prior management history. Because the approach also distinguishes between different types of forest management, the effects of prescribed burning and thinning on later fire severity are also discernible (data not shown).

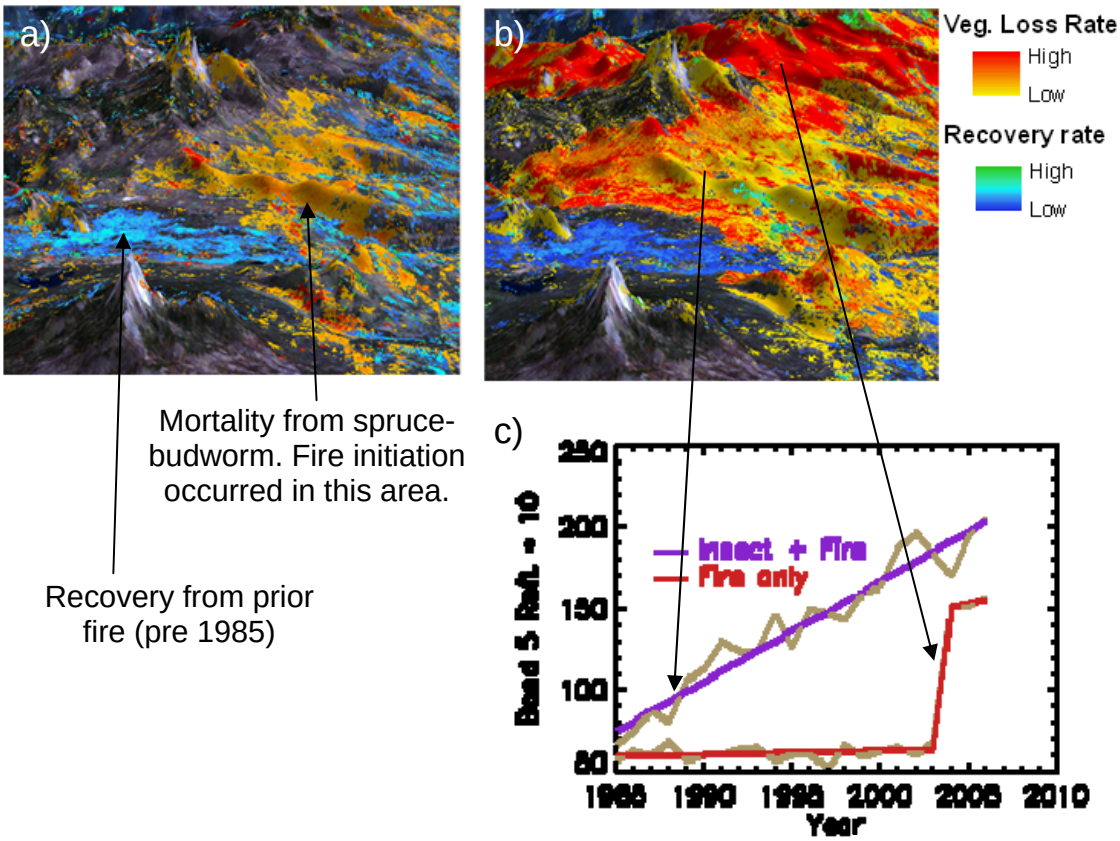

Figure 3. Vegetation dynamics of the B&B complex fire and surrounding areas, August-September 2003. a) North-looking perspective view of rates of forest vegetation change in the years preceding the fire, inferred from TBCD. Areas in orange correspond to mortality from spruce budworm, blue areas to increasing vegetation cover. b) Rate of vegetation change during and after the fire. c) Fitted trajectories of one pixel with pre-fire mortality (purple) and one pixel without such mortality (red).

Science Goals

The science plan of the project is structured around three goals, each corresponding approximately to one year of the project:
1) Use TBCD to map vegetation dynamics at selected national parks in the western U.S.
2) Test spatial and temporal correlations between vegetation dynamics and hypothesized drivers to address key questions in Table 2, and
3) Expand and generalize TBCD to improve temporal and spatial comparisons across parks and time.

Goal 1: Map vegetation dynamics at selected national parks in the western U.S.

Study areas:

Table 1 lists the parks at which this work is proposed. Collaborators have been identified either at individual parks, or at the I&M network that includes each park. These parks include many socially, economically, and ecologically important vegetation types, including boreal tundra and spruce forest, temperate rainforest, alpine and sub-alpine shrubs and herbs, temperate coniferous and hardwood forest, dry ponderosa forest, oak savanna, mixed conifer, true-fir forest, juniper woodland, desert grassland. They also sample from climatic zones expected to experience different effects of cyclic climate oscillations (See discussion in Goal 2).

Table 3: National parks at which proposed research will occur

NPS Inventory and Monitoring Network	*Parks*
Southwest Alaska	Katmai, Kenai Fjords
North Coast and Cascades	Olympic, North Cascades
Sierra Nevada	Sequoia, Kings Canyon
Northern Colorado Plateau	Bryce, Zion
Southern Colorado Plateau	North Rim Grand Canyon, Mesa Verde

Methods: Image processing

TBCD will be applied to Landsat TM and ETM+ imagery for the parks in Table 3 to create maps of vegetation dynamics for the period from approximately 1984 forward. Map products will be similar to those shown in Figures 1 through 3. Anticipated processes to be mapped include the full continuum of disturbance and mortality in woody vegetation caused by human-mediated clearing, by abiotic disturbance agents including fire, wind, volcanic activity, and by biotic disturbance agents including insects and pathogens. For each such disturbance observed in the observation interval, as well as those prior to it, revegetation rates will also be mapped. Year of onset, intensity or rate, and duration of the process will all be mapped explicitly within and outside each park.

Validation of these products will vary according to the specific product. For abrupt disturbance events, year of disturbance can be corroborated by direct interpretation of the imagery using rules analogous to those used in photogrammetry, as described in

Kennedy et al. (2007b). Disturbance can be independently verified for multi-year periods with opportunistic use of high-resolution airphotos such as digital orthoquads (DOQs)., although the years of availability of these DOQs varies greatly. When available, these photos can also be used to verify level of disturbance. The PI's experience with several park networks suggests that a variety of other park-specific airphoto products can be opportunistically used for some types of validation, including recovery from disturbance, but that these resources often can only be used for partial validation. For disturbances and recovery processes occurring near the end of the interval (i.e. near the present), field validation will be carried out during the summers of 2008 and 2009, using methods described in Kennedy et al. (2007a).

Cost realism and management:

Year 1 will focus on image acquisition and processing for the ten parks lists in Table 3. Low-cost or free imagery will be acquired for as many cases as possible. For many of these parks, a subset of the required imagery has already been acquired during ongoing collaborations with the target parks. Through collaborator Zhi-Liang Zhu, the PI will have free access to the extremely large set of images being assembled for the Landfire project (Rollins and Frame 2006) and for the MTBS project (http://svinetfc4.fs.fed.us/mtbs/). Purchase of full-cost imagery is anticipated for only a handful of occasions. Image processing at the ten parks listed in Table 3 is feasible through automation. Steps for geometric and radiometric normalization of TM imagery are highly automated (Kennedy et al. 2007b; Schroeder et al. 2006), allowing relatively fast production of image stacks. At that point, TBCD is essentially automated. Depending on the needs of resource managers and interpreters/education specialists at the parks, a variety of map products may need to be produced in this first year as well. Validation will begin in year 1 and continue through year 2. Because of the large number of parks, efforts will be focused on cost-efficient means of corroboration available directly from the parks. Image processing and validation will be overseen by the PI and conducted primarily by the research assistant (see Budget).

Relevance to user community and NASA:

The PI has found enthusiastic response in the NPS community and in the remote sensing community for development of historical maps of vegetation dynamics with the TBCD. From the perspective of NPS managers and I&M scientists (Collaborators Gross, Story, Miller, Kuhn, Mutch, Garman, Lauver), recent historical vegetation dynamics are critical for understanding how to manage their parks, especially under the recognition that climate change and past fire suppression have been altering vegetation dynamics at the landscape scale. Park interpreters and education specialists are eager to work with satellite imagery and images of landscape change tailored to their parks, particularly because the subtle processes potentially captured with the TBCD are more relevant to the dynamics within many parks than the typical change detection products developed with two-date change detection (Collaborators Matsumoto, Smithson, Rea, Poe; See Education Plan below). Remote sensing scientists are interested in how well the TBCD approach can accurately capture subtle dynamics in varied ecosystems, particularly because its essentially automated approach could be used in other studies if it proves useful here (Collaborators Zhu, Townsend, Cohen, Zhiqiang). All of these collaborators have agreed to work with the PI to provide contacts, data, and expertise as necessary to apply the

TBCD in the parks in Table 3. Development of these approaches is of direct relevance to NASA's Earth Science program, as they provide novel approaches for the application of space-based research to understanding trends in the land surface. While the TBCD as applied here is based on the Landsat sensor archive, which is no longer administered by NASA, the underlying strength of this project will be its emphasis on utilizing long-term records of consistently-measured satellite data. This underlying issue illustrates the need for continued monitoring of the Earth system from space.

Goal 2: Investigate questions of management and climate change

Management and climate change interact to affect vegetation dynamics, making attribution solely to one or the other unproductive. Nevertheless, correlative techniques that examine spatial and temporal responses to cyclic climate change have been used in a variety of regional to continental studies to infer broad-scale patterns of causation in wildfire occurrence (Westerling et al. 2006), drought (McCabe et al. 2004), winter snowfall (Hunter et al. 2006), and insect outbreaks (Bale et al. 2002). To make such inferences, these studies leverage the contrasting temporal and geographic pressures caused by cyclic effects of the El Niño/Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO; Mantua and Hare 2002), and the Atlantic Multidecadal Oscillation (AMO; Hurrell 1997). At the local scale where ecosystems are managed, however, the particular history and developmental state of each patch of vegetation may be more critical to determining its fate than the broad patterns of climate. For example, tree mortality has been linked with periods drought in Yosemite National Park (Guarin and Taylor 2005), but the strength of the linkage was itself a function landscape position and history. With a nested design that allows inference at the park, regional, and cross-regional geographic scale and at the yearly, multi-year, and decadal temporal scale, this project will begin to addressing this general question of scale as it explores the specific questions in Table 2.

Method: Correlative analysis

Maps produced for each park under Goal 1 will be analyzed in Years 1 and 2 to address the key questions in Table 2. Except for question #1 – which involves minimal manipulation of the maps themselves –trends in vegetation dynamics (rate, type, and timing) will be considered dependent variables in multivariate statistical investigations of relationships with a variety of predictor variables. Equations will be of the following general form, here illustrated at the pixel grain:

$$R_p \sim asp + greenness + manage + vegtype$$

In where R_p is rate of mortality inferred from TBCD for individual pixels, *asp* is a transformed aspect variable for that pixel, *greenness* is a proxy for vegetative amount derived from the imagery, *manage* is an indicator variable related to expected ownership or prior management, and *vegtype* is another indicator variable for the type of vegetation present before onset of mortality. Using the first part of Question 2 in Table 2 as an example ("Are abiotic disturbance events [drought, fire, flood, wind] changing in frequency or severity because of past management and/or climate change?"), Table 4 provides a list of initial dependent and independent variables expected to be needed for the question, as well as the scale at which the question can be addressed.

Table 4. An example of the forms of equation needed to address the first part of Question 2 in Table 2.

Question component	Dependent variable(s)	Independent variables	Stratifying variables	Spatial/ Temporal Grain	Extent
Frequency of disturb-ance	# of discrete disturbance events /yr	Temperature/ precip in current year or prior years	Management (ownership); elevation; beginning vegetation type	Stratum or entire park/ yearly	Park vs. adjacent lands; Park vs. Park within one region; Across regions (e.g. PNW vs. Southwest)
Severity of disturbance	Magnitude of spectral change in fitted trajectories	Temperature/ precip or anomalies thereof in current year or prior years; heat exposure (aspect and slope);	Management; beginning vegetation type; past management within type	Pixel; Patch / Yearly; mean across years	Within park; park vs. adjacent lands; cross-park

Cost realism and management:

Analyses of correlative effects of climate and management will take place primarily in year 2. Once maps of vegetation dynamics are in place, development of statistical models is relatively straightforward. Economies of scale should improve efficiency: When possible, scripts will be written generically to allow quick swapping of statistical tests from one park into the next for analysis, facilitated by the use of a common set of output and input data from the TBCD and from ancillary spatial data sources. Implementation within and across parks will require the acquisition of a variety of ancillary data; in most cases, the PI will already have such ancillary data from work done under protocol development projects with park networks. Where such data are not on hand, the PI and research assistant will tap into the large team of committed collaborators to establish contact and acquire data.

Relevance to user community and NASA:

Interpretation of causal agents will be aided by the expertise and interest of collaborators within and outside the parks. Network and park-level collaborators will have particular interest in aiding interpretation at their parks. Understanding the specific drivers of change across the landscape of each park will be another critical element for better management of each park. Trends across parks are of interest to a larger science community, as they speak to questions of scale and climate change that must eventually be understood and incorporated into predictive models and management paradigms. Specific vegetative processes across parks are of particular interest to collaborators as well. For example, insect mortality trends are a central theme in collaborator Townsend's

research program, and fire in collaborator Zhu's Landfire program. Finally, understanding the relative roles of human and natural changes in the land surface is an explicit goal of NASA's Earth Science Research Program (Strategic Sub-goal 3a in NASA's strategic plan).

Goal 3: Expand and generalize TBCD to improve temporal and spatial comparisons across parks and time.

Methods:

Several extensions of the TBCD approach will be tested in Year 3 of the project. Most importantly, methods to extend the approach into the MSS era are needed to fully capture 30+ years of change, a goal made particularly relevant by the climatic regime shift toward warmer temperatures that occurred in 1976, just at the beginning of the MSS era. Extension into the MSS era will require exploration of indices other than Band 5, since MSS has no spectral band in the short-wave infared region. The first approach tested will be to examine the utility of using either the brightness or greenness indices from the tasseled-cap transformation, since these apply fairly consistently across the MSS and TM eras.

A second thrust of research will be to examine the potential utility of indices derived from the PIs "probability of membership" (POM) approach, now being implemented for two-date change detection protocols in the NCCN and SWAN. This approach builds on several existing change detection strategies, including maximum-likelihood class surfaces in spectral space (Richards 1993), change-vector analysis (Malila 1980), and change detection through spectral unmixing (Roberts et al. 1998). A small set of "physiognomic classes" with Gaussian likelihood surfaces is defined to cover the entire spectral space of an image, and changes over time are characterized as changes in the n-dimensional probability space of those likelihood surfaces (Kennedy et al. 2007a). As applied here, the physiognomic classes will be defined in brightness-greenness space, allowing cross-walk between the TM and MSS era, and the TBCD approach applied to physiognomic class pairs that are thought to highlight particular changes of interest. For example, a hybrid index can be built from the combined likelihoods of a shrub-dominated physiognomic class and a grass-dominated class. This index would essentially trace a path through spectral space associated with a particular vegetation dynamic (in-filling of grasslands with shrubs). By calculating this index across all images in the stack, the TBCD can be applied to track subtle changes in the shrub/grass matrix over the 30+ year period of record.

The POM approach may also facilitate compensation for phenological variability in the yearly record of TM data. With the expertise of collaborator Reed, a recognized expert on the quantification of phenological signals from AVHRR and MODIS data, the PI will explore with the MODIS NBAR product (MOD43b) may serve as a reference source on which the spectral space of all individual parks can be anchored. By translating POM classes into the tasseled cap space of the MODIS NBAR product, the phenological progression of each physiognomic class can be tracked and potentially used to compensate for the effects year to year variation in phenological signals and Landsat image acquisition effects. This analysis is recognized to be primarily exploratory in nature.

Cost realism and management:

The priority analyses in the third year will be extension to the MSS era and testing of simply POM-based indices in TBCD. Acquisition and processing of MSS data will follow the automated geometric and radiometric normalization methods already included in the TM and ETM+ processing flow of the PI (Kennedy et al. 2007a). The expertise of collaborator Cohen will be tapped for aid in working with MSS data. Testing the POM approach to TBCD will focus on physiognomic classes considered to be especially relevant to the key questions in Table 2. If time and cost constraints dictate, both analyses will be constrained to a subset of the 10 original parks, with at least one park in each region a target for inclusion.

Relevance to user community and NASA:

Extension of mapping into the MSS era will increase the utility of the map products to the managers and scientists in the NPS I&M program. Tailoring the TBCD to specific POM-related classes will also be of interest to those park networks that are implementing or plan to implement the POM approach for future monitoring, as they will eventually be able to tie this project with future monitoring through use of common physiognomic classes. Finally, tests of approaches to generalize the TBCD to indices with potentially greater global relevance will be relevant in addressing NASA's goal of tracking land surface changes over large areas.

Education and Outreach Plan

Conducting research in national parks brings with it the opportunity to tap into a strong educational and outreach community. The National Park Service has as one of its main objectives the education of the general public about the natural and cultural resources of the Parks, and strives to educate in a manner that challenges people to further learning. Through its interpretive programs and staff, the NPS is widely known as a leader in informal education, and also has a well-established and strong relationship with the formal education community.

Parks provide a compelling setting for education and outreach activities. Research has shown that education experienced outside the formal classroom setting enhances motivation and learning, increases early interest in science, and influences career choice. National Parks, in particular, provide opportunities to foster long-term memories, the foundation of learning. Learning is "constructed over time as the individual moves through his/her socio-cultural and physical world; over time, meaning is built up, layer upon layer," and family visits to Parks become part of our store of long-term memories (ASTC, 2002). . Additionally,

The education plan in this proposal has as its primary goal the training of those in the national parks who educate and inspire the public: National Park Service Interpreters and Education Specialists. Interpretation is a proven Informal Education methodology that provides the opportunity for people to form their own intellectual and emotional connections to the meanings and significances inherent in natural and cultural resources. Rangers conduct research on content and use a highly developed skill set to produce these programs and products. Education specialists develop curricula that are used in formal education settings with students ranging from children to retirees. formal educators frequently use Parks as classrooms for experiential learning in science, history,

geography and the arts. Within the Park Service internal educational framework, many linkages exist between formal and informal educational activities and programs. [Note: When discussing this plan, relevance to OSS E/PO Evaluation Criteria will be indicated in italics, and reference will be made to the criterion number as described in the "Explanatory guide to the NASA Office of Space Science Education & Public Outreach Evaluation Criteria," Version 3.0 March 2004].

It is estimated that one-third to one-half of all park visitors interact with components of formal or informal education programs designed by these specialists (Forist 2003), making them powerful conduits to a diverse public audience. Education and interpretation specialists are eager to bring satellite imagery and other new technologies into their programs, as indicated by the enthusiastic and dedicated team of collaborative specialists who have helped the PI develop the education plan (Jenny Matsumoto, Elizabeth Wasserman, Carol Rea, Michael Smithson, Kevin Poe). They express particular interest in using such imagery to help visitors and students understand the dynamically changing nature of their parks, and how climate change may be affecting their parks. Thus, the science research in this proposal has a direct linkage with the needs of the interpretive and education communities *[OSS E/PO Evaluation* ***Criteria 1 and 2****]*

The education plan is organized into two components.

- targeted professional development for NPS interpreters and education specialists
- integration of space-based information into interpretive and educational programs by those collaborating NPS specialists

For each component, independent evaluation of the methods used to achieve professional development will be conducted.

Lines of management responsibility: [OSS E/PO Evaluation Criterion 1] The PI has primary responsibility for overseeing the education and outreach program, devoting 1/3 of his time on the project to the education component. The research assistant (see Budget) will aid the PI in logistical and conceptual development (two months of RA time per year). Co-Investigator Davis will act as liaison between this project and the Landsat E/PO office and the Earth-to-Sky initiative, will aid in conceptual development of training sessions, and will attend (at a minimum through distance learning capacity) the majority of the planned training sessions. *Earth to Sky* is a NASA-funded partnership with NPS that actively fosters collaborative work between the science and interpretation/education communities of NPS and NASA, with the ultimate goal of enriching the experiences of millions of park visitors (http://www.earthtosky.org). Consultant Dr. Theresa Coble at Stephen F. Austin State University (SFA) will lead the front-end, formative and summative evaluation components for the project. In that capacity, Dr. Coble will arrange phone consultations, compile and distribute participant briefs, prepare training session evaluation instruments and procedures, compile session evaluation results, facilitate peer-to-peer interactions regarding interpretive product development efforts, identify final project evaluation procedures, and compile final project evaluation results. Consultant Zelenka will develop a simple project-level website that will allow participating interpretive and education specialists to share their ongoing modules and programs, and will provide examples of how space-based imagery may be

used in interpretive and education programs. Collaborating interpreters have all committed to utilizing products from the PI's research in their interpretive or education program, although commitments necessarily vary by park depending on level of commitment to ongoing internal park processes. Potential products range from simple inclusion of digital images in ongoing powerpoint slide presentations all the way up to development of new curricula based on this research *[OSS E/PO Evaluation Criterion 3]*.

Component 1: Professional development of NPS interpreters and education specialists

The goal in this component is to train the trainers. In Year 1, the PI will conduct three distance-learning videoconferences for interpreters, education specialists, and any other interested resource management park personnel. According to our NPS collaborators, many parks have the capacity to participate in such distance learning sessions, or have such capacity at a nearby park. The trainings will include basic background in remote sensing interpretation and analysis using modules and best practices established and used by the Earth-to-Sky program and the Landsat E/PO office. To further ensure the usefulness of the presentations, the PI will consult with interpreter trainers from the *Earth to Sky* workshops and Landsat EPO to tailor the presentation to best meet park needs. This methodology is one of the lessons learned/best practices highlighted in the *Earth to Sky* final report. The NASA science content of this professional development work will focus on research methodology and basics of remote sensing imagery as it applies to the parks. The PI will describe the scope of work of the research, and provide a wide range of visual examples of maps of vegetation change *[OSS E/PO Evaluation Criteria 5]*. The objective for these sessions is for each participant to develop an Action Plan for creating interpretive and/or educational products that will incorporate the research and remote sensing images presented. Another objective of the first year is for the PI to better understand the varied stories of the parks, which in turn can affect the specific path of the scientific research that occurs in the remainder of the project.

The trainings will occur in the off-season for park specialists, meaning that these will occur as much as eight months into the project. The PI will then have map products from Science Goal 1 for a handful of parks that can be used as examples in the training workshops *[OSS E/PO Evaluation Criteria 5]*. The use of videoconferencing cababilities will allow an extremely cost-effective means of engaging many NPS staff simultaneously *[OSS E/PO Evaluation Criteria 8]*. The professional development (PD) methodology will draw from best practices developed by the *Earth to Sky* partnership and the Landsat Education and Public Outreach (EPO) team. During these training sessions, there will be dedicated time for specialists to begin establishing outlines of potential interpretive and education programs and curricula.

Because of the importance of these initial training sessions in setting up partnerships and personal investment by NPS specialists in the project, two strategies will be used to improve the odds of establishing longer term relationships. First, the PI will precede the cross-park distance learning training sessions with in-person visits to the parks. To improve cost-effectiveness, these visits will be coordinated with science-based visits (see Budget Justification: Narrative, *OSS E/PO Evaluation Criteria 8*). These visits will allow the interpretation and education specialists to make a direct connection with

the PI, which experience has shown aid significantly on ongoing program success (Davis, *pers. Comm.*.). The core group of collaborating interpreters and education specialists will act a seed group to recruit other interpreters and education specialists to these meetings. Collaborator Matsumoto, for example, will act as a liaison to specialists in parks in and around her park (see letter of commitment). Second, consultant Coble will conduct a front-end evaluation before training sessions have been finalized. During this phase, a series of phone consultations will be arranged so that participating park staff can get to know each other, become familiar with project goals, objectives, format and procedures, and ask any questions they might have about the project. After this initial round of phone consultations, participants will be asked to prepare a 2-3 page project brief in which they outline their project-related professional development and interpretive program development goals, highlight any information needs they might have regarding key science concepts, technology, and Landsat image analysis, and identify potential links between their own park ecosystem and larger scale patterns of landscape change. Summaries of the phone consultations and a notebook with participants' briefs will be compiled and distributed to all project participants *[OSS E/PO Evaluation Criteria 4]*.

Prior to initial training sessions, consultant Zelenka will develop a project web page that will be hosted on the Earth-to-Sky website. This website will provide basic visual examples of the range of products from the PI's research (such as those in Figures 1-3 of this proposal) to spur innovation by interpreters and education specialists. It will also act as a central clearinghouse for information on the project, and will link into Earth-to-Sky capabilities for web-based forums to allow participants to interact before, during, and after the training sessions. This website will be maintained and updated throughout the three-year project to include products developed by NPS interpretive and education specialists. It is envisioned that some components of this web interface may eventually be incorporated into park-specific websites (i.e. nps.gov sites), once the role and the content of the site can be shown to NPS staff.

Also centered around these training sessions, consultant Coble will conduct *formative evaluations*. The formative evaluation process will consist of two key elements: (1) training session evaluations and (2) peer-to-peer dialogue sessions regarding interpretive product development. Each time a training session is held, including face-to-face and distance learning sessions, an evaluation process will be used to assess session effectiveness and to identify opportunities for session improvement. In addition, during year two, as park interpreters begin to develop new interpretive products that incorporate Landsat information, phone meetings will be arranged to provide a forum for peer-to-peer consultation and critiques *[OSS E/PO Evaluation Criteria 4]*.

This project is specifically linked to the NASA *Earth to Sky* Explorer Institutes. NPS facilitators from *Earth to Sky* workshops have expressed interest in participating in the professional development aspect of our project, to help assure meaningful and long lasting use of the research and associated imagery by participants. One *Earth to Sky* facilitator is also participating to obtain new, useful information for creating interpretive products for his park. The PI will also serve as a guest speaker at future Earth to Sky workshops, pending continued funding of that partnership. We are thus linking two major initiatives of NASA's education program: Informal Education and the New Investigator Program. Additionally, as the research from this project is accomplished, and new educational products developed, they will be linked to the Landsat education effort, via

inclusion in teacher workshops, as well as posting to the Landsat education website *[OSS E/PO Evaluation Criteria 2]*.

Participants will also be made aware of and invited to participate in other EPO opportunities. For example, many NPS interpreters also conduct classroom education, train teachers, and design and conduct curriculum-based activities for visiting school groups. These rangers have a vested interest in NASA's broad formal education program. We will provide ample opportunities for rangers to learn about and acquire information on relevant formal education materials and programs, with particular emphasis on Landsat products, but also highlighting other sources (eg., NASA's Museum Alliance, Aerospace Education Services Program, Imagine the Universe, Space Place, Mars Public Engagement Program, Explorer Schools, Education Product Reviews, NASA's Education Newsletter, Sci@NASA, and the Earth Observatory).

This project also has potential to reach significantly larger numbers of interpreters through professional development sessions at the annual National Interpreters Workshop hosted by the National Association for Interpretation (NAI). NAI is a professional organization for interpreters at parks, zoos, historic sites, museums, aquariums, nature centers and other such venues, with a current membership of 5,000 individuals, covering 50 states and 32 countries. The NAI provides opportunities for networking and professional development through its certification programs, publications, and regional, national and international workshops. The PI will co-present with Co-I Davis at the 2008 and 2009 NAI meetings *[OSS E/PO Evaluation Criteria 2]*.

Component 2: Integration of space-based information into interpretive and educational programs by those collaborating NPS specialists

Products spawned in the training sessions of Year 1 will be actively monitored and guided during Year 2 by the PI, the Co-I, and the consulting evaluation specialist (Coble) *[OSS E/PO Evaluation Criteria 3]*. Rangers will develop and test in their parks interpretive and educational products/programs (including potential web sites and print materials), with PI serving as content consultant *[OSS E/PO Evalutation Criteria 5]*. Year 3 will see the implementation of programs and products, including printing of brochures or pamphlets for distribution in the parks (see Budget narrative), as well as another series of videoconference-based meetings designed to summarize and evaluate the overall effectiveness of the programs *[OSS E/PO Evaluation Criteria 4]*.

While it is impossible to know which components of the research will be utilized the interpretive and education specialists, discussions among the collaborating team suggest that 3-d perspective views (as in Figure 3), as well as before and after change imagery, could be quickly integrated into many aspects of their work. The three education specialists listed as collaborators (Rea, Wasserman, and Matsumoto) have all expressed strong interest in development of curricula based on work in this project, providing direct outreach to underserved communities in science and technology *[OSS E/PO Evaluation Criteria 6,7, &8]*.

Although the primary development of programs will be conducted by the interpreters and education specialists, the PI, the Co-I, and the evaluation consultant will all be involved in ongoing engagement and consultation with this group during this phase of the project. In particular, the PI and the PI's research assistant will maintain logisitical and consultative science connections with the group of specialists. When necessary and

appropriate, further distance-learning sessions will be conducted throughout Years 2 and 3.

The summarizing videoconference-based meetings in Year 3 are critical. Held mid-year of the project this meeting would bring together all participants, as well as recruit new participants from other parks. The key topic will be understanding if and how participants feel that interpretive products from this project supported their overall effort in public outreach, with a focus on collecting and summarizing specific reactions of the usefulness of the remote-sensing based products *[OSS E/PO Evaluation Criteria 4]*.

Consultant Coble will conduct summative evaluation in which feedback is gathered from all participants to assess the quality of their participant experiences, the effectiveness of the process, and any recommendations they might have for future training and implementation. Taken together, the front-end, formative and summative evaluation procedures will enhance participant experiences, provide feedback to session presenters, ensure high quality interpretive product development, and suggest ways to improve the education component in future projects.

Overall time line for project

Year 1:

- PI will supervise the research assistant in the acquisition and processing of Landsat TM and ETM+ imagery for all 10 parks in Table 3, as well application of the TBCD approach to develop maps of changing vegetation dynamics
- PI will travel to each group of parks for science and education/outreach goals
- Research assistant will begin validation efforts in parks in PNW
- Consultant Zelenka will set up initial project website
- Consultant Coble will develop and implement front-end evaluations in preparation for training sessions
- PI will conduct, with aid of Co-I Davis and Earth-to-Sky personnel, videoconference-based distance-learning training sessions.
- NPS interpretive and education specialists will begin developing products and programs based on initial training sessions. Some initial publications and hardcopy products will be published for immediate use.
- Coble will conduct formative evaluations of training sessions and report back to group and PI for improvement

Year 2:

- Research assistant will acquire necessary ancillary data for use in correlative analysis and for use in validation, and will travel to Sierra and Southwest parks for validation
- PI will conduct correlative, cross-scale analysis of linkages between vegetation dynamics and hypothesized drivers, addressing key questions in Table 2
- PI will submit one paper for peer review summarizing TBCD-based vegetation dynamics across parks

- PI, Co-I, and evaluator will monitor and engage NPS interpretive through ongoing videoconference-based meetings, through discussions on project web site, and conference calls
- NPS interpretive and education specialists will develop tools and programs integrating research into their outreach and education activities

Year 3

- PI will supervise research assistant in acquisition of MSS imagery for extension of TBCD to the 1970s
- Research assistant will conduct validation of vegetation dynamics maps in Alaska parks
- PI will conduct analysis of POM approach for application in TBCD, and potentially integration of MODIS POM approach for phenological effects
- PI will lead with assistance of Co-I and evaluation consultant Coble wrap-up meetings via videoconferencing
- Coble will conduct summative evaluation of these training sessions and write up summary evaluations
- PI will submit paper for peer review summarizing cross-scale relationships between vegetation dynamics and driving factors, and one paper with Co-I Davis and consultant Coble describing overall education and outreach program successes and needed improvements

Roles of collaborators

This project will take advantage of the interest and expertise of a large group of collaborators. The enthusiastic response and interest of these science and education specialists underscores the potential impact this project can have.

Collaborator(s)	Role
Gross, Story	Aid PI in institutional and data contacts, disseminate role of project to larger NPS community
Zhu	Provide PI with access to Landsat imagery from Landfire project; collaborate on potential applications of TBCD for Landfire project
Townsend, Reed, Cohen, Zhiqiang	Provide consultative guidance to PI on interpretation and specific processing of imagery and maps
Garman, Lauver, Miller, Kuhn, Mutch	Provide monitoring-network level contacts and facilitate acquisition of data by PI for analysis; advise PI on utility of different TBCD-based products; use vegetation dynamics maps as basis for ongoing monitoring
Matsumoto, Wasserman, Rea, Smithson, Poe	Help PI develop education and outreach goals and plans; act as core group to recruit other education and interpretive specialists; develop interpretive and education programs and products from vegetation dynamics maps and analysis of PI

References:

Bachelet, D., Lenihan, J.M., Daly, C., & Neilson, R.P. (2000). Interactions between fire, grazing and climate change at Wind Cave National Park, SD. *Ecological Modelling, 134*, 229-244

Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K., Butterfield, J., Buse, A., Coulson, J.C., Farrar, J., Good, J.E.G., Harrington, R., Hartley, S., Jones, T.H., Lindroth, R.L., Press, M.C., Symrnioudis, I., Watt, A.D., & Whittaker, J.B. (2002). Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology, 8*, 1-16

Cohen, W.B., & Goward, S.N. (2004). Landsat's role in ecological applications of remote sensing. *Bioscience, 54*, 535-545

Cook, E.R., Woodhouse, C.A., Eakin, C.M., Meko, D.M., & Stahle, D.W. (2004). Long-term aridity changes in the western United States. *Science, 306*, 1015-1018

Floyd, M.L., Romme, W.H., & Hanna, D.D. (2000). Fire history and vegetation pattern in Mesa Verde National Park, Colorado, USA. *Ecological Applications, 10*, 1666-1680

Franklin, S.E., Lavigne, M.B., Wulder, M.A., & Stenhouse, G.B. (2002). Change detection and landscape structure mapping using remote sensing. *Forestry Chronicle, 78*, 618-625

Graham, R.L., Turner, M.G., & Dale, V.H. (1990). How increasing CO2 and climate change affect forests. *Bioscience, 40*, 575-587

Guarin, A., & Taylor, A.H. (2005). Drought triggered tree mortality in mixed conifer forests in Yosemite National Park, California, USA. *Forest Ecology and Management, 218*, 229-244

Healey, S.P., Cohen, W.B., Yang, Z.Q., & Krankina, O.N. (2005). Comparison of Tasseled Cap-based Landsat data structures for use in forest disturbance detection. *Remote Sensing of Environment, 97*, 301-310

Hunter, T., Tootle, G., & Piechota, T. (2006). Oceanic-atmospheric variability and western US snowfall. *Geophysical Research Letters, 33*, -

Keane, R.E., Cary, G.J., & Parsons, R. (2003). Using simulation to map fire regimes: an evaluation of approaches, strategies, and limitations. *International Journal of Wildland Fire, 12*, 309-322

Kennedy, R.E., Cohen, W.B., Kirschbaum, A.A., & Haunreiter, E. (2007a). *Protocol for Landsat-based Monitoring of Landscape Dynamics at North Coast and Cascades Network Parks*: USGS Biological Resources Division

Kennedy, R.E., Cohen, W.B., & Schroeder, T.A. (2007b). Trajectory-based change detection for automated characterization of forest disturbance dynamics. *Remote Sensing of Environment, 110*, 370-386

Kitzberger, T., Brown, P.M., Heyerdahl, E.K., Swetnam, T.W., & Veblen, T.T. (2007). Contingent Pacific-Atlantic Ocean influence on multicentury wildfire synchrony over western North America. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 543-548

Lewis, S.L., Malhi, Y., & Phillips, O.L. (2004). Fingerprinting the impacts of global change on tropical forests. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences, 359*, 437-462

Logan, J.A., Regniere, J., & Powell, J.A. (2003). Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment, 1*, 130-137
Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing, 25*, 2365-2407
Malila, W.A. (1980). Change vector analysis: An approach for detecting forest changes with Landsat. In P.G. Burroff & D.B. Morrison (Eds.) (pp. 326-335). West Lafayette IN: Purdue U. Lab. App. Remote Sens.
Mast, J.N., & Wolf, J.J. (2004). Ecotonal changes and altered tree spatial patterns in lower mixed-conifer forests, Grand Canyon National Park, Arizona, USA. *Landscape Ecology, 19*, 167-180
McCabe, G.J., Palecki, M.A., & Betancourt, J.L. (2004). Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. *Proceedings of the National Academy of Sciences of the United States of America, 101*, 4136-4141
Oerlemans, J. (2005). Extracting a climate signal from 169 glacier records. *Science, 308*, 675-678
Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature, 421*, 37-42
Program], N.A.D. (2000). Nitrogen in the nation's rain*Volume*Number of 16: http://nadp.sws.uiuc.edu/
Richards, J.A. (1993). *Remote sensing digital image analysis: An introduction*. Berlin: Springer-Verlag
Roberts, D.A., Batista, G.T., Pereira, J.L.G., Waller, E.K., & Nelson, B.W. (1998). Change identification using multitemporal spectral mixture analysis: applications in eastern Amazonia. In R.S. Lunetta & C.D. Elvidge (Eds.), *Remote sensing change detection: environmental monitoring methods and applications* (pp. 137-161). Chelsea, MI: Ann Arbor Press
Rollins, M.G., & Frame, C.K. (Eds.) (2006). *The LANDFIRE Prototype Project: nationally consistent and locally relevant geospatial data for wildland fire management.* Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station
Schimel, D.S., Emanuel, W., Rizzo, B., Smith, T., Woodward, F.I., Fisher, H., Kittel, T.G.F., McKeown, R., Painter, T., Rosenbloom, N., Ojima, D.S., Parton, W.J., Kicklighter, D.W., McGuire, A.D., Melillo, J.M., Pan, Y., Haxeltine, A., Prentice, C., Sitch, S., Hibbard, K., Nemani, R., Pierce, L., Running, S., Borchers, J., Chaney, J., Neilson, R., & Braswell, B.H. (1997). Continental scale variability in ecosystem processes: Models, data, and the role of disturbance. *Ecological Monographs, 67*, 251-271
Schroeder, T.A., Cohen, W.B., Song, C., Canty, M.J., & Yang, Z. (2006). Radiometric Calibration of Landsat Data For Characterization of Early Successional Forest Patterns in Western Oregon. *Remote Sensing of Environment, 103*, 16-26
Seastedt, T.R., Bowman, W.D., Caine, T.N., McKnight, D., Townsend, A., & Williams, M.W. (2004). The landscape continuum: A model for high-elevation ecosystems. *Bioscience, 54*, 111-121
van Wagtendonk, J.W., Root, R.R., & Key, C.H. (2004). Comparison of AVIRIS and Landsat ETM+ detection capabilities for burn severity. *Remote Sensing of Environment, 92*, 397-408

Vitousek, P.M., Mooney, H.A., Lubchenco, J., & Melillo, J.M. (1997). Human domination of Earth's ecosystems. *Science, 277*, 494-499
Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O., & Bairlein, F. (2002). Ecological responses to recent climate change. *Nature, 416*, 389-395
Westerling, A.L., Hidalgo, H.G., Cayan, D.R., & Swetnam, T.W. (2006). Warming and earlier spring increase western US forest wildfire activity. *Science, 313*, 940-943
Wimberly, M.C., & Spies, T.A. (2001). Influences of environment and disturbance on forest patterns in coastal Oregon watersheds. *Ecology, 82*, 1443-1459
Zhu, Z., Vogelmann, J., Ohlen, D., Kost, J., Chen, X., & Tolk, B. (2006). Mapping existing vegetation composition and structure for the LANDFIRE prototype project. In M.G. Rollins & C.K. Frame (Eds.), *The LANDFIRE Prototype Project: nationally consistent and locally relevant geospatial data for wildland fire management.* (pp. 197-215). Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station