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Monitoring vegetation change and dynamics on U.S. Army training lands using satellite image time series analysis

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ABSTRACT

Given the significant land holdings of the U.S. Department of Defense, and the importance of those lands to support a variety of inherently damaging activities, application of sound natural resource conservation principles and proactive monitoring practices are necessary to manage military training lands in a sustainable manner. This study explores a method for, and the utility of, analyzing vegetation condition and trends as sustainability indicators for use by military commanders and land managers, at both the national and local levels, in identifying when and where vegetation-related environmental impacts might exist. The BFAST time series decomposition method was applied to a ten-year MODIS NDVI time series dataset for the Fort Riley military installation and Konza Prairie Biological Station (KPBS) in northeastern Kansas. Imagery selected for time-series analysis were 16-day MODIS NDVI (MOD13Q1 Collection 5) composites capable of characterizing vegetation change induced by human activities and climate variability. Three indicators related to *gradual interannual* or *abrupt intraannual* vegetation change for each pixel were calculated from the trend component resulting from the BFAST decomposition. Assessment of gradual interannual NDVI trends showed the majority of Fort Riley experienced browning between 2001 and 2010. This result is supported by validation using high spatial resolution imagery. The observed versus expected frequency of linear trends detected at Fort Riley and KPBS were significantly different and suggest a causal link between military training activities and/or land management practices. While both sites were similar with regards to overall disturbance frequency and the relative spatial extents of monotonic or interrupted trends, vegetation trajectories after disturbance were significantly different. This suggests that the type and magnitude of disturbances characteristic of each location result in distinct post-disturbance vegetation responses. Using a remotely-sensed vegetation index time series with BFAST and the indicators outlined here provides a consistent and relatively rapid assessment of military training lands with applicability outside of grassland biomes. Characterizing overall trends and disturbance responses of vegetation can promote sustainable use of military lands and assist land managers in targeting specific areas for various rehabilitation activities.

1. Introduction

1.1. Sustainable use of military training lands

The Department of Defense (DoD) is one of the largest land stewards in the United States (U.S.), responsible for over 7.8 million hectares (ha) of owned land (Congressional Research Service, 2012) in the U.S. and U.S. territories. Including lands leased by the DoD, that total increases to nearly 11.3 million ha (DoD, 2010). Though Cohn (1996) described the DoD as the second largest land steward, current figures rank it third, well behind the U.S. Forest Service (Department of Agriculture) and subagencies of the Department of Interior even if leased land were included in the total (Congressional Research Service, 2012) (Fig. 1). These DoD lands are among the most valuable resources used by U.S. military forces. This is particularly true for land forces such as the U.S. Army and U.S. Marine Corps which rely on the availability and accessibility of military lands to conduct training activities that prepare units to execute their wartime missions with maximum effectiveness and minimal loss of life.

These very same training activities, which are necessary for military preparedness, can also cause significant impacts on the

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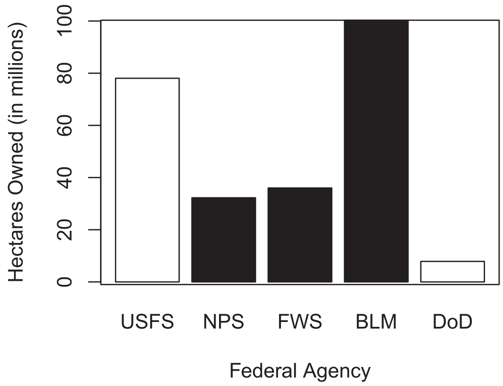

Fig. 1. Federal land ownership by agency and subagency. USFS = United States Forest Service (Department of Agriculture), NPS = National Park Service (Department of Interior), FWS = Fish and Wildlife Service (Department of Interior), BLM = Bureau of Land Management (Department of Interior), DoD = Department of Defense. Total hectares includes terrestrial land areas only in the U.S. and U.S. territories.

environment, leading to degradation in the form of vegetation removal and change, accelerated rates of soil erosion, increased soil compaction, and loss of wildlife habitat. Training activities including vehicle-based maneuvers, foot traffic, and indirect fire weapons (*e.g.,* artillery, mortars) are known to have major environmental impacts. Such exercises often include vehicles that can be large and heavy, and have the capability of traversing significant distances (Quist et al., 2003). Vehicle movements contribute to land degradation by compacting the soil and removing the vegetative cover (Milchunas et al., 1999), which overexposes the ground surface to rainfall and surface runoff water and increases the potential for erosion. Compressed pore structure within compacted soil slows water infiltration and decreases soil aeration which, in turn, inhibits root growth, nutrient uptake by plants, and seedling emergence (Chancellor, 1977). Reductions in vegetation cover results in less precipitation interception, less dissipation of raindrop energy, reduced water infiltration, and increased soil erosion rates (Thurow, 1991; Thurow et al., 1993).

The magnitude of environmental impacts by training on the landscape is also dependent upon the specific type of military vehicles involved, their operating characteristics, vehicle speed and turning radii, and existing soil conditions (Liu et al., 2009). Compounding these known effects is (1) the high intensity nature of training that, at discrete points in time during an exercise, concentrates impacts over relatively small areas and (2) the increased need for larger and more versatile training lands to support technological advances in weapon systems, as well as philosophical shifts in military doctrine, unit composition, and tactics (Houston et al., 2001).

Given the significant land holdings within DoD, and the importance of those lands to support a variety of inherently damaging activities, application of sound natural resource conservation principles and practices is highlighted in a number of military publications and regulations. The "Sikes Act", enacted in 1960, requires military installations to develop and implement comprehensive Integrated National Resource management Plans (INRMPs) in cooperation with the U.S. Fish and Wildlife Service. In Instruction No. 4715.03 (DoD, 2011), the Department of Defense re-emphasizes working within the mandate of the Sikes Act, and other key natural resource conservation actions, by clearly stating the DoD policy that:

> "The principal purpose of DoD lands, waters, airspace, and coastal resources is to support mission-related activities. All DoD natural resources conservation program activities shall work to guarantee DoD continued access to its land, air, and water resources for realistic military training and testing and to sustain the long-term ecological integrity of the resource base and the ecosystem services it provides … DoD shall follow an ecosystem-based management approach to natural resources-related practices and decisions, using scientifically sound conservation procedures, techniques, and data"

Since passage of the National Environmental Policy Act of 1969 (NEPA) and publication of U.S. Army Regulation 200-2 (Department of the Army, 1988), the U.S. Army has challenged itself to consider environmental effects and costs identified through decision-making based upon "a systematic, interdisciplinary approach that ensures integrated use of the natural and social sciences, planning, and the environmental design arts". To help achieve this requirement, U.S. Army Regulation 350-19 mandates the critical goal of "maximizing the capability, availability, and accessibility of ranges and training lands to support doctrinal requirements, mobilization, and deployments" (Department of the Army, 2005). This same regulation established the Integrated Training Area Management (ITAM) program at the installation level whose objective is to establish the "policies and procedures to achieve optimum, sustainable use of training and testing lands" through implementation of "a uniform land management program." A key term used in U.S. Army Regulation 350-19 is "sustainable use" which helps ITAM personnel develop a local philosophy for training land management, as well as identifying specific methods and approaches for managing and maintaining training lands to support military mission readiness at the installation level.

Current ITAM land monitoring practices, however, are essentially done on an "ad hoc" basis with little guidance on what should be examined and how the results of environmental assessment are to be interpreted and reported. This decentralized approach prevents the consistent description of the condition of training lands across all U.S. Army installations which, among other things, hampers the ability to implement early and proactive land rehabilitation efforts and to fund those efforts in an efficient, and prioritized, manner. This study explores a method for, and the utility of, analyzing vegetation condition and trends as sustainability indicators that could assist military commanders and land managers, at both the national and local levels, in identifying when and where vegetation-related environmental impacts might exist that would prevent use of training lands in a sustainable manner.

1.2. Background and purpose

The presence of healthy vegetation, and continuous vegetative cover, is essential to training land availability and access as it reduces soil erosion, prevents formation of dangerous gullies, and provides natural cover for soldiers and vehicles during training exercises. Degradation of vegetation health results from gradual or abrupt changes in the level of vegetation activity over time (de Jong et al., 2011), which can be routinely monitored by collecting and analyzing time-series Normalized Difference Vegetation Index (NDVI) data from medium and coarse spatial resolution satellite sensors (Beck et al., 2006; Dash et al., 2010; Julien and Sobrino, 2009; Verbesselt et al., 2010a, 2010b). Time series datasets using NDVI products from the Moderate Resolution Imaging Spectrometer (MODIS) sensor have been successfully used to quantify vegetation activity and vegetation dynamics (Alh et al., 2006; Jacquin et al., 2010; Zhang et al., 2003).

Among recent methods used for analyzing the trends in continuous vegetation index time series datasets, temporal decomposition techniques have been shown relevant to the study of vegetation seasonality (Jönsson and Eklundh, 2002) and the detection of vegetation changes in relation to agricultural practices