Using Remote Sensing to Evaluate the Influence of Grassland Restoration Activities on Ecosystem Forage Provisioning Services

Carolyn M. Malmstrom, H. Scott Butterfield, Christopher Barber, Barbara Dieter, Richard Harrison, Jiaqiu Qi, David Riaño, Abbie Schrotenboer, Scott Stone, Chantal J. Stoner, and Jeanne Wirka

Abstract
As valuation of ecosystem goods and services derived from ecological processes becomes increasingly important in environmental decision-making, the need to quantify how restoration activities influence ecosystem function has grown more urgent, particularly within income-generating or subsistence-providing landscapes where economic needs and biodiversity goals must be balanced. However, quantification of restoration effects is often hindered by logistical issues, which include (1) the difficulty of systematically monitoring responses over large areas and (2) lack of comparison sites necessary for assessing treatment effect. We explored the use of remote sensing to quantify the effects of native grass seeding and prescribed burns on ecosystem forage provisioning services within a California (U.S.A.) rangeland landscape. We used Landsat time series to monitor forage (green biomass) dynamics within 296 ha of treatment areas—distributed throughout a 36-km² watershed—for 6 years and to identify post hoc comparison areas when a priori comparisons were lacking. Remote sensing analysis documented gains and losses in forage provisioning services due to restoration efforts and provided critical information for adaptive management. Our results demonstrate the degree to which invaded grasslands can be resistant to change and suggest that increasing the functional complexity of restoration mixes might help increase forage availability and reduce opportunities for weed reinvasion.

Key words: California native grass restoration, ecosystem services, forage provisioning services, prescribed burn, remote sensing, semiarid rangeland.

Introduction
As environmental challenges demand increasing pragmatism from ecological science, arguments offered for preserving and restoring ecosystems will likely become increasingly economic and more dependent upon explicit quantitative valuation (Costanza et al. 1997; Balvanera et al. 2001; Palmer et al. 2004; Kareiva et al. 2007). As a result, restoration ecologists can expect to be increasingly asked to demonstrate the level of improvements in ecosystem goods and services brought about by restoration efforts, where these goods and services represent the benefits humans derive from ecosystem functions (ecological properties and processes) (Costanza et al. 1997). The need to quantify the effects of restoration activities on these factors is particularly evident when restoration activities take place on lands that are used to provide subsistence or generate income (e.g., rangelands, timberlands) and/or when landowners incur costs in the process. Even when landowners are generous with their resources and motivated by personal interest in conservation, as many are, the need to evaluate costs and benefits of restoration efforts remains.

A key question thus becomes, how can we quantify the effects of restoration efforts on ecosystem function and related ecosystem goods and services? Restoration ecology already has recognized the general need to improve quantification of restoration effects (Hobbs & Norton 1996; Holt et al. 2003), yet quantification continues to be limited. One reason for this is the pervasiveness of logistical challenges, which include (1) resource and time constraints that limit monitoring efforts and (2) lack of comparison sites (controls) necessary for assessing...