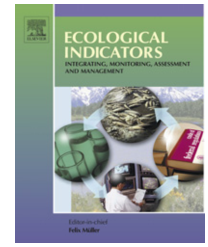
ECOLOGICAL INDICATORS 8 (2008) 89–99

available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecolind



Detecting changes in riparian habitat conditions based on patterns of greenness change: A case study from the Upper San Pedro River Basin, USA

K. Bruce Jones [a,*], Curtis E. Edmonds [a,1], E. Terrance Slonecker [b], James D. Wickham [c], Anne C. Neale [a], Timothy G. Wade [c], Kurt H. Riitters [d], William G. Kepner [a]

[a] U.S. Environmental Protection Agency, Las Vegas, NV, USA
[b] U.S. Environmental Protection Agency, Reston, VA, USA
[c] U.S. Environmental Protection Agency, Research Triangle Park, NC, USA
[d] U.S. Forest Service, Raleigh, NC, USA

ARTICLE INFO

Article history:
Received 15 May 2006
Received in revised form
17 December 2006
Accepted 5 January 2007

Keywords:
Greenness change
NDVI
Riparian ecosystems

ABSTRACT

Healthy riparian ecosystems in arid and semi-arid regions exhibit shifting patterns of vegetation in response to periodic flooding. Their conditions also depend upon the amount of grazing and other human uses. Taking advantage of these system properties, we developed and tested an approach that utilizes historical Landsat data to track changes in the patterns of greenness (Normalized Difference Vegetation Index) within riparian zones. We tested the approach in the Upper San Pedro River of southeastern Arizona of the US, an unimpounded river system that flows north into the US from northern Mexico. We evaluated changes in the pattern of greenness in the San Pedro River National Conservation Area (SPRNCA), an area protected from grazing and development since 1988, and in a relatively unprotected area north of the SPRNCA (NA). The SPRNCA exhibited greater positive changes in greenness than did the NA. The SPRNCA also exhibited larger, more continuous patches of positive change than did the NA. These pattern differences may reflect greater pressures from grazing and urban sprawl in the NA than in the SPRNCA, as well as differences in floodplain width, depth to ground water, and base geology. The SPRNCA has greater amounts of ground and surface water available to support a riparian gallery forest than does the NA, and this may have influenced changes during the study period.

Estimates of the direction of greenness change (positive or negative) from satellite imagery were similar to estimates derived from aerial photography, except in areas where changes were from one type of shrub community to another, and in areas with agriculture. Change estimates in these areas may be more difficult because of relatively low greenness values, and because of differences in soil moisture, sun-angle, and crop rotations among the dates of data collection. The potential for applying a satellite-based, greenness change approach to evaluate riparian ecosystem condition over broad geographic areas is also discussed.

* Corresponding author. Present address: U.S. Geological Survey, Reston, VA, USA. Tel.: +1 703 648 4762; fax: +1 703 648 5792.
E-mail address: kbjones@usgs.gov (K.B. Jones).

1 Retired.

1470-160X/$ – see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2007.01.001

1. Introduction

In many arid and semi-arid regions of the world there is great concern over the condition of riparian ecosystems (Swift, 1984; Stromberg and Patten, 1990; Armour et al., 1991; Gregory et al., 1991; Zube and Sheehan, 1994; Stromberg et al., 1996; Todd and Elmore, 1997; Nilsson and Berggren, 2000). In the western United States, there may be as little as two percent of the original forested riparian habitat left (Todd and Elmore, 1997), and environmental managers and the general public alike are concerned about how the loss of such large amounts of riparian habitat might affect the sustainability of biological diversity in arid regions where human populations are rapidly expanding. Riparian ecosystems have declined substantially since the early 1900s, primarily as a result of construction of dams for flood control and water storage, pumping of surface and ground water from floodplains for agriculture and human consumption, and livestock grazing (Lytle and Merritt, 2004). Dams, such as those along the Colorado and Gila river systems in the US, have substantially decreased the frequency and magnitude of flooding events that are needed to establish and maintain tree stands over long periods of time (Brady et al., 1985).

Riparian ecosystems, especially those with mature tree stands, often possess a disproportionately larger number of plant and animal species than do adjacent desert areas because of moderated climatic conditions, high plant productivity and structure, and abundant food and water (Jones and Glinski, 1985; Jones et al., 1985; Knopf and Samson, 1994). They also serve as important migration corridors for birds and other wildlife, especially across areas dominated by agriculture or vast deserts (Knopf and Samson, 1994). Riparian ecosystems also serve important ecological functions in arid watersheds, including dissipation of energy associated with flooding events, storage of nutrients and sediments, and filtering of other non-point source pollution that would otherwise end up in streams (Swanson et al., 1982; Lowrance et al., 1984; Rhodes et al., 1985). Mature trees in riparian zones intercept flood waters and trap sediment and debris, helping to reduce sediment in the water and to create debris piles which are important in maintaining wildlife species that are normally associated with more mesic habitats (Jones and Glinski, 1985; Jones, 1988). Vegetation cover along the edge of the riparian zone also helps reduce stream bank erosion (Likens and Bormann, 1974; Swanson et al., 1982; Lowrance et al., 1984; Rhodes et al., 1985).

In arid and semi-arid regions of the western United States, healthy riparian ecosystems are characterized by well-developed stands of cottonwood (*Populus*) and willow (*Salix*), as well as stands of seedlings located in beds along stream margins (Brady et al., 1985; Stromberg, 1998). Periodic flooding helps create and maintain stands in different age classes. High intensity floods often result in relocation of the stream bottom and the distribution of gravel and sand beds where tree seedlings germinate and develop into new stands (Brady et al., 1985; Stromberg, 1998; Levine and Stromberg, 2001). As a result of flooding and stream bank relocation, the distribution of tree patches in floodplains is quite dynamic and spatially heterogeneous, and healthy riparian ecosystems appear to maintain mature tree patches over long periods of time (Brady et al., 1985). Therefore, the condition of the riparian zone is intricately linked to hydrological function and condition.

Despite considerable concern over the condition of riparian ecosystems, we lack both monitoring data and methods for evaluating status and trends of these ecosystems over large geographic areas. Evaluating trends over large areas through a systematic monitoring approach is necessary to evaluate the relative conditions of riparian habitats and the effectiveness of riparian management and restoration programs.

In arid regions, the contrast in greenness between deciduous trees in the riparian zone and desert shrubs in adjacent areas permit a relatively accurate mapping and characterization of riparian ecosystems through the analysis and interpretation of remote sensing imagery, including imagery from the Landsat satellite (Hewitt, 1990; Lee and Marsh, 1995). This interpretation often involves classification of imagery into land cover classes (e.g., Vogelmann et al., 2001) which can be fairly time consuming and costly, especially if applied over extensive areas. Several indices of greenness, including the Normalized Difference Vegetation Index (NDVI), have been generated from satellite imagery and used to evaluate changes in vegetation composition and condition (Huete and Jackson, 1987; Kennedy, 1989; Chilar et al., 1991; Paruelo and Lauenroth, 1995; Shoshany et al., 1996; Grist et al., 1997), including riparian vegetation (Nagler et al., 2001). These indices require less processing and interpretation than generation of land cover and, therefore, may be especially valuable in monitoring the condition of riparian ecosystems over broad areas.

We developed and applied a remote sensing method to detect the amount and pattern of greenness change as it relates to riparian habitat condition, and tested the method by comparing changes in greenness inside an area protected from livestock grazing and mining (the San Pedro River Riparian National Conservation Area, hereafter referred to as the SPRNCA) to a relatively unprotected area north of the SPRNCA with multiple land uses (hereafter referred to as the NA). Since the San Pedro River is unimpounded, we anticipated that both areas would exhibit spatial patterns of gains and losses, due to lateral migration of the stream channel in response to large flooding events and subsequent losses and gains in cottonwood and willow trees. However, we hypothesized that the SPRNCA would exhibit a greater amount of positive greenness change between 1973 and 1992 than the NA, primarily because of protection from grazing, mining, and urbanization in the former area, and because the SPRNCA has greater ground and surface water availability.

2. Materials and methods

2.1. Description of the study area

The study location is the Upper San Pedro River Basin that originates in Sonora, Mexico and flows north into southeastern Arizona (Fig. 1). The Upper San Pedro Watershed represents a transition area between the Sonoran and Chihuahuan deserts and is internationally renowned for its biodiversity. It supports the second highest land mammal diversity in the world (Simpson, 1964) and provides habitat for