Ecological Engineering 70 (2014) 241–254

Contents lists available at ScienceDirect

Ecological Engineering

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

Remote sensing analysis of riparian vegetation response to desert marsh restoration in the Mexican Highlands

Laura Norman[a,*], Miguel Villarreal[a], H. Ronald Pulliam[b], Robert Minckley[c], Leila Gass[a], Cindy Tolle[d], Michelle Coe[e]

[a] US Geological Survey, Western Geographic Science Center, 520N. Park Ave., Ste. #102K, Tucson, AZ 85719, United States
[b] Borderlands Restoration, L3C; P.O. Box 1239, Patagonia, AZ 85624, United States
[c] University of Rochester, Department of Biology, River Campus, Box 270211, Rochester, NY 14627-0211, United States
[d] Tutuaca Mountain School, 12134 Mountain Goat Lane, Custer, SD 57730, United States
[e] University of Arizona, School of Geography, Tucson, AZ 85719, United States

ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form 16 April 2014
Accepted 18 May 2014

Keywords:
Gabions
Cienega
Wetlands
Restoration
NDVI

ABSTRACT

Desert marshes, or cienegas, are extremely biodiverse habitats imperiled by anthropogenic demands for water and changing climates. Given their widespread loss and increased recognition, remarkably little is known about restoration techniques. In this study, we examine the effects of gabions (wire baskets filled with rocks used as dams) on vegetation in the Cienega San Bernardino, in the Arizona, Sonora portion of the US-Mexico border, using a remote-sensing analysis coupled with field data. The Normalized Difference Vegetation Index (NDVI), used here as a proxy for plant biomass, is compared at gabion and control sites over a 27-year period during the driest months (May/June). Over this period, green-up occurred at most sites where there were gabions and at a few of the control sites where gabions had not been constructed. When we statistically controlled for differences among sites in source area, stream order, elevation, and interannual winter rainfall, as well as comparisons of before and after the initiation of gabion construction, vegetation increased around gabions yet did not change (or decreased) where there were no gabions. We found that NDVI does not vary with precipitation inputs prior to construction of gabions but demonstrates a strong response to precipitation after the gabions are built. Field data describing plant cover, species richness, and species composition document increases from 2000 to 2012 and corroborate reestablished biomass at gabions. Our findings validate that gabions can be used to restore riparian vegetation and potentially ameliorate drought conditions in a desert cienega.

1. Introduction

Although wetlands represent a very small area of arid and semi-arid regions in North America, they contribute disproportionately to regional biodiversity because of their structural complexity and the surface water associated with them. Desert wetlands, called cienegas, occur where groundwater comes to the surface, usually fed by springs. Access to otherwise scarce surface water has resulted in a long and particularly close association between desert wetlands and humans. The largest pre-European settlements regularly burned them to plant crops and improve hunting (Davis et al., 2001). More recently, human impacts on wetlands have intensified as demands from livestock and on groundwater have risen to supply larger populations (Webb and Leake, 2006). If climate change predictions are realized, conservation challenges related to water management will be further exacerbated (Davies, 2010). There is a consensus that western North America will become hotter and drier in the near future (Seager et al., 2007), with some areas getting a more intense monsoon (Dominguez and Cañon, 2010). This leads to potentially more variable streamflow (Milly et al., 2008). As such, assessing different restoration approaches of wetland and riparian areas in arid and semi-arid regions for effectiveness is timely and important (Heller and Zavaleta, 2009; Gibbs, 2000).

The Mexican Highlands subarea, part of the Basin and Range physiographic province, extends about 275 km along the US-Mexico border (Woodard and Durall, 1996). A large percent of this overlaps with the Madrean Archipelago or Sky Island region, where unparalleled biodiversity exists (Omernik, 1987; Warshall,

* Corresponding author. Tel.: +1 5206705510.
E-mail address: lnorman@usgs.gov (L. Norman).

http://dx.doi.org/10.1016/j.ecoleng.2014.05.012
0925-8574/

1995; Skroch and Matt, 2008; Spector, 2002; Fig. 1). The broad valleys (basins) separated by steeply rising mountains (ranges) result in multiple independent hydrologic systems. Although predominately classified as "desert", this region is also known for its vegetation diversity, high-elevation forests and diverse freshwater ecosystems, many of which are remnants from when the area was wetter (Papoulias, 1997). In the early 1900s, overgrazing and prolonged drought resulted in near full appropriation of surface water in these aridlands, leaving augmentation dependent on groundwater supplies (Turner et al., 2003). The drawdown of groundwater has resulted in reduced stream- and spring-flow and a reduction in riparian habitat in the 21st century (Webb and Leake, 2006).

Precipitation in the Mexican Highland/Madrean Archipelago is strongly influenced by the North American Monsoon. During this late-summer period, short, intense rain events deliver more than half of the area's annual precipitation (Loik et al., 2004) and these sparse but high-intensity rainfall events generate overland flow and surface runoff that can lead to erosion of poorly-vegetated landscape. Arroyos are ephemeral creekbeds carved into the floodplain when erratic overland flow occurs (Betancourt et al., 1993). Arroyos drain river-bed marshes and change the natural flora and fauna by widening and deepening the channel (Schumm and Hadley, 1957; Vogt, 2003). When surface runoff is high, little recharge infiltrates to the basin aquifer, and high-intensity flow transports heavy sediment loads to channels, which contributes to nonpoint source pollution in surface water bodies. In wild lands, sediment is the primary pollutant in streams (Branson et al., 1981). Negative effects of accelerated erosion and sedimentation on water quality and on long-term site productivity have been well-documented in this region (Lopes and Ffolliott, 1992; Marsh, 1968).

Federal agencies, including the US Forest Service, National Park Service, Fish and Wildlife Service, Bureau of Land Management, and Department of Defense are major land managers in the US portion of the Mexican Highlands, endeavoring to sustain natural resources and engage in best management practices (Norman et al., 2008; Quijada-Mascareñas et al., 2012). Additionally, private ranch owners have identified the need to restore and maintain natural processes for diverse populations in the future (McDonald, 1995; Curtin, 2002; Sayre, 2005). One approach to conserve water from episodic rains is to install check dams, gabions, and trincheras. Trincheras, the Spanish word for trenches, are loose-rock structures, like riprap or one-rock dams that are used to line and stabilize channels and hillsides first developed by ancient cultures. Entire hillsides terraced by trincheras exist in the Mexican Highland region, with the earliest date of 1000 B.C. from just south at Cerro Juanaquena, Chihuahua (Herold, 1965; Anyon and Leblanc, 1985; Fish et al., 2013).

In this study, we examine the effects of structures similar to trincheras on vegetation in a riparian habitat of the Chihuahuan Desert. Wire-enclosed rock structures, or gabions, were placed in a channelized streambed to reduce water flow, and prevent and repair arroyo-cutting in a dryland cienega. A gabion is a stationary grouping of rocks encased in wire mesh, and like check dams, are used to slow water and reduce erosion in streams (Waterfall, 2004). These infrastructure detain water, sediment and debris, thus slowing runoff and allowing for infiltration and recharge. Sediment deposition raises the bed level behind the gabion, and is thought to facilitate the establishment of riparian vegetation. Gabion emplacement and vegetation are predicted to establish a positive feedback loop where vegetation will further reduce flow velocity and flooding, decrease erosion, and increase sediment deposition (Wischmeier and Smith, 1978). As a result, subsurface water recharge could be enhanced by gabions because of greater soil moisture storage capacity and infiltration rates of captured sediments (Kamber Engineering, 1990).

The efficacy of water control structures for rangeland restoration in the western U.S. is unclear. Hadley and McQueen (1961) showed that downstream from diversion structures on rangelands in Wyoming, peak flow was reduced and that sediments loads were diminished by up to 75%s. Peterson and Hadley (1960) surveyed nearly 200 erosion control structures on semiarid rangelands in the Upper Gila River basin, at the southern Arizona-New Mexico border, and found that vegetation did not change around these structures. Although they did not report the number of control structures that had breached, they concluded that expensive maintenance limits this practice. However, their study was conducted during and immediately after the most severe drought in the last century. Peterson and Branson (1962) evaluated Civilian Conservation Corps treatments from the 1930s, including earthen dams, spreaders, and rock check dams, finding that more than half of the structures had breached within a few years after construction but otherwise, vegetation cover was improved. Miller et al. (1969) concluded that water spreader structures in the western United States positively impacted vegetation if precipitation is more than 280 mm per year and have little or no effect on vegetation where annual precipitation is less than 203 mm. Baker et al. (1999) document positive results of restoration efforts from 1934 in the main channel the San Simon Valley cienega, Arizona, which included diversion dikes, spreaders, detention dams, gully plugs and seeding; they conclude that while side-channel structures are perceived as largely ineffective for restoration, they prevent further headcutting and reduce water velocities. Norman et al. (2010) modeled the use of gabions for reduced peak flows in Nogales, Sonora, Mexico, and Gass et al. (2013) found no impact of these on vegetation response. No studies have evaluated how gabions influence vegetation green up for desert marshland recovery.

Our research assesses vegetation changes around sites where gabions have been installed to restore a desert cienega on both sides of the US-Mexico border. Cienegas or desert marshlands are particularly rare habitats that support an estimated 19% of endangered, threatened and candidate species in this region (Minckley et al., 2013). We hypothesized that rock gabion structures would be related to increased water availability and soil moisture capacity resulting in a detectable green-up response in nearby vegetation. We used remote sensing data, which are commonly used to monitor ecological changes over large scales related to management activities (Mas, 1999; Pettorelli et al., 2005). Multispectral data have been used successfully to map and monitor riparian vegetation in arid environments (Nagler et al., 2001; Johansen and Stuart, 2006; Villarreal et al., 2012). Jones et al. (2008) evaluated changes in the pattern of greenness of riparian areas using satellite imagery in an area protected from grazing and development since 1988, and in a relatively unprotected area. They found that the protected area was greener and had larger, more continuous patches of positive change. Henshaw et al. (2013) demonstrated the capacity of remotely sensed data to enhance our understanding of interactions between fluvial processes and riparian vegetation, specifically using Landsat TM satellite data covering the last 30 years. Their study demonstrated these data provide a wealth of information that could support further biogeomorphological investigations in other large rivers.

To analyze changes in riparian vegetation related to watershed restoration efforts in the Mexican Highlands, we calculated the Normalized Difference Vegetation Index (NDVI) from a series of multitemporal Landsat Thematic Mapper (TM) images and sampled NDVI at areas with gabions. Comparisons were made before and after installation and also in relationship to areas randomly selected (controls) to isolate and quantify changes in vegetation greenness specifically resulting from gabion installation. We then