





## Article

# Assessing Riparian Vegetation Condition and Function in Disturbed Sites of the Arid Northwestern Mexico

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**Abstract:** Transformation or modification of vegetation distribution and structure in arid riparian ecosystems can lead to the loss of ecological function. Mexico has 101,500,000 ha of arid lands, however there is a general lack of information regarding how arid riparian ecosystems are being modified. To assess these modifications, we use eight sites in the San Miguel River (central Sonora) to analyze (1) riparian vegetation composition, structure and distribution using field sampling and remote sensing data from Unmanned Aerial Vehicles (UAV); (2) productivity (proxies), using vegetation indices derived from satellite data; and (3) variability posed by riparian vegetation and vegetation adjacent to riparian habitats. The development of a simple yet informative Anthropogenic-disturbance Index (ADI) allowed us to classify and describe each study site. We found sharp differences in vegetation composition and structure between sites due to the absence/presence of obligate-riparian species. We also report significant difference between *EVI* (Enhanced Vegetation Index) values for the dry season among vegetation types that develop near the edges of the river but differ in composition, suggesting that land cover changes from obligate-riparian to facultative-riparian species can lead to a loss in potential productivity. Finally, our tests suggest that sites with higher disturbance present lower photosynthetic activity.

**Keywords:** riparian ecosystems; Sonoran desert; remote sensing; land cover/land use

## 1. Introduction

It has been thoroughly documented that human activities, which modify water availability and promote drastic habitat modifications, have caused dramatic changes in riparian vegetation of arid ecosystems in the American southwest [1–4]. Due to the similarities between geographic and ecological conditions of this region and the Mexican northwest, it is reasonable to expect that the disturbance processes could be similar, although fewer studies of riparian ecosystems in the Mexican northwest have been conducted.

Water availability in the Mexican northwest is critical, since many of its watersheds and groundwater sources are overexploited, due to intensive use by economic activities such as agriculture and cattle ranching [5–7]. Moreover, previous work suggests that water management practices could potentially modify the structure and function of key ecosystems in arid environments [3,8–10]. In this sense, recent studies describe how groundwater depth restricts the establishment of riparian vegetation in watersheds located in arid environments of central Sonora (northwestern Mexico), particularly in

places where high levels of groundwater depth coincide with a denser distribution of agricultural wells [8]. Groundwater levels can also affect surface runoff, possibly narrowing the river channel; a negative correlation has been found between channel width and the percentage of agricultural land use along the river sides, in several rivers in Sonora [11]. Alteration of groundwater levels and surface runoff can prevent the establishment of obligate-riparian species such as *Salix gooddingii* and *Populus fremontii* [12], sometimes causing the complete loss of riparian vegetation or its replacement by drought tolerant desert species like *Prosopis* sp. or *Acacia* sp.; these changes in composition can have several consequences on the ecosystem: loss of local biodiversity [13], increase the susceptibility to invasive species [3,14], loss of riparian native corridors [15,16] and decrease in vegetation indices values [17].

Riparian ecosystems are often considered hotspots for ecosystem services [18–20]. In arid environments, this is evident since most economic, social and cultural activities are closely tied to this systems [21–23]. Therefore, riparian ecosystems in arid environments are highly dynamic in terms of changes on land use and land cover [24,25]. These changes often result in the modification of the structure and function of riparian vegetation due to active change (e.g., the clearing of riparian vegetation to establish agricultural areas) or changes introduced by constant pressure posed by human activities (e.g., Cattle Ranching) [11,26,27].

For arid environments, there is a lack of information regarding the assessment of disturbance, however, it is of utmost importance to understand how different disturbance-causing activities are changing riparian habitats in Sonora, and how these changes could be compromising the provision of ecosystem services. Since agriculture and cattle ranching are the main subsistence and commercial activities in the region and because these activities are registered to be the ones that cause the greatest changes in ecosystems all over the state [28,29], we consider them as playing an essential role when assessing disturbance in riparian habitats. Also, for a region with critical water availability issues it is important to have a better understanding of how human activities are changing riparian ecosystems, thus, the monitoring of different vegetation parameters and the generation of a disturb-based classification method can help assess the ecological condition of these ecosystems in Sonora.

Different remote sensing techniques can be used to identify areas where obligate-riparian vegetation is being transformed in terms of its composition, aerial images can be especially useful to discriminate vegetation types along rivers [30,31]; at the same time satellite image analysis can be used to derive vegetation indices [32–34] which can provide important information about the behavior of the ecosystem in terms of its productivity. Previous studies using remote sensing suggest a trend towards the modification of riparian vegetation, due to the establishment on facultative species in north western Mexico [8,35]. However, assessments using high spatial resolution imagery to evaluate the previous (using UAV's) are scarce.

The objective of the present study was to analyze disturbance and its effects on function and structure of riparian habitats in arid regions of northwestern Mexico. For the previous we explore the combined use of satellite imagery, Unmanned Aerial Vehicles (UAV) photography and field vegetation sampling to assess the differences and similarities within and between 8 disturbed sites along the San Miguel River in central Sonora. Also, we evaluated several characteristics of riparian vegetation and the adjacent desert scrub: composition, diversity, cover and photosynthetic activity (represented by the Enhanced Vegetation Index, *EVI*). Finally, we assessed the disturbance degree by the development and application of the ADI.

By following the suggested approach, we will be able to assess how disturbance at the local level affects riparian vegetation variables (composition, structure, diversity and cover) and how changes in these relate to shifts in function (photosynthesis) at the landscape level.

## 2. Materials and Methods

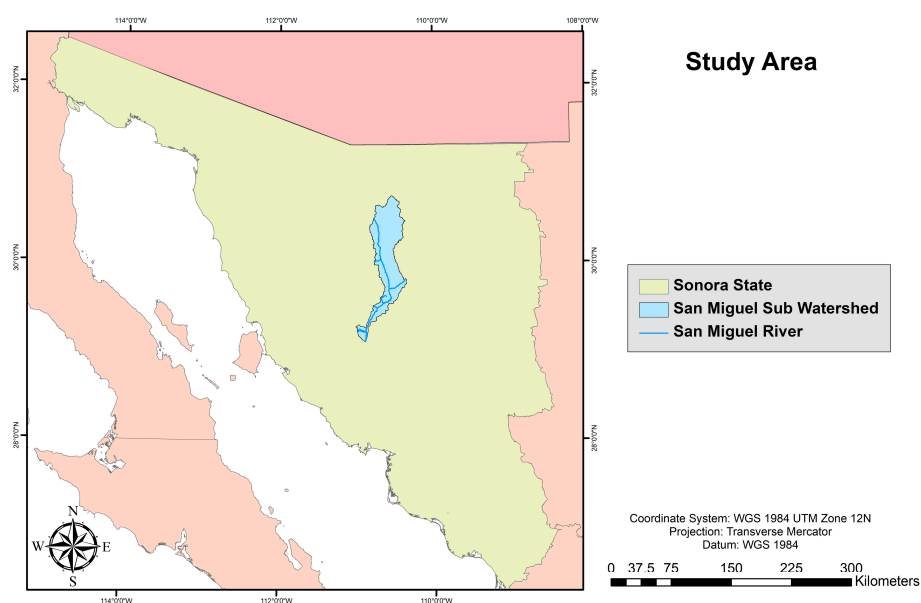
In order to assess disturbance of riparian habitats we developed specific qualitative parameters and applied them during site visits. Following this, we evaluated structure, composition and cover of

vegetation on different sites along the river by field sampling. To complement site description, we used aerial imagery to define which vegetation types were present in each site and determine plant cover. Finally, satellite imagery was used to derive the *EVI*.

## 2.1. Study Area

The San Miguel river (SMR) is located in the central part of the northern Mexican state of Sonora (Figure 1), between 30°45.75'N–29°6.5'N latitude and 111°4.11'W–110°21.1'W longitude and it is a sub watershed of the much larger Sonoran river watershed. It has an extension of 3845 km<sup>2</sup>. These two rivers (San Miguel and Sonora) are the main sources of water for the capital city of Hermosillo. The mean annual temperature is of 21 °C and the mean annual precipitation is of 421 mm. The 8 study sites are located along the San Miguel River, two in the northern part, two in the northern-central, two in the southern-central and two in the southern part. According to Shreve and Wiggins [36] classification, the SMR is located in the Plains of Sonora, which is designated as *Arbosuffrutescent Desert* and it is characterized by the presence of *Olneya tesota* trees and *Encelia farinosa* bushes. Classification made by the National Institute of Geography and Statistics establishes the following types of vegetation and land uses in the area: oak forest, oak-pine forest, microphyllous desert scrub, mesquite forest, xerophilous mesquite, subtropical scrub, native and introduced grasslands, riparian vegetation and agriculture. The main economic activities in the region are agriculture and cattle ranching. There is a total of 8266 hectares of irrigated lands, 75% of which correspond to forage production [21]. These activities have developed in the region over hundreds of years, however in the past decades, due to the technological advances and the intensive use of riparian habitat, the system has become very dynamic in terms of land cover shifts. On top of this, it has been reported that the SMR aquifer shows signs of overexploitation based on recharge-extraction analyses; official data reported an annual deficit of 1,500,000 m<sup>3</sup> [7], although the most recent update reports an availability of 17,508,107 m<sup>3</sup> [5], which arises some confusion and concern due to the fact that this last number was based on a 2008 hydrogeological study elaborated for a mining project. Given the above, riparian habitats show different scenarios where water availability has become an economical [22], social [21,23] and ecological [8,37] issue that needs to be addressed by managers and land owners.

The study sites were selected through satellite image observation and exploration field trips. Final selection was based on the presence of several land uses of interest: agriculture, livestock grazing, human settlements, roads, recreational activity and the presence of riparian vegetation.



**Figure 1.** Location of study area.

## 2.2. Disturbance Assessment

To establish the degree of disturbance on each site, we developed a series of qualitative criteria regarding (1) the intensity and type of human activities; (2) the state of the riparian vegetation; (3) the presence/absence of surface water. Classification of sites was made through applying the ADI, which evaluates the sites according to several criteria (Table 1). A number was assigned to indicate the presence, absence, evidence or intensity of the features observed: superficial water flow, *Populus* and/or *Salix* species, cattle, agriculture, roads and/or human settlements and recreational activity.

Although the San Miguel River is an intermittent river [38,39], superficial water flow can be continuous during rainy season. Average precipitation in the region during the sampling year was of 382 mm [40]. Since field sampling was done through the rainy season, superficial water flow was expected to be present and, thus, it was considered among the classification criteria. *Populus* and *Salix* species are particularly susceptible to groundwater fluctuations and their absence could be an indicator of groundwater scarcity. Livestock and agriculture are the most common economic activities in the area, so their presence and closeness to the river was considered for site classification. Human settlements and recreational activity can also be sources of disturbance so they were also considered for site classification.

The selection of the criteria used to develop this index is based on literature that evaluates human water use and its impacts on river flow in the American southwest; these studies report that overexploitation of rivers has caused a reduction in the presence of riparian trees such as *Populus fremontii* and *Salix gooddingii* [12,13]. Agriculture, livestock grazing, human settlements and recreational activity were also considered as criteria since these are the main disturbance types reported for riparian ecosystems [4,24,41]. Criteria selection and structure for the index was also based on the environmental condition of riparian areas, as a methodology reported by González and García [42]. The criteria and interpretation of the index values are explained on Tables 1 and 2.

**Table 1.** Criteria used to determine the ADI.

	Yes	VALUE	Little/Few	VALUE	No	VALUE
<b>Superficial water flow</b>	Continuous flow	1	Intermittent flow	2	Dry riverbed	3
<b>Presence of <i>Populus</i> and/or <i>Salix</i> species</b>	High frequency of these species	1	Lower frequency than other trees	2	Absence of these species	3
<b>Presence or evidence of cattle</b>	Absence of cattle	1	Evidence of grazing, feces, or buffel grass	2	Cattle was seen near or around the river	3
<b>Agriculture</b>	No agricultural areas were seen	1	Presence of agricultural areas smaller than 100 sq. meters	2	Agricultural areas less than 500 m from the river	3
<b>Roads and/or human settlements</b>	Study site located 500 m away from any road or house	1	Presence of roads but no houses	2	Houses and roads near the river	3
<b>Recreational activity</b>	No human presence or infrastructure	1	Human presence but no infrastructure	2	Evidence of human presence (parking places, grills, trash cans, trash)	3

**Table 2.** Interpretation of the ADI values.

ADI	Disturbance Category
6–8	Low: there's no observable evidence of anthropogenic disturbance. Superficial water flow is continuous (during rainy season); vegetation is dominated by obligate-riparian species.
9–11	Low-medium: there's an observable evidence of human activities in low intensity; vegetation is dominated by obligate-riparian species.
12–14	Intermediate: superficial water flow may be intermittent, human activities diversify; vegetation is characterized by the presence of facultative-riparian species along with obligate-riparian species.
15–17	Medium-high: superficial water flow is intermittent or the riverbed is dry, human activities diversify, absence of obligate-riparian species and dominance of non-riparian species.
18	High: dry riverbed, human activities intensify, absence of obligate-riparian species and dominance of non-riparian species.

### 2.3. Field Measurements and Derivation of Diversity Index

Vegetation description on each site was made through the registry and derivation of several variables (Table 3). Field sampling was done following the *relevé* method and protocol [43]. Two major vegetation types were sampled on each site (riparian vegetation and adjacent desert scrub), the purpose of this vegetation description was to compare the variation of several vegetation characteristics of riparian sites and of the adjacent desert scrub sites.

**Table 3.** Variables used for the vegetation description.

Variable	Description	How Was It Measured?
<b>Composition</b>	The list of species found in each stand.	Field identification and registry, herbarium identification.
<b>Cover</b>	Vertical crown or shoot-area projection for each vegetation strata (herbs, shrubs and trees) per plot.	Continuous (65%) = crown touching. Intermittent (30–64%) = interlocking or touching crowns interrupted by openings. Open (29%) = crowns not touching or infrequently touching.
<b>Richness</b>	Total number of species per stand (for tree and shrub strata only).	Count the different species present on each stand.
<b>Diversity</b>	Diversity of each stand (for tree and shrub strata only).	Represented by the Shannon-Weiner diversity index.
<b>Dominance</b>	Tree and shrub species with the highest number of individuals per stand.	Count the number of individuals per species.

Two sampling units (stands) were established on each site, one for riparian vegetation and another for the adjacent desert scrub located approximately 200 m from the first stand and in the opposite direction of the river, this distance was considered enough to go past the transition area between riparian vegetation and the adjacent desert vegetation. San Juan Ranch was the only site where desert scrub was not sampled, due to time and climate restrictions.

Field sampling consisted in identifying vegetation strata and registering composition and cover for each. First, a 30 × 30 m square was delineated, in which tree species were registered along with the number of individuals per species, cover was estimated for the whole tree strata. Then, a second square of 10 × 10 m was delineated inside the first one and shrub species, number of individuals and strata cover were registered. Finally, a third square of 1 × 1 m was delineated inside the second square and the number of different herbaceous species and strata cover were registered. Two repetitions were made, resulting in a 30 × 90 m (three repetitions per vegetation strata in each sample) stand with a total of 2700 sq. meters sampled for each vegetation type on each site.

For each sampling site we calculated diversity of the tree and shrub strata by the derivation of the Shannon-Weiner diversity index [44]. Diversity of the shrub and tree strata for each stand was estimated using the Shannon-Weiner diversity index:

$$H' = - \sum_{i=1}^s p_i \log_2 p_i$$

where  $S$  is the total number of species,  $p_i$  the proportion of individuals of each species based on the total of individuals ( $n_i/N$ ),  $n_i$  is the number of individuals of each species and  $N$  the total of all individuals of all species.

#### 2.4. Aerial Imagery Sampling and Mosaicking

Aerial imagery acquisition requires two processes. First, obtaining aerial images in the field and second, processing those images for the orthomosaic generation. A total of 13 flights were performed in the different study sites, using a UAV (Unmanned Aerial Vehicle). See Supplementary Materials for spatial and temporal specifications of each flight (Table S1). The following subsections describe the process of the image acquisition and orthomosaic generation.

##### 2.4.1. Aerial Imagery Sampling

For the acquisition of aerial images several flights were performed at each study site. See Supplementary Materials for flight requirements and image specifications (Table S2). All flights were performed during growing season (August, September and October 2016) with the purpose of recording vegetation cover at its greatest; and during the day (between 11 a.m. and 2 p.m.) to ensure appropriate light conditions.

##### 2.4.2. Mosaicking process

The image processing is based on pattern recognition, which establishes a relationship between a pattern (vector of features describing an object) and a class label; those features can be spectral reflectance, texture, emittance values from optical imagery, or geographical features and the object can be a single pixel or a set of adjacent pixels forming a geographical entity [45].

The mosaicking process is performed by photogrammetry software. The process consists on finding common points (keypoints) between the images. When the same keypoint is found on 2 different images they are matched and this will generate a 3D point (Pix4D). These 3D points are needed to generate a Point Cloud from which a Digital Surface Model and an Orthomosaic will derive. This process requires a high overlap between images, which in most cases is at least 75% (Pix4D).

Since the UAV has a built-in GPS, all images taken were automatically georeferenced and no ground control points were needed. Georeferenced images from each flight were added to the photogrammetry software for the stitching process, resulting in a total of 13 orthomosaics with an approximate area of 5 hectares each. The spatial resolution expected from the orthomosaic is of 3 cm.

#### 2.5. Satellite Imagery

Satellite data was obtained as a land surface reflectance (LASRC) from the Landsat 8 OLI (Operational Land Imager)/TIRS (Thermal Infrared Sensors) Pre-Collection L1T data type, directly from the United States Geological Survey 'Earth Explorer' website; these products are radiometrically calibrated and orthorectified using ground control points and digital elevation model data to correct for relief displacement [46]. Landsat 8 data includes 11 bands, from which 7 of them (1–7) were selected and processed in ERDAS IMAGINE 9.2 to create the final stack. Bands 8, 9, 10 and 11 were not used.

Since the study area comprises two Landsat 8 scenes and because we wanted to compare photosynthetic activity variations between two seasons, a total of 4 scenes were chosen for two different dates on 2016: May and September. See Supplementary Materials for scene specifications (Table S3).

The vegetation index was derived for the complete four scenes but the only pixels involved in the analysis were those corresponding to the digitalized areas from the orthomosaics, obtained from the UAV analysis previously described.



## 2.6. Vegetation Index Derivation

Vegetation indices (VI) are designed based on the spectral response to light of each type of vegetation; this is how indices can provide qualitative and quantitative measurements that can be used to describe photosynthetic activity, structure characteristics and canopy density, among other variables [47,48]. As explained by the previous references, several VI have been related to structural aspects of vegetation, such as Leaf Area Index (LAI); this parameter is related to the amount of available photosynthesizing biomass. The previous can be used as a theoretical basis to derive Net Primary Production from satellite data, as explained by Running et al. [49].

The Normalized Difference Vegetation Index (NDVI) is commonly used in arid regions because of their strong seasonality change but when vegetation density increases during the growth season NDVI can reflect high values with very little variation, which can be interpreted as a spectral signal saturation [50]. Thus, another vegetation index was selected for this study, the Enhanced Vegetation Index (EVI), which presents higher sensitivity in areas where vegetation is dense and it is less prone to light saturation.

Enhanced Vegetation Index (EVI) is derived by using the following equation:

$$EVI = G \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + C_1 \times \rho_{red} - C_2 \times \rho_{blue} + L}$$

where  $\rho$  is the surface reflectance with atmospheric correction,  $L$  is the canopy background adjustment;  $C_1$  and  $C_2$  are the aerosol resistance coefficients, as described by [50].

EVI values range from 0 to 1, those closer to 1 indicate a greater density and photosynthetic activity of vegetation, those closer to 0 indicate vegetation is scarce or less productive. Although EVI values do not reflect a direct amount of Net Primary Productivity, it is considered as an accurate measure of photosynthetic activity, which is related to the amount of biomass.

## 2.7. Land Cover Assessment

Once obtained, we used orthomosaics to identify the different vegetation types in the sample areas. Our class scheme (Table 4) was developed using observations from the field (regarding community composition and stand physiognomy) and previous classification studies conducted in the area [8]. In order to simplify the classification scheme, all desert vegetation types adjacent to the river is referred to as “Desert Scrub”, even though the formal designation for the Plains of Sonora region (as described by Shreve and Wiggins 1964 classification) is *Arbosuffrutescent Desert*.

Division of riparian classes (Riparian Vegetation and Riparian Mesquite Woodland) is based mainly on the differences in composition between two classes. Considering that Riparian Vegetation is composed mainly by obligate-riparian species and Riparian Mesquite Woodland by facultative-riparian species [51].

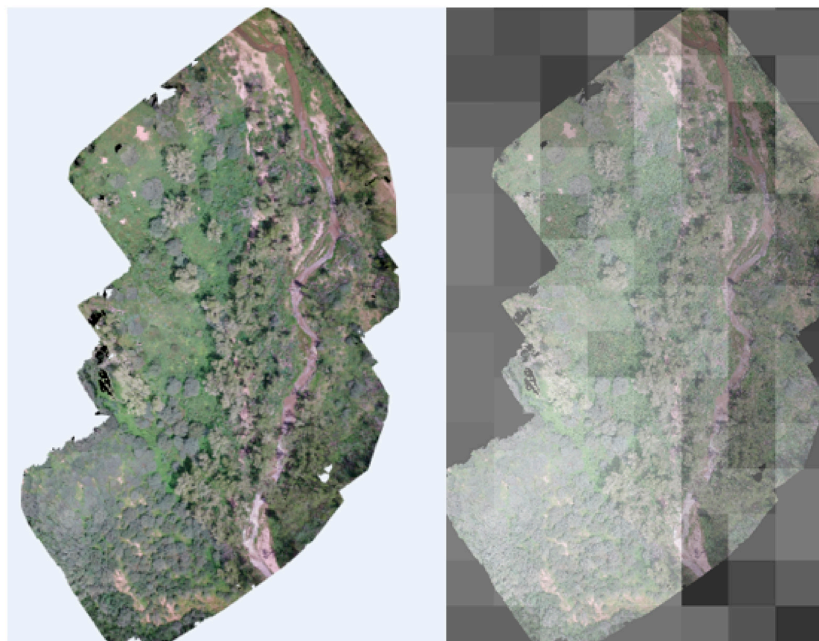
Land cover distinction was done through field observation and comparing the field sampling sites with what was shown on the orthomosaic, thus the field sampling sites served as ground control points. Differentiation between land cover types, on the aerial photography was possible through (1) extensive training on the field and (2) training on the analysis and management of each orthomosaic generated. Therefore, our land cover classification was conducted via “heads up digitizing” analysis through expert knowledge. Some of the main elements of photo interpretation used for this analysis were: color (different tree species vary in color), cover (e.g., riparian mesquite woodland tends to be denser than riparian vegetation), distribution, frequency and pattern (e.g., bare ground patches dominated by columnar cacti like *Stenocereus thurberi* and *Lophocereus schottii*).

**Table 4.** Land cover descriptions.

Land Cover Class	Description	Literature
Riparian Vegetation	The most important tree species found in riparian ecosystems in Sonora are <i>Salix goodingii</i> and <i>S. bonplandiana</i> , <i>Prosopis velutina</i> and <i>Populus fremontii</i> . Common shrubs include <i>Baccharis salicifolia</i> , <i>Hymenoclea monogyra</i> , <i>Acacia constricta</i> and <i>A. farnesiana</i> , <i>Celtis pallida</i> , <i>Nicotiana glauca</i> .	Scott et al. 2009 [11]
Riparian Mesquite Woodland	Common vegetation found on streamways includes <i>Prosopis</i> , <i>Parkinsonia florida</i> , <i>Olneya</i> , <i>Acacia greggii</i> and <i>Acacia occidentalis</i> . Common shrubs include <i>Celtis pallida</i> , <i>Baccharis sarothroides</i> and <i>Lycium</i> .	Shreve and Wiggins, 1964 [36]
Desert Scrub	Open scrubland with small, low-branching trees, with irregular colonies of shrubs and widely spaced columnar cacti ( <i>Stenocereus thurberi</i> , <i>Lophocereus schottii</i> ). <i>Parkinsonia</i> , <i>Olneya</i> and <i>Prosopis</i> find their optimum conditions, alternated with colonies of <i>Larrea</i> . Common shrubs include <i>Phaulothamnus spinescens</i> , <i>Mimosa laxiflora</i> and <i>Celtis pallida</i> .	Shreve and Wiggins, 1964 [36]
Herbaceous cover	This cover was considered as an independent class, due to the amount of cover variation between seasons, which has a considerable influence on EVI values.	All herbaceous cover identified from the orthomosaic was integrated in this class.

### 2.8. Cover Estimations from the Combination of Aerial and Satellite Imagery

Cover estimations were derived from each orthomosaic. Orthomosaics were displayed on top of the satellite scenes (Figure 2) and the image pixel was used as the measuring unit for the vegetation types seen on the orthomosaic, thus, every orthomosaic was divided in a grid of  $30 \times 30$  m cells. Orthomosaic area selection consisted in selecting those pixels with more than 90% of visible coverage and excluding pixels with more than 10% of visual errors such as dark parts (generally pixels at the edges of the mosaic) or pixels with too much shadow.



**Figure 2.** Left: Orthomosaic showing the river section in Galera site. Right: Image showing the over-positioning of orthomosaic on Landsat scene, each square represents a Landsat pixel.

Estimations were made for each of the 900 square meter Landsat 8 pixels by direct digitalization using GIS, starting in the inferior left corner of each pixel and continuing clockwise. Measures were registered for each vegetation type found on each pixel and then added to have a total sum for each cover class; this sum was converted into a percentage based on the total area used for digitalization.



### 2.9. Photosynthesis Analysis on Land Cover Classes

Using *EVI* values as a variable for vegetation function, a comparison was made among all land cover classes, among particular land cover classes of interest and between photosynthetic activity and disturbance. *EVI* values were selected as described below.

Each pixel of the Landsat 8 scenes has a unique *EVI* value. The interposition of the orthomosaic over the Landsat scene allowed us to discern the vegetation types of each pixel, thus having a precise distinction of the photosynthetic activity for each class, which facilitated its comparison. Not all pixels of the orthomosaics were used for the photosynthesis analysis, only those where the land cover class covered more than 50% of the pixel. This pixel selection was done to guarantee that the photosynthetic activity signal corresponds to a dominant land cover class.

#### 2.9.1. Seasonal Photosynthetic Activity per Land Cover Class

Photosynthetic activity variation within each vegetation type was analyzed in order to determine if there's a significant difference among them. *EVI* values for both seasons (May and September) and for each land cover class were selected and residuals for change were obtained by subtracting May *EVI* values from September *EVI* values. A Kruskal-Wallis test was applied to the residues of each land cover class. This analysis was applied to all land cover classes present in all of the study sites.

#### 2.9.2. Photosynthetic Activity of Riparian Vegetation and Riparian Mesquite Woodland

The first step for this analysis was to identify which sites represented Riparian Vegetation and Riparian Mesquite Woodland along the edge of the river. The objective is to compare the physiological response (measured as photosynthetic activity) of two land cover classes that develop in the same area and supposedly have the same resource availability (in this case, water).

In order to assess the differences in photosynthetic activity between the two riparian land cover classes (Riparian Vegetation and Riparian Mesquite Woodland), *EVI* values for both seasons (May and September) were selected and analyzed using two Mann-Whitney tests for each site, one for May-data and another for September-data.

#### 2.9.3. Photosynthetic Activity and Disturbance

Photosynthetic activity represented by the vegetation index is an important parameter to assess vegetation condition. Thus, it is important to know how this parameter varies in relation to disturbance.

Since the ADI was applied to evaluate the condition of riparian sites, this analysis only includes data from land cover classes developed near the river (Riparian Vegetation and Riparian Mesquite Woodland). In order to establish if there's a relation between photosynthetic activity values of riparian vegetation and disturbance, a linear regression was applied between *EVI* average values for September and the ADI values for each site.

## 3. Results

### 3.1. Site Classification According to the ADI

Results of the Anthropogenic-disturbance Index application are presented on Table 5. Distribution and ranking of study sites are presented on Figure 3.

**Table 5.** Criteria intensity (Y yes, L/F low or few, N no) registered on each site for derivation of the Anthropogenic-disturbance Index.

	Superficial Water Flow			Presence of <i>Populus</i> and/or <i>Salix</i> Species			Presence or Evidence of Cattle			Agriculture			Roads and/or Human Settlements			Recreational Activity			ADI	Disturbance Category
	Y	L/F	N	Y	L/F	N	Y	L/F	N	Y	L/F	N	Y	L/F	N	Y	L/F	N		
Aguilar Ranch	X			X				X		X			X					X	11	Low-medium
Cienega		X			X		X					X	X					X	12	Intermediate
Living Fences	X			X			X			X			X					X	12	Intermediate
El Cajon	X					X	X			X			X			X			16	Medium-high
Nogalera			X			X		X		X			X					X	15	Medium-high
Galera	X			X				X		X			X					X	11	Low-medium
San Juan Ranch	X			X				X			X		X					X	10	Low-medium
Tomas Ranch	X			X				X			X		X					X	10	Low-medium

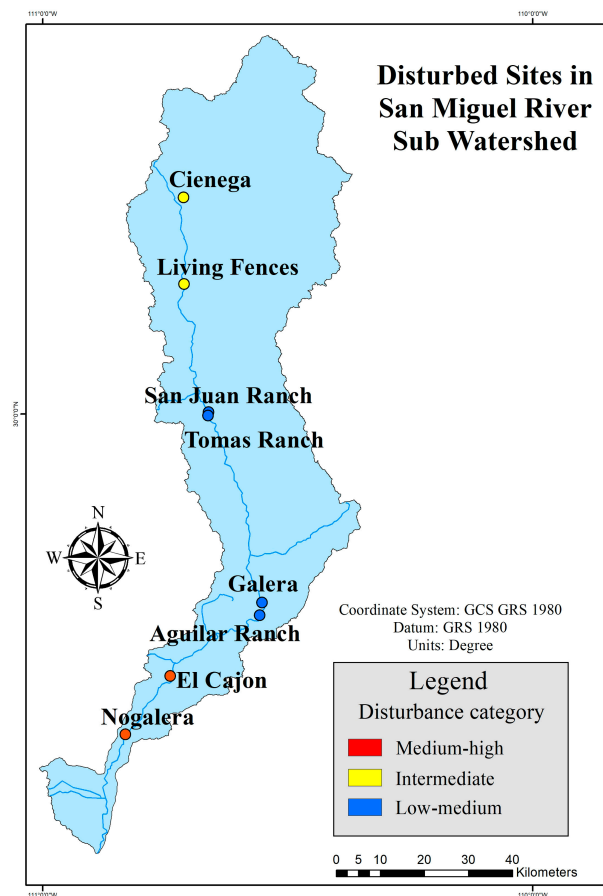


Figure 3. Distribution of sites along the sub watershed.

The two northern sites have an intermediate level of disturbance—they are approximately at a 10 km distance from the largest town (Cucurpe) and share the presence of cattle near the river. Both sites present some type of management. Cienega stands out due to the presence of cattle all over the site. On the other hand, the Living Fences site presents living fence rows made of *Salix* and *Populus* species in several river sections of the site, all of them in different stages of growth.

All central sites present the lowest level of disturbance, low-medium, which was unexpected because most of the sites are ranches where different types of management are definitely present. In spite of this, the vegetation on these sites did not show signs of great disturbance, their main common characteristics are: the presence and dominance of obligate-riparian species such as *Populus fremontii* and *Salix gooddingii*, the presence of a constant superficial water flow and the absence of recreational activities.

The two southern sites are the ones with the highest level of disturbance (Cajon and Nogalera) and have certain similarities such as the absence of obligate-riparian trees and the presence of at least three human activities developed around the river. Commercial agricultural activity in Nogalera stands out, due to the presence of extensive pecan tree (probably *Carya illinoensis*) fields about 500 m away from the river. El Cajon stands out due to the presence of intense recreational activity.

### 3.2. Cover, Composition and Diversity from Field Estimations

Field measurements are presented for Riparian Vegetation and Desert Scrub stands on each site. Cover is presented as a percentage and it was estimated for each vegetation strata (herbs, shrubs and trees). Composition was determined for the bush and tree strata on each site. Diversity was derived from field data applying the Shannon-Wiener diversity index.

### 3.2.1. Vegetation Strata Cover for Riparian Vegetation and Desert Scrub Stands

Riparian Vegetation in all sites shows an herbaceous cover of 50% or more, this can be due to the fact that field sampling was done during the growing season. Shrub cover is variable among all sites, the lowest percentages in Aguilar Ranch, Cienega and San Juan Ranch can be due to the constant presence of cattle and the negative effect it has on shrubs [4,11,26,52–55]. Trees cover more than 30% of the area in most sites (Figure 4), which indicates certain stability among the canopy. Although tree composition in all sites varies, canopy stability is important to maintain riparian habitat conditions.

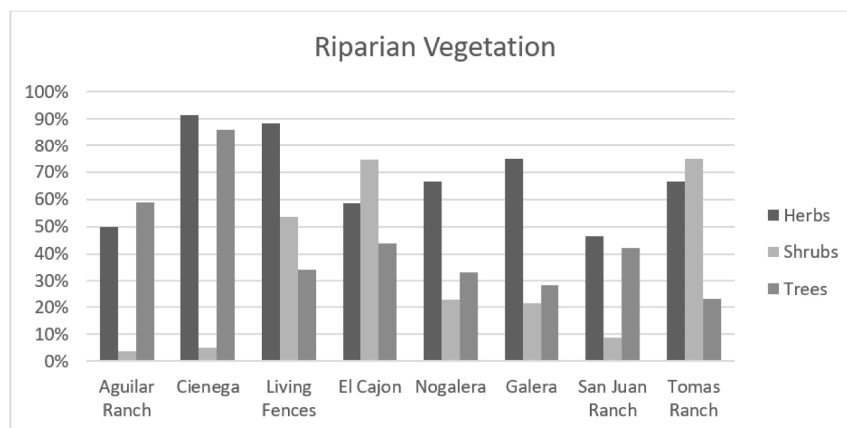


Figure 4. Cover percentage for vegetation strata on the riparian vegetation stands.

Desert Scrub cover (Figure 5) varies greatly among sites, this makes sense given the distinct terrain characteristics of each site. The two most disturbed sites (El Cajon and Nogalera) differ greatly in herbaceous and shrub cover. Shrubs have the highest cover in El Cajon (sampling site was a rocky hill) and the lowest in Nogalera (sampling site was a plain). Herbaceous cover on the Nogalera site stands out as the highest of all sites. Tree strata is higher in the northern site Cienega (63%) and lowest in the other northern site Living Fences (7%), sampling stand in this last site was a steep rocky hill. In contrast with riparian sites, covers for desert scrub are considerably low.

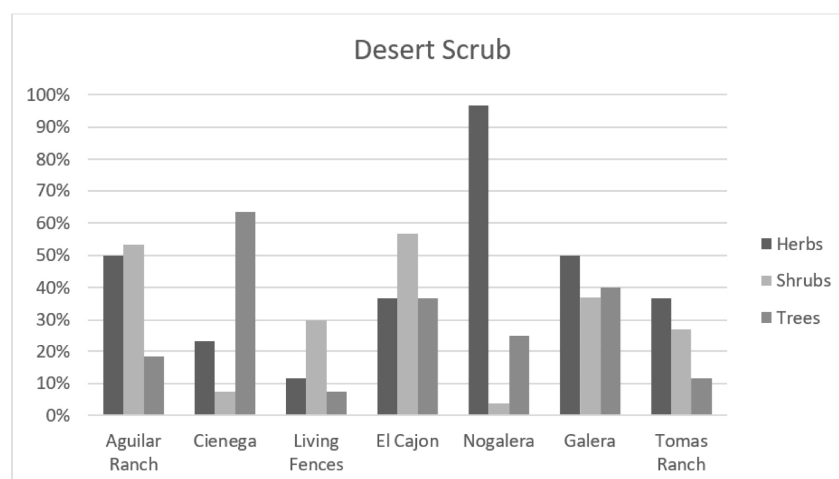


Figure 5. Cover percentage for vegetation strata on the desert scrub stands.

### 3.2.2. Shrub and Tree Composition for Riparian Vegetation and Desert Scrub Stands

Riparian Vegetation stands represented a dominance of obligate-riparian trees such as *Populus fremontii*, *Fraxinus velutina* and *Salix gooddingii*, for sites Aguilar Ranch, Cienega, Living Fences,

Galera, San Juan Ranch and Tomas Ranch (Table 5). El Cajon and Nogalera sites were dominated by facultative-riparian and non-riparian tree species such as *Prosopis velutina* and *Parkinsonia florida*.

The bush strata in half of the sites were dominated by naturalized/disturb-indicator species such as *Ricinus communis* and *Nicotiana glauca* (Table 6). It is important to note that buffel grass (*Cenchrus ciliaris*) was present in both southern sites, very close to the river, in low frequency but higher in Nogalera than in Cajon. Nogalera site was the only site where a desert tree (*Parkinsonia florida*) presented the highest number of individuals in the Riparian Vegetation stand, other Desert Scrub species were also found near the dry riverbed such as *Cylindropuntia leptocaulis* and *Lophocereus schottii*, although in low frequency.

Desert Scrub stands are dominated by facultative-riparian and desert species (Table 7). Some bushes such as *Celtis pallida* share their distribution between stands and are found along almost every site.

Facultative-riparian tree *Prosopis velutina* was the most common tree found in both the riparian and desert habitats, most of the time having a higher number of individuals on the Desert Scrub stands, except for sites El Cajon and Nogalera, where mesquite trees were present in a much higher frequency in the Riparian Vegetation stands than in the Desert Scrub stands.



**Table 6.** Dominant bush and tree species by number of individuals in Riparian Vegetation stands for each site.

	Aguilar Ranch	Cienega	Living Fences	El Cajon	Nogalera	Galera	San Juan Ranch	Tomas Ranch
<b>Bushes</b>	<i>Ricinus communis</i> <i>Baccharis salicifolia</i>	<i>Celtis pallida</i>	<i>Baccharis salicifolia</i> <i>Nicotiana glauca</i>	<i>Celtis pallida</i> <i>Vallesia glabra</i>	<i>Lycium berlandieri</i>	<i>Ricinus communis</i> <i>Nicotiana glauca</i> <i>Ambrosia ambrosioides</i>	<i>Nicotiana glauca</i> <i>Baccharis salicifolia</i> <i>Ricinus communis</i>	<i>Baccharis salicifolia</i>
<b>Trees</b>	<i>Populus fremontii</i> <i>Prosopis velutina</i> <i>Acacia farnesiana</i>	<i>Fraxinus velutina</i>	<i>Salix gooddingii</i>	<i>Prosopis velutina</i>	<i>Parkinsonia florida</i> <i>Prosopis velutina</i>	<i>Populus fremontii</i> <i>Parkinsonia aculeata</i>	<i>Salix gooddingii</i>	<i>Salix gooddingii</i>

**Table 7.** Dominant bush and tree species by number of individuals in Desert Scrub stands for each site.

	Aguilar Ranch	Cienega	Living Fences	El Cajon	Nogalera	Galera	San Juan Ranch	Tomas Ranch
<b>Bushes</b>	<i>Celtis pallida</i>	<i>Lycium berlandieri</i> <i>Celtis pallida</i>	<i>Mimosa laxiflora</i>	<i>Mimosa laxiflora</i>	<i>Jathropha cardiophylla</i>	<i>Celtis pallida</i>	n/a	<i>Celtis pallida</i>
<b>Trees</b>	<i>Prosopis velutina</i>	<i>Prosopis velutina</i>	<i>Prosopis velutina</i>	<i>Stenocereus thurberi</i> <i>Olneya tesota</i>	<i>Olneya tesota</i> <i>Parkinsonia florida</i>	<i>Prosopis velutina</i>	n/a	<i>Prosopis velutina</i>

### 3.2.3. Shrub and Tree Diversity and Richness for Riparian Vegetation and Desert Scrub Stands

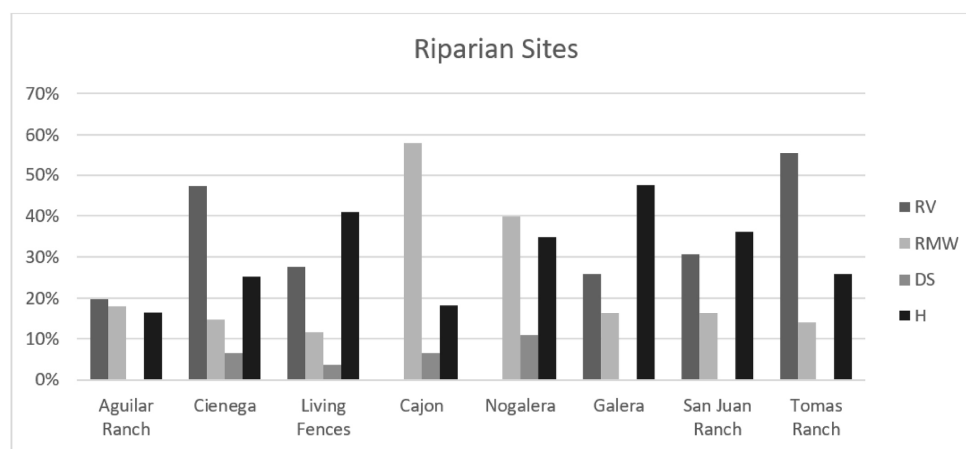
Shannon-Weiner diversity index results (Table 8) shows that, for Riparian Vegetation, one of the least disturbed sites (Galera) has the higher value and one of the intermediate disturbed sites (Cienega) has the lowest value. In general, half of the sites had higher diversity values for the Desert Scrub and the other half had higher diversity values for Riparian Vegetation. Both of the southern sites (El Cajon and Nogalera) present high levels of shrubs and trees diversity.

**Table 8.** Shannon-Weiner diversity index and richness values for Riparian Vegetation and Desert Scrub stands, for each site (shrubs and trees).

	Riparian Vegetation		Desert Scrub	
	Shannon-Weiner Diversity Index	Richness	Shannon-Weiner Diversity Index	Richness
Aguilar Ranch	1.5821	8	1.6510	11
Cienega	0.4957	4	1.1365	9
Living Fences	1.8725	13	1.8230	11
El Cajon	1.8535	11	1.7179	7
Nogalera	1.3557	12	1.9141	14
Galera	1.9389	11	0.9598	7
San Juan Ranch	1.8029	11		
Tomas Ranch	0.5909	3	1.0350	11

### 3.3. Land Cover Assessment from Aerial Imagery

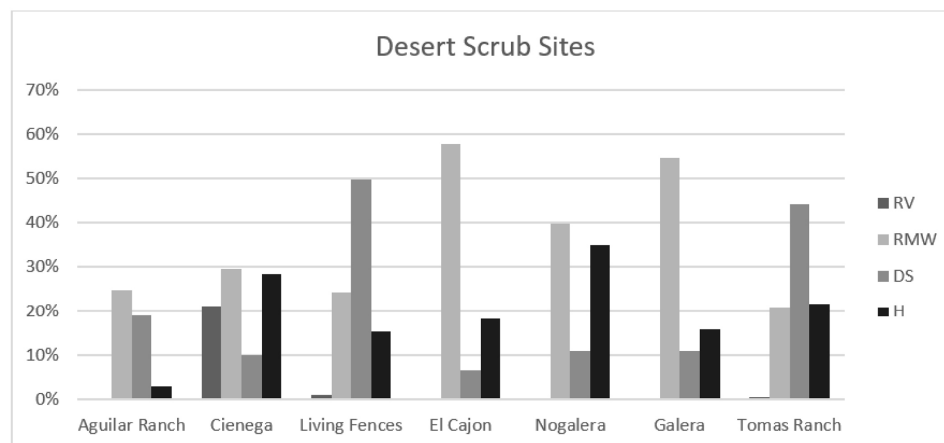
A total of 15 orthomosaics were derived from UAV flights, 8 correspond to Riparian Vegetation sites and 7 to Desert Scrub sites (Figures 6 and 7).



**Figure 6.** Cover percentage for Land Cover Classes for each site, derived from orthomosaics of Riparian sites. RV (Riparian Vegetation), RMW (Riparian Mesquite Woodland), DS (Desert Scrub), H (Herbaceous cover).

Tomas Ranch has the highest cover of riparian vegetation, which may include trees as well as shrubs and when compared with field measurements it can be established that most of the riparian vegetation in this site is represented by shrubs. Cienega is the next site with the highest cover of riparian vegetation, which is dominated mostly by ash trees (*Fraxinus velutina*). Aguilar Ranch stands out to be the site with less vegetation coverage for all land cover classes, this could be due to the closeness of agriculture fields to the riparian study site. Cajon and Nogalera sites differ from the rest of the sites because riparian vegetation here is represented by mesquite woodland. Cajon has the highest cover of Riparian Mesquite Woodland and most of it is composed by shrubs. This high percentage of cover could be related to the physiography of the place, since its surrounded by low hills which could

lower species dissemination to adjacent places and promote species gathering in the same area [44], this could also explain the high richness and diversity of this site. The high percentages of herbaceous cover also mean there are more open spaces between the canopy, along with the fact that none of the classes cover more than 60% of the terrain, this can be a sign of landscape modifications and species dominance shifts [56].



**Figure 7.** Cover percentage for Land Cover Classes for each site, derived from orthomosaics of Desert Scrub sites. RV (Riparian Vegetation), RMW (Riparian Mesquite Woodland), DS (Desert Scrub), H (Herbaceous cover).

Living Fences and Tomas Ranch have the highest cover for Desert Scrub class. The steep hill where Desert Scrub was sampled in Living Fences site can be a cause of its cover reaching 50%, preventing the place to have continuous disturbance such as the one caused by cattle, since it would not be as easy to graze on the hills as it is on flatter terrains. Even though disturbance was not assessed on the Desert Scrub sites, in some places management practices were evident, such as in Tomas Ranch, where half of the site was covered with buffel grass, which comprises at least half of the Desert Scrub cover percentage.

### 3.4. Photosynthetic Activity Analysis

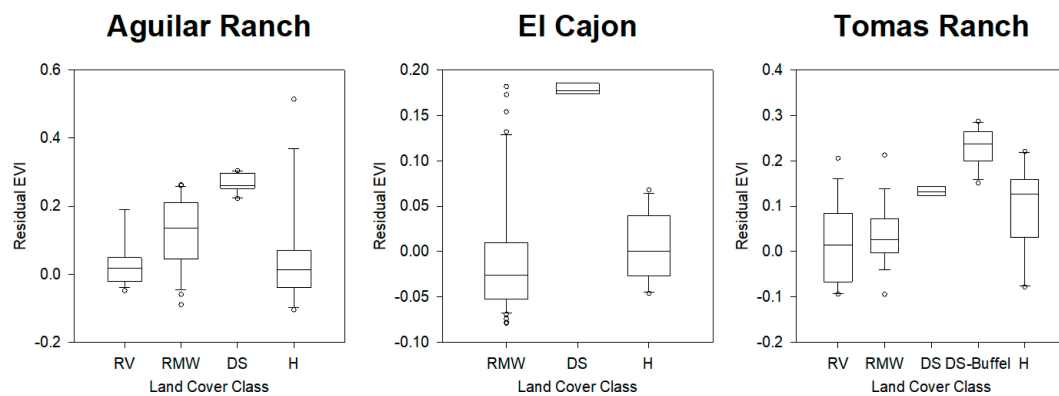
#### 3.4.1. Seasonal Photosynthetic Activity per Vegetation Type

The analysis of variance performed with the residual *EVI* values of May and September shows a clear seasonal difference between the Desert Scrub class and the rest of the cover classes and minor differences among the other classes (Riparian Vegetation, Riparian Mesquite Woodland and Herbaceous Cover), this could be due the relative stability of water availability for riparian vegetation and the opposite for desert scrub, thus showing a drastic increase on photosynthetic activity during the rainy season in some of our sites (Figure 8).

Desert Scrub class values in Aguilar Ranch show to be higher than any other class, meaning that this class has a higher seasonal variation. Riparian Vegetation and Herbaceous cover show the lowest residual values, indicating a low seasonal variation in its photosynthetic activity.

Desert Scrub residual values indicate a strong seasonal photosynthetic response. The other two classes present values lower than zero indicating that May's photosynthetic activity is higher or similar to September's photosynthetic activity.

Desert Scrub and Herbaceous residual values are the highest in this site, indicating a higher seasonal variation than the other classes. Riparian Vegetation shows values below zero, indicating that in some cases May's photosynthetic activity is higher or similar to September's photosynthetic activity.



**Figure 8.** Differences among residual values of each land cover class in Aguilar Ranch, El Cajon and Tomas Ranch. RV (Riparian Vegetation), RMW (Riparian Mesquite Woodland), DS (Desert Scrub), H (Herbaceous cover). Aguilar Ranch:  $H = 28.23$ ,  $P \leq 0.001$ ,  $N = RV(16)$   $RMW(24)$   $DS(11)$   $H(13)$ . El Cajon:  $H = 14.76$ ,  $P \leq 0.001$ ,  $N = RMW(44)$   $DS(5)$   $H(14)$ . Tomas Ranch:  $H = 33$ ,  $P \leq 0.001$ ,  $N = VR(17)$   $MR(15)$   $MD(5)$   $MD-Buffer(11)$   $HE(17)$ .

### 3.4.2. Photosynthetic Activity of Riparian Vegetation and Riparian Mesquite Woodland

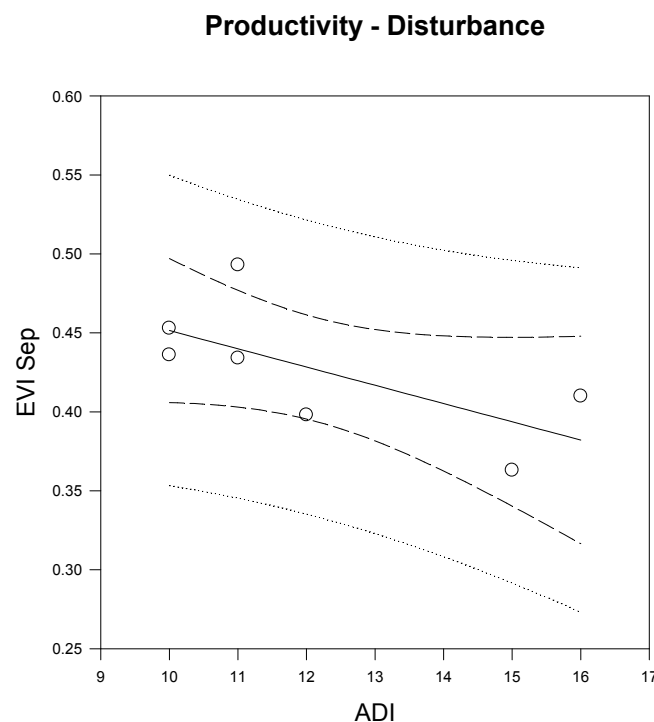
There were five sites with Riparian Vegetation and Riparian Mesquite Woodland present along the edges of the river. September *EVI* values show no significant difference for most of the sites but two (San Juan Ranch and Tomas Ranch). These two sites are ranches close to each other, they have a low-medium disturbance and riparian tree species are dominant in both. On the other hand, May *EVI* values show a significant difference between the two classes on four of the sites, with Riparian Vegetation maintaining higher photosynthetic activity than Riparian Mesquite Woodland (Table 9). This suggests that even when Riparian Mesquite Woodland establishes near the river it stills requires having precipitation to maintain photosynthetic activity values similar to those of Riparian Vegetation.

**Table 9.** *EVI* averages for May and September for sites with Riparian Vegetation (RV) and Riparian Mesquite Woodland (RMW). Significance level ( $P$ ). Values with \* show a significant difference.

	<i>EVI-May</i>		$P$	<i>EVI-September</i>		$P$
	RV	RMW		RV	RMW	
<b>Aguilar Ranch</b>	0.408	0.372	0.132	0.432	0.408	0.228
<b>Living Fences</b>	0.364	0.221	0.003 *	0.361	0.425	0.145
<b>Galera</b>	0.364	0.406	0.009 *	0.484	0.469	0.132
<b>San Juan Ranch</b>	0.330	0.201	0.001 *	0.456	0.349	0.001 *
<b>Tomas Ranch</b>	0.388	0.211	0.008 *	0.436	0.354	0.001 *

### 3.4.3. Photosynthetic Activity and Disturbance

We performed a correlation analysis between *EVI* and *ADI* values of seven of our sites (we exclude Cienega since it presented unique conditions). Our finding suggests that disturbance, as measured by the *ADI*, could partially predict photosynthetic activity of a site (estimated by *EVI*) (Figure 9). Productivity decline in riparian ecosystems has been reported as one of the main consequences of disturbance caused by human activities, such as water deviation, agriculture, raise-cattle and mining [4,20,41]. More specifically, vegetation indices such as *NDVI* and *EVI* have been found to have a relationship with many climatic variables and also with surface and groundwater levels, finding that, in many cases, the indices decline with deeper levels of groundwater and with decreased flood flows [17,57].



**Figure 9.** EVI-September values of Riparian Vegetation relation with the Anthropogenic Disturb Index (ADI).  $R^2 = 0.448$ ,  $P = 0.100$ .

## 4. Discussion

### 4.1. Disturbance in the SMR Watershed

There is no previous study in the SMR that analyses disturbance in riparian ecosystems. Previous land use and vegetation classification studies in the area have found that agriculture and cattle ranching are the activities that contribute the most to land cover dynamics [8], which is consistent with the present study given that those activities were present in all of the study sites and are determinant to the disturbance degree of riparian habitats. Different indices that evaluate ecological parameters in riparian habitats have been used in many places in Mexico [15,58–60], all of them use vegetation parameters such as composition, cover and species density to estimate riparian habitat condition. The ADI proposed in this study includes composition and human activities mainly but not cover. Even though cover is not included in the ADI, our results show that this parameter could be related to disturbance.

The Riparian Quality Index (RQI) developed by Gonzalez and Garcia [42] uses several vegetation characteristics (e.g., continuity, regeneration and composition) and hydro-morphological factors to evaluate the ecological condition of rivers, even though this index was designed for a particular European riparian environment, most of its elements can be used in other environments. Even though the ADI shares some similarities with the RQI, our main focus is the assessment of disturbance to evaluate the ecological condition of rivers.

Distribution of disturbed sites along the river shows that those with the highest ADI are located in the south, closer to the city of Hermosillo. These results are consistent with previous studies [23] that demonstrate how peri-urban communities experience changes in land use due to urban water transfer, these changes include the loss of agricultural land and habitat transformations due to recreational sites establishment. The two most disturbed sites in the present study (El Cajon and Nogalera) have been modified by non-typical activities for the region: commercial agriculture and the other is recreational activity. These activities require a different management and resource administration compared to



other more traditional activities (such as subsistence agriculture). Therefore, ecological modification of the riparian habitat by either of the activities mentioned could represent new scenarios for local people.

Sites located in the central part of the sub watershed have a low-medium disturbance, most of them are ranches. This stands out due to the fact that ranches are places with frequent human presence and most of the times include some type of resource management. In this case, it could be that the effect of disturbance is not so strong due to the relatively small size of the ranches, where human activities are present but not necessarily intense.

The northern sites present an intermediate disturbance degree; they both include some type of management. In the case of Cienega there's an intense presence of cattle, which could be related to the low shrub cover in both Riparian and Desert habitats, which was less than 10% in both cases. Living Fences site stands out due to the presence of cottonwood and willow fences along the edges of the river, it is important to notice that most of the riparian tree cover was composed by these living fences, that is, almost no other riparian trees were found that were not managed. These living fences are a main characteristic of the traditional type of agricultural activity in the region. Considering the high disturbance degree found in these riparian habitats, the present study could be an update on what Nabhan and Sheridan [61] called a "stable agroecosystem in the upper San Miguel," stating that it is not necessarily stable if disturbance is so high and riparian vegetation so scarce, although living fences might still hold some additional benefits to the riparian habitat.

#### 4.2. Cover and Composition of Riparian habitats and Desert Habitats

Field estimations show that Riparian Vegetation cover is higher than Desert Scrub cover, for all vegetation strata; which is most likely due to resource availability and physical characteristics in riparian habitats which enable vegetation growth, such as soil moisture, organic matter deposition and groundwater [62].

Herbaceous cover was the strata with the highest values for both habitats but it did not reach 100% in any site. Since herbs and shrubs are the most affected by cattle [4], it is interesting to note that one of the places with greatest cattle presence (Cienega) shows a 90% herbaceous cover and a 5% shrub cover, in the riparian habitat. In this particular site, cattle might be having a greater effect on shrub removal and the high percentage of herbaceous cover may be a response to the climatic conditions at the time of sampling (rainy season). The same situation can be seen in the desert habitat for the same site, where shrub cover is only 7%.

Compositions of both habitats present some similarities, such as *Prosopis velutina*, *Parkinsonia florida*, *Celtis pallida* and *Lycium berlandieri*. Riparian habitats show the presence of exotic species *Ricinus communis* and *Nicotiana glauca* in most of the low-medium disturbed sites. *Ricinus communis* is considered as an indicator of disturbed habitats [63]. *Nicotiana glauca* is widely common in Sonoran rivers [64] and high dominant values in its presence have been found in many places where half of the land has been transformed to agriculture [11]. It stands out that these species were found in the sites with the lowest disturbance degree.

Even though many desert species can be found on riparian habitats, this study considers that the abundance and high presence of these species can be a sign of change in the riparian ecosystem. This can be seen in the two sites with the highest disturbance degree (Cajon and Nogalera) where *Prosopis velutina* and *Parkinsonia florida* dominated the tree strata. The presence of cacti such as *Cylindropuntia leptocaulis* and *Lophocereus schottii*, along with the presence of the invasive buffel grass in riparian habitats of these two sites, could also be an indicator of a gradual vegetation transformation or an increase of aridity in the riparian habitat.

Diversity of shrub and tree strata in Cienega is the lowest for riparian habitats, this might be due to the fact that most of the canopy was dominated by a single tree species *Fraxinus velutina* and almost no other tree species were present. Something similar can be seen in Galera, where the desert habitat has the lowest diversity value and the composition shows a dominance of mesquite in the sampling site.

Contrary to what was expected, vegetation class covers derived from orthomosaics (UAV) show similar averages for both habitats. Riparian habitat shows a 25% cover for Riparian Vegetation and a 23% for Riparian Mesquite Woodland and Desert habitat shows a 21% cover for Desert Scrub and a 27% for Riparian Mesquite Woodland. These similarities can also be a sign of degradation of riparian habitats, where vegetation cover is expected to be higher than in desert habitats. Although when riparian habitat covers are compared within each site, Riparian Vegetation presents higher covers than Riparian Mesquite Woodland in all sites, except for those where it is not present (Cajon and Nogalera). In the desert habitat, Riparian Mesquite Woodland has a higher cover than Desert Scrub in most of the sites.

#### 4.3. Photosynthetic Activity of Riparian Habitats and Desert Habitats

Differences in *EVI* averages between riparian and desert habitats are consistent with other findings [8,17,35] where a higher productivity is attributed to riparian vegetation when compared to its adjacent vegetation and with the fact that water availability promotes vegetation productivity in riparian habitats [55,65,66]. Also, the seasonal difference in *EVI* values for desert habitat is much greater than in riparian habitat, showing that riparian habitats maintain more stable productivity rates than desert habitats, which respond drastically during the growth season when water is available through precipitation.

Riparian vegetation shows higher *EVI* average values than Riparian Mesquite Woodland in most of the 5 sites where these two classes are present; this was consistent for both seasons. This photosynthetic activity variation is important and could mean that, even when both classes share the same environment and water availability, Riparian Vegetation remains more productive than Riparian Mesquite Woodland. Soil characteristics between these two classes might explain part of the productivity differences, since, as registered by Trujillo [67], Riparian Vegetation in the San Miguel river has a greater amount of carbon and nitrogen and also greater mycorrhizal activity, than Riparian Mesquite Woodland.

The productivity-disturbance inverse relationship shows to be significant and consistent with what has been reported before [41], in terms of productivity decline being one of the main consequences of disturbance (according to ADI scores). Based on *EVI* analysis, our results suggest that riparian sites with high disturbance due to human activities (which include changes in water availability, as suggested by previous studies [8,23,35] and changes in the composition and structure of vegetation) have lower photosynthetic activity (and hence productivity) than less disturbed areas.

The use of aerial photography in this study was very helpful to perform a detailed classification analysis since different vegetation types can be easily identified with high spatial resolution imagery. Also, digitalization of the different vegetation types allows for very accurate cover estimation, due to the clear visualization of tree and shrub canopies. In addition, when combined with a coarser resolution sensor (OLI) we were able to identify the exact productivity values for each vegetation type, which was an essential part of this study.

## 5. Conclusions

According to our analysis, the increase of land-cover-change associated human activities can increase disturbance on the vegetation of riparian ecosystems in the San Miguel River. As disturbance increases, photosynthetic activity of Riparian Vegetation decreases.

The two sites with the highest degree of disturbance according to the ADI are characterized by the development of particular activities (non-traditional) that were not found in any other site, such as commercial agriculture and recreational activity. Riparian composition in these two sites differs greatly from riparian vegetation in the rest of the sites, due to the almost total absence of obligate-riparian species. Composition in places with the highest disturbance is dominated by facultative-riparian species.

The presence of non-riparian species and facultative-riparian species in riparian habitats is not uncommon, in this study we suggest that the dominant presence of such species could be related to the intensity of human activities developed in the site. Further studies need to be made to sustain or dismiss this suggestion.

Disturbance as measured by the Anthropogenic-disturbance Index shows to have no significant effect on shrub and trees richness and diversity. Further studies would need to assess herbaceous composition and diversity and its relation to disturbance.

Unmanned Aerial Vehicles constitute an efficient tool to assess and monitor riparian ecosystems. Further studies or management proposals should take this into account for the development of regular monitoring programs on arid and semi-arid watersheds. The remote sensing methods used in this study should be further explored for the study of riparian ecosystems. Especially the use of high efficiency drones could be applied for a more extensive mapping of riparian habitats. The coupling of aerial technologies along with free-access satellite data, is a feasible option for riparian characterization and monitoring.

In spite of their small extension and of being highly variable, riparian habitats in arid regions are of crucial importance, an evidence of this is the capacity of Riparian Vegetation to maintain higher photosynthetic activity levels than other vegetation types such as Riparian Mesquite Woodland and Desert Scrub. Since riparian habitats demonstrate high variability in terms of land use, we believe that it is necessary to increase the number of studies regarding their composition and the effects/threats posed by human disturbance. For the previous, the present study provides potential tools to evaluate the effects of different management practices on riparian habitats in arid environments.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2073-445x/7/1/13/s1>, Table S1: Spatial and temporal location of each flight performed. (R) and (D) after site name indicate flight performed over riparian vegetation (R) and over adjacent desert scrub (D). SMH is the abbreviation for San Miguel de Horcasitas municipality, Table S2: Flight requirements and image specifications, Table S3: Characteristics of Landsat 8 scenes.

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**Author Contributions:** Lara Cornejo-Denman was the primary author and all authors contributed to the final paper. Jose Raul Romo-Leon contributed to all steps of the analysis and commented on the manuscript. Alejandro E. Castellanos, Jose Luis Moreno-Vázquez and Rolando E. Diaz-Caravantes made important contributions during the development of the research project and commented and revised the manuscript. Romeo Mendez-Estrella contributed with discussion and field work. All authors reviewed and approved the final manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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