Spatiotemporal river use patterns and implications for Texas wild-rice distribution in the San Marcos River (Texas, USA) for summer 2016

by

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1. Introduction

The Texas Hill Country is becoming increasingly urbanized, populated, and visited by tourists. The growing popularity of the region may be contributing to increased recreation impacts on the waterways and ecosystems (World Population Review, 2021). Along with recreational impacts, the natural environment of the region is threatened with intensive development, urban sprawl, introduced species, pollution, habitat fragmentation, and climate change. Specialist species of the region are susceptible to more threats than non-specialist species as they are often sensitive to environmental changes and their resource needs may be disproportionately impacted. Among these specialist species is the native aquatic plant *Zizania texana* (Texas wild-rice)—a perennial grass endemic to the spring-fed San Marcos River in San Marcos, Texas.

The San Marcos River ecosystem is directly and indirectly affected by recreation activities, including swimming, kayaking, paddle boarding, scuba diving, canoeing, tubing, and fishing. Previous studies such as Brauman (2015), Castro et al. (2016), and Julian et al. (2018) make the connection between how an ecosystem is managed and the benefits (or ecosystem services) of that ecosystem. This study provides a short-term analysis of temporal and spatial recreational use patterns of the 2016 summer recreation season on the San Marcos River (*Figure 1*) and examines potential implications of river-related recreation on Texas wild-rice distribution changes between April and October 2016 in an area of high recreational river use.

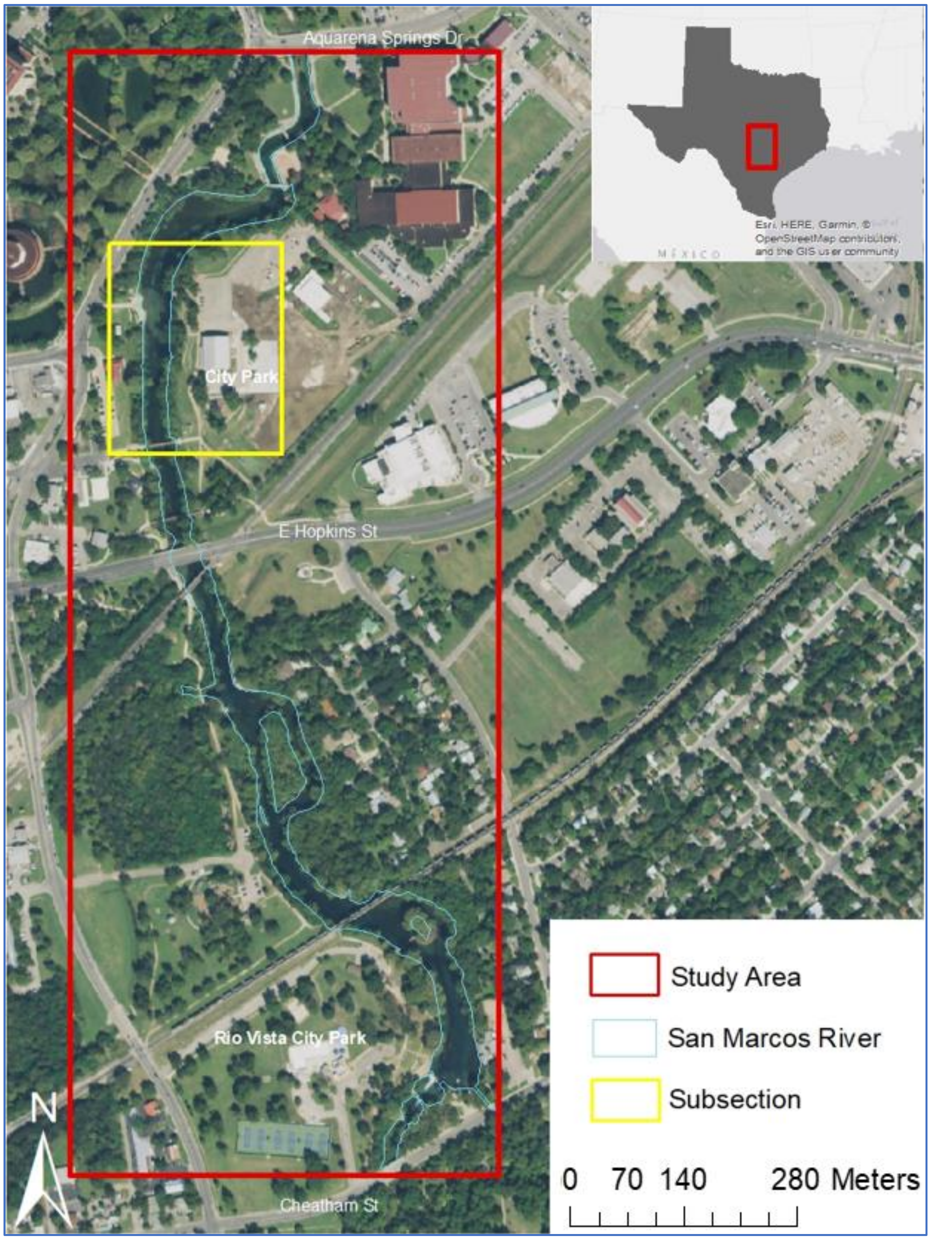

Figure 1. San Marcos River (Texas, USA) study area, which includes the 4.93 ha and 1,240 m long reach (measured from top and bottom points of river) between Aquarena Springs Drive and Hopkins Street. Subsection is 0.64 ha and 230 m long.

Texas wild-rice is an aquatic perennial grass that occurs from the headwaters at Spring Lake to the confluence with the Blanco River (Poole, 1999). The spring-fed waters of the San Marcos River have a relatively constant temperature close to 22°C and geomorphic characteristics are favorable for the aquatic grass. Texas wild-rice roots in bed substrates and can grow in water depths from 0.2 to 3 meters deep. The plant consists of culms typically 1-2 meters in length that bend and flow underwater and grow emergent above the water's surface to flower.

Texas wild-rice was first listed as endangered in 1978 due to increases in habitat alteration along the San Marcos River, non-native species numbers, urbanization, and the reduction of spring flows (Poole, 1999). Additionally, Texas wild-rice populations declined about 40% following the severe drought of 1996 and the flood of 1998 (Kimmel, 2006).

Management efforts are currently in place for the restoration, conservation, and protection of the endangered and threatened species of the San Marcos ecosystem through the Edwards Aquifer Habitat Conservation Plan (EAHCP). The EAHCP was initiated in 2012 in response to intensive groundwater pumping, to protect and manage the endangered species of the San Marcos and Comal rivers and springs in coordination with Texas Parks and Wildlife Department, U.S. Fish and Wildlife Service, the Edwards Aquifer Authority, the City of New Braunfels, Texas State University, the San Antonio Water System, the City of San Marcos, and the Guadalupe-Blanco River Authority. A key activity of the EAHCP directly related to Texas wild-rice involves the removal of invasive species, planting of native species, and protection of Texas wild-rice stands as State Scientific Areas (SSAs); these actions mitigate a variety of activities, including recreational impacts, that affect Texas wild-rice.

This study aims to (1) analyze, map, and characterize the temporal patterns of visitor river usage of the study area for the summer of 2016, (2) analyze, map, and characterize the spatiotemporal distribution of Texas wild-rice for a subsection of the study area for the months of April and October of 2016, and (3) compare the results of the two analyses.

2. Literature Review

2.1. Studies of Texas wild-rice

Studies pertaining to Texas wild-rice in the San Marcos River have mainly focused on the viability of the grass rather than on recreational impacts upon it. Although emergent inflorescences have been observed in the wild population of Texas wild-rice, the plants rarely set seed in the San Marcos River (Owens et al., 2001). This characteristic makes it difficult for the plant to proliferate. Texas wild-rice is a wind-pollinated anemochore and contains short-lived pollen subjected to a decline in viability after 10 minutes of the release of anthers, then completely dying off approximately an hour after the anthers release. Pollen desiccates after the anthers open and increasingly desiccates the longer it remains in the open anthers. Therefore, wind currents are necessary for the removal of pollen from the open anthers and deposition of the pollen onto receptive stigmas before the desiccation sets in (Power, 2004). Texas wild-rice is gregarious, wherein large contiguous, colonies are most conducive to reproductive success through anemophily. However, Tolley-Jordan and Power's (2007) study established plants are susceptible to herbivory during the reproductive stage as reproductive structures tend to contain more biomass.

A study conducted by Poole and Bowles (1995) sought to critically compare non-rice transects to those containing rice, a feat not accomplished until then. The 1995 study found that the Texas wild-rice in tested transects prefer shallower sites at <1 m in depth with current velocities of $\geq$ 0.46 m s^{-1} as measured and averaged at the root zone. The transects which excluded Texas wild-rice had lower current velocities of about $\leq$ 0.22 m s^{-1}. The preference for high current velocities and shallower water suggests Texas wild-rice does not thrive in the lentic conditions produced by the presence of dams. Deeper water, not direct competition, is attributed for the proliferation of non-native species in the non-rice sites. In spring of 1995 a total of 15 transects were further examined and the Texas wild-rice appeared to prefer areas of moderate to coarse-moderate substrate and not those composed of fine or fine-clay sediments. Organic matter also did not exceed 45% at any one of the sampled transects. Although statistical analyses of the aquatic macrophyte data was not attempted, basic counts were recorded in Poole and Bowles's (1995) study. The number of Texas wild-rice plants during 1995 totaled 36 in May, 44 in August, and 24 in January. Lower numbers in January can be attributed to reduced sunlight hours in the winter season. Reduced spring flows and sunlight result in greater temperature fluctuations not ideal to Texas wild-rice as the San Marcos River is constantly at about 21 $\pm$ 3°C (Tolley-Jordan, 2007).

2.2. Studies Focused on General Ecosystem Services

Studies which analyzed the benefits of aquatic ecosystems and incorporated a portion of the human component (recreation) composed the largest part of the literature on aquatic vegetation. Stakeholders' tendency to prioritize freshwater for economic development often comes at the detriment of ecosystem health. Therefore, little attention is given to the general public's preferences (usually made up of non-monetary indicators) and perceptions for ecosystem services (Castro et al., 2016). This contrasts with the findings Castro et al. collected for their study on social demand for ecosystem systems in the Kiamichi River watershed in Oklahoma. Roughly 96% of the 505 individuals surveyed believed the Kiamichi River provides benefits to human well-being at some level and 80% of this number believed it provides more substantial benefits. Well-being was generally defined as encompassing health, happiness, and income. All stakeholders surveyed agreed habitat for species and water regulation are the most important aspects to focus on in the watershed management of the Kiamichi River.

An ecohydrology designed study produced on the leeward side of the island of Hawai'i evaluated the impact of plausible land-use transitions in groundwater recharge and the related effects on human well-being (Brauman, 2015). In the study, preliminary interviews were conducted with stakeholders worried about the changes caused by upland use. The main factors Brauman considered regarding managing groundwater recharge were drinking, irrigation, hydropower, transport, and cultural and aesthetic appreciation. Economic valuation can pose a disadvantage for ecosystem service analyses, potentially undervaluing or 'selling-out' nature. Most of the studies from the bibliographic review of Brauman's paper focused on ecosystem impacts to water quality and quantity rather than the integration linking biophysical processes and human well-being.

2.3. Studies on the Effects of Recreational Activities on River Systems

In the field of ecology, several studies have been conducted about recreation and its effect on biota in aquatic ecosystems (Mumma et al., 1996; Monz et al., 2013; Markus et al., 2018). Vegetation trampling is the most common and systematically researched topic in recreation ecology (Monz et al., 2013). Historically, most studies on the impact of recreational activities focus on the effects of biking, hiking, camping, walking, horse riding, and off-road riding on terrestrial vegetation (e.g., Pickering and Hill, 2007; Cole 2004; Martin 2017). These activities crush, shear, and uproot vegetation. Such trampling includes reductions in plant height, stem length, leaf area, and seed production as the soil is compacted and porosity is reduced (Cole, 2004). Similarly, the effects of recreation on aquatic vegetation are akin to those enacted on terrestrial plants.

Recreational boating is another activity shown to significantly affect aquatic vegetation (Eriksson et al., 2004, Sagerman et al., 2019, Herbert et al., 2018, Hansen et al., 2019).

Recreational boating introduces chemical pollutants in the form of boat fuel, lubricants, and anti-fouling components which are placed on submerged surfaces to protect against aquatic elements and organisms (Hansen et al., 2019), and shears and tears plants through increased wave-action. The wave-action caused by boating augments water turbulence by resuspending sediment and nutrients which reduces light availability for the vegetation and stresses the ecosystem.

There is little research to be found specifically on the San Marcos River and the effects of recreation on endemic species such as Texas wild-rice (TWR). Despite the river's high management levels, there is insufficient research on recreation impact on the San Marcos River. One key study conducted on the San Marcos River by Shannon L. Breslin (1997) analyzed the impacts on Texas wild-rice by recording the contact intensity caused by swimming, tubing, fishing, boating, and dogs. Breslin observed the plant was susceptible to uprooting, trampling, and pulling. Direct contact caused leaf tears and submersed or severed inflorescences. Breslin also noted flood control measures imparted by the flood control dams increased deposition which allowed for invasive exotic aquatic macrophytes to proliferate. Breslin concluded that although recreation negatively impacts Texas wild-rice, the actual amount of damage was not severe. The overall total coverage of Texas wild-rice was increasing gradually, but the coverages between some varying segments were decreasing. These segments consist of areas where recreation is heavily concentrated such as City Park.

Few studies have been done on the impact of recreational activities on river systems. By the year 2000, there was an average of 500,000 visitors to the San Marcos River per year (Halff, 2010). Unfortunately, as the demand for river activity grows there is compelling physical evidence of trampled vegetation, bank damage, and bank erosion caused by recreational visitors (Halff, 2010). The Initial Study of the Recreational Impacts to Protected Species and Habitats in the Comal and San Marcos Springs Ecosystems contracted by the Texas Water Development Board in 2010 investigated the recreational impacts imposed on the San Marcos River. They extrapolated figures based on survey data provided by the only tube vendor in the city (Lion's Club) for one particular year. As Lion's Club's hours of operation in the summer ran from mid-May to September (10 a.m. to 7 p.m.), any data outside of these hours had to be extrapolated. River-based recreation data was also extrapolated from the data included in two previous studies as there were no specific data on recreation in either study. Instead, the temporal use data collected was presented in terms of relative intensity: high, low, or medium. However, not all visitors to the river rent tubes. In 2005, about 29,829 tubes were rented out by Lion's Club which accounted for only about 50-60% of tubers. There are those who bring their own tubes and those who were swimming or recreating without tubes. The Initial Study (2010) found that peak visitor use coincides with Memorial Day and Labor Day weekends. Long weekends, particularly on Saturday rather than Sunday, during 11am-4pm, also showed peak use. During high-use days the biomass of damaged plants significantly increased as user activity increased. In comparison, the biomass of drifting plants did not significantly change throughout the day as recreational use increased on the low and medium-use days (Mumma et al., 1996). Recreation tends to break off fragments of exotics which then flow downstream and are typically aggressive enough to survive breakage and thrive whereas Texas wild-rice cannot (Owens et al., 2001). Bradsby's 1994 thesis studying recreation deduced small level use does have large initial impacts on the vegetation but as time goes on those damages proportionately decrease. Bradsby also determined early afternoon hours had the highest concentration of use while morning had the lowest. Of the recreational activities tubing was the most popular during the early afternoon hours.

Recreation impacts clearly impact native ecosystems. It is no longer a question of whether these effects should be acceptable but rather how much impact is acceptable. Overall, impacts on localized rare populations can be serious for individual plants and animals.

2.4. Background on Sewell Park, City Park, and Rio Vista Park

The upper 1,240 m reach of the San Marcos River contains several recreational parks and three that provide direct river access: Sewell Park, City Park, and Rio Vista Park. These parks are free and easy to access, contributing to their popularity for recreational water activities.

In 1916, a Southwest Texas State Normal College (currently Texas State University) professor, Dr. S.M. Sewell, sought to create a park for the university. The U.S. Bureau of Fisheries leased four acres of land crossed by the San Marcos River to the college and were turned into a park. Sewell Park contains picnic tables, steps for easy river access, a basketball court, and volleyball courts. The green space surrounding the river provides an area for lounging and sunbathing. Sewell Park is supposed to be limited to use by university faculty, staff, and students.

City Park is an eighteen-acre park downstream of Sewell Park. This park contains a basketball court, jogging trails, a playground, and a Recreational Hall used by the Lion's Club for tube rentals during the summer. The shallower water in this section of the river along with the hardened riverbank containing steps allows greater access for recreational use.

The third park is Rio Vista Park located south of City Park and near the I-35 corridor. Rio Vista Park contains a series of man-made rapids, a deep watering hole, tennis courts, a basketball court, playground, picnic facilities, city swimming pool, restrooms, and trails (San Marcos Texas Convention and Visitor Bureau, 2021). This park is also the Lion's Club shuttle pick up for those renting tubes from upstream at City Park and floating downstream to Rio Vista.

3. Research Methods

3.1. Visitor Counts

I used three datasets to characterize river usage patterns for the Summer of 2016. The datasets were created and provided by Lion's Club, Dr. Jason Julian, and River Watch. Each dataset was composed of daily counts for visitors using the San Marcos River during the peak recreational season of 2016.

3.1.1. Dataset A – Lion's Club

The first set of visitor count data was one collected during the summer of 2016 between the hours of 10:00 a.m. to 7:00 p.m. by Lion's Club, a tube rental concessionaire located at City Park along the San Marcos River. The data from Dataset A came from two worksheets used for Lion's Club: 1) a worksheet including details such as zipcodes from where visitors were traveling, month of survey, the number of nights staying in a hotel in town, and the number of visitors in each party for the months of June, July, and August, and 2) a worksheet including the estimated party-size groups (1, 2-5, and 5+) of visitors per party for observed dates and time stamps around the same timeframe as the first dataset. Both worksheets from the dataset were used in estimating the visitor count from Lion's Club.

3.1.2. Dataset B – Aerial Imagery

Dr. Jason Julian of Texas State University's Geography Department provided visitor count data from a previous survey. The primary data was collected from three varying times of the day (9:00 a.m., 1:00 p.m., and 5:00 p.m.) in 2016 on the following days: July 14, July 16, July 22, July 27, July 29, August 1, August 5, and August 12. These dates were chosen as they cover the ‘outdoor season’ which typically begins with Memorial Day weekend and ends on Labor Day weekend. The visitor counts depicted were those observed as being on areas within the river or on park grounds surrounding the river as mapped during the summer of 2016 from May to September.

A DJI Phantom 4 Pro (P4P) collected the data from approximately 200 feet above ground level to maintain high image resolutions while also encompassing sufficient area by taking photos in a gridded manner with ample overlap to account for radial distortions during data processing. Each flight time consisted of an estimated fifty minutes with each observation time requiring three batteries to complete each flight. On average a thousand photos were taken per site and on each date during the flights. The photos were processed using Agisoft Metashape by combining the photos by each day and hour of observation. The photos were aligned to generate a sparse point cloud consisting of tie points relating features in separate photos to one another. Following this step, a dense point cloud was created enabling the production of the final orthomosaic for the entire study area. The orthomosaic was georeferenced to UTM 14N NAD83 for analysis then exported with a 0.03 m spatial resolution to ArcMap as TIF files for visual interpretation. Shapefiles were created for each observation day and time to populate with point features by placing a point corresponding each identifiable person to their location in the orthomosaic.

3.1.3. Dataset C – River Watch

River Watch, an advocacy group which keeps track of the traffic along the San Marcos River, also collected visitor counts in 2016, for two different reaches including an upper and lower section. This study uses the data for the upper section only. The data was collected between 9:00 a.m. to 7:00 p.m. from June 11 to September 2 of 2016. The attribute table for the

River Watch visitor counts includes columns with the type of device used along the river such as inflatables (tubes), kayaks, coolers, canoes, and paddle boards. For this report the assumption was that each device represented one visitor. This assumption explains why cooler devices were excluded from analysis as they do not directly represent visitors. The collected data from River Watch spans from August 2014 until September 2016. Only the 2016 dataset was used for this study.

3.2. Vegetation Surveys and Mapping

The vegetation data used for this study was collected and mapped by sub-contractors for the EAHCP, and was obtained from the Edwards Aquifer Authority (EAA). The sub-contractors conducted drone surveys collecting high-resolution aerial imagery of the distribution of all submerged aquatic vegetation along the San Marcos River for two seasons, April 2016 and October 2016. They used the aerial drone imagery to map the submerged and emergent vegetation distribution in the study sub-section spanning the river reach from Aquarena Springs to the pedestrian bridge above Hopkins Street in San Marcos, Texas.

The sub-contractors created shapefiles for April and October consisting of multiple polygons and an associated attribute table that included an estimated area (in m^2) for each type of submerged aquatic vegetation. For a majority of the polygons there were multiple species present. Each of these different species occupied a percentage out of 100% total from the area of every polygon.. The species with the highest percentage of a polygon determined the polygon name used for labeling. For example, if there were *Hydrilla spp.*, *Hygrophila spp.*, and Texas wild-rice at 20%, 25%, and 50%, respectively, then the polygon would be labeled as Texas wild-rice. Only the three highest percentages of vegetation species per polygon were labeled and considered for the analysis. Determining the areal percentage of the three most common species per polygon was visually estimated by a single observer when creating the polygons. Verification of the species present per polygon was implemented by underwater observers as part of the mapping process.

3.3. Analysis

3.3.1. Visitor Count Analysis

This study sought to estimate the total number of visitors for the summer season of 2016 and general visitation patterns. Additionally, a comparison between the Texas wild-rice vegetation and the visitor count shapefiles was required to discern what relationship existed between the growth or loss of Texas wild-rice and recreation. Visitor counts spanning the entirety of the study area, from Aquarena Springs Drive to Rio Vista City Park, were plotted according to the entity which collected the dataset.

3.3.1.1. Dataset A – Lion's Club

The two worksheets comprising Dataset A from Lion's Club were organized in Microsoft Excel by counting the number of each party-size group for the months of June, July, and August. The first worksheet contained previously calculated total sums for the months plus totals of party-size groups (*Table 1*) while the second worksheet contained only estimates of party-size groups ranging from 1, 2-5, and 5+. Getting an estimate for the visitor counts required each party-size group to have a coefficient, an average number for each of the group categories, since the party-size groups were initially collected as ranges. For example: a party-size group of 1 averaged to a new coefficient of 1, party-size groups of 2-5 averaged to the coefficient of 3.1, and party-size groups of 5+ averaged at 8.3 for the month of June. New coefficients were calculated for each party-size group (1, 2-5, and 5+) for the month of June, July, and August by averaging the monthly visitor counts for each group of party size.

Table 1. Dataset A: Lion's Club 2016 survey data with operation hours between 10 a.m. to 7 p.m. Table 1 shows the number of groups per party size for the months of June, July, and August 2016.

PARTY SIZE	NUMBER OF GROUPS PER PARTY SIZE		
	JUNE	JULY	AUGUST
1	44	37	44
2	148	258	294
3	117	176	223
4	104	188	164
5	51	126	121
6	41	82	70
7	21	31	32
8	8	26	27
9	5	12	28
10	19	15	24
11	4	4	10
12	2	4	10
13	1	0	1
14	2	2	2
15	2	3	6
16	1	2	2
17	0	2	0
20	1	2	0
25	0	2	0
29	1	0	0
40	0	1	4
45	0	1	0
116	0	1	0

In Excel, a column was added to Dataset A Worksheet 1 to filter and sort the sums of visitor counts for June, July, and August into the respective party-size groups (1, 2-5, and 5+). The months were separated into the three party-size groups and the sums of party-size groups were totaled for each month. The sums were then divided by the count of party-size groups per month. The new values represented the average number for each party-size group per month and were considered the coefficients needed to estimate visitor counts for missing data in Dataset A Worksheet 2. The newly calculated coefficients were multiplied by the count to get the estimated sum. To check the validity of the average coefficient per category, the estimated sum of each category was calculated by multiplying the average coefficient per category by the observation count and subsequently checked against the sum provided. If the estimated sum was relatively close to the initially provided sum, then the coefficient was noted as sufficient. After the coefficients were derived, the mean of the coefficients for each party-size group per month was calculated. The final coefficients were used to calculate the estimated sums of visitor counts for the missing data in May for Dataset A Worksheet 2.

3.3.1.2. Dataset B – Aerial Imagery

Attribute tables for the Dataset B visitor observation shapefiles were edited for easier manipulation in ArcMap. Shapefiles from the corresponding day of the week were merged accordingly and columns were added to the attribute tables with time, date, and day of the week for the visitor observations. Of the three datasets, only Dataset B's shapefiles contained distinct location points for visitor counts. The presence of location points made this dataset ideal for use with the submerged aquatic vegetation shapefiles. It was decided that the cumulative visitor counts from all eight survey days and observed hours from Dataset B would be used for that analysis. All the visitor counts from the eight days from Dataset B were plotted on a map extending from Aquarena Springs Drive to Rio Vista City Park in San Marcos, TX (*Figure 2*). The query builder function was used to isolate a variable to plot the different iterations of the visitor densities on a map. The queries were performed based on the variable day of the week (Monday, Tuesday, Thursday, Friday, Saturday, and Sunday) and on the variable of time surveyed (9:00 a.m., 1:00 p.m., and 5:00 p.m.).

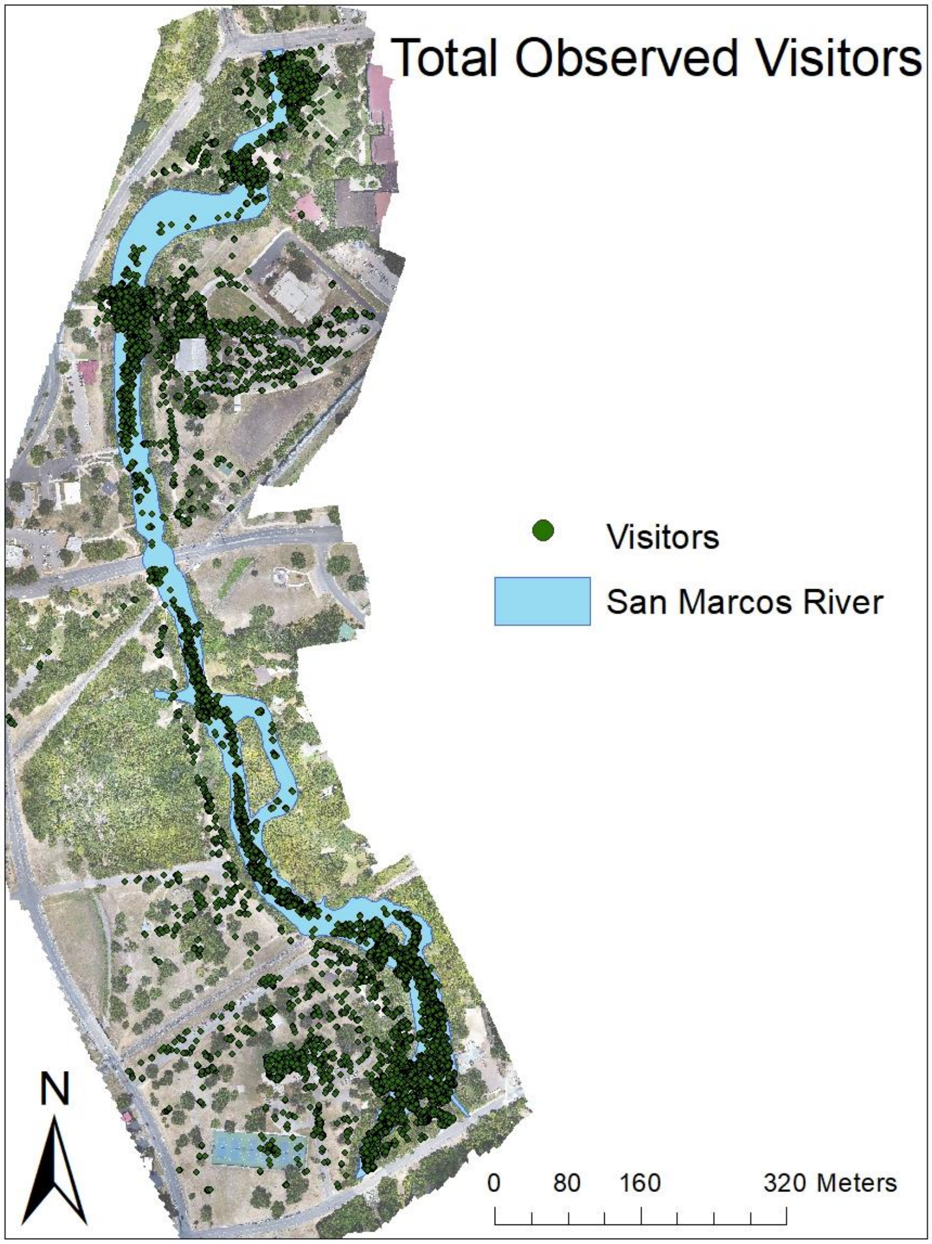

Figure 2. 2016 visitor count for study area consisting of Sewell Park down to Rio Vista Park. Visitor counts depicted are from all eight of the observed days (July 14th, 16th, 22nd, 27th, and 29th and August 1st, 5th, and 12th). Total number of points equal 12,779.

For calculating the estimated daily visitation, Dataset B was organized and sorted to exclude days with less than six hours (three observed hours) to use with Datasets A and C Dataset B was further broken down by calculating the number of visitors per hour (*Table 2*).

Table 2. Dataset B: Aerial survey days visitor count totals. Each survey consisted of a two-hour duration for the observed hours of 9:00 a.m., 1:00 p.m., and 5:00 p.m.

Date	Day	Observed Hours	Estimated Hours	Visitor Total	Visitors per hour
7/29/2016	Friday	3	6	1,679	280
8/01/2016	Monday	3	6	792	132
8/05/2016	Friday	3	6	1,397	233
8/12/2016	Friday	3	6	1,387	231

3.3.1.3. Dataset C – River Watch

Since Dataset C was considered the 'most inclusive' in terms of daily visitation, the other two datasets had to be adapted to fit Dataset C. Charts for Datasets B and C did not require a coefficient per day as definite numbers of visitors were provided per day. Dataset A differed from Datasets B and C in how visitor counts were calculated in ranges and then averaged to find a new coefficient for each party-size group. Dataset C's survey was recorded according to the devices being used (kayaks, inflatables, canoes, and paddle boards); the assumption is each device represents one visitor each (cooler devices were excluded). The visitor count sums were calculated for each day and then totaled for June, July, August, and September.

3.3.1.4. Estimated Daily Visitation (EDV)

The monthly totals from each dataset were totaled and graphed on a bar graph for the months of May, June, July, August, and September. The monthly totals depicted on the bar graph are the totals that were calculated from the separate datasets and not the estimated daily visitation (EDV) hours. The EDV hours were derived in a different manner to calculate the total estimated visitation for the summer season of 2016.

Totals for the daily visitor counts were tallied and listed onto a table for the three datasets. The values were then used to analyze the relationships between the datasets to estimate daily visitation. Total visitor counts for Dataset A and B excluded days with less than six hours and calculations were made on the assumption the two datasets were equal to the ten hour days of Dataset C. For each dataset, the dates were listed in groups according to days of the week. If only Dataset C had visitors present for a particular day, the daily total was determined by that dataset as it was considered the most accurate. Saturdays, Sundays, and holidays were grouped together, Monday through Thursday composed another day group, and Fridays were the third day group. Wednesday was the only day not recorded for any of the datasets and results were based on estimations but was estimated with the Monday through Thursday day group.

Since Dataset C was the most accurate, Datasets A and B were used to fill in missing days for Dataset C in the table. Using Saturdays, Dataset A was compared to Dataset C by calculating a multiplier for days where both datasets had data. Visitor counts for Dataset A were multiplied by the multiplier average to derive the estimation for Dataset C's visitor counts. The same procedure was applied to any day including Dataset A visitor counts. A new table column was added which included the new estimated visitor counts for Dataset C. Each day group's EDV was averaged to find the final EDV for each day group. The final EDVs were multiplied by the number of days of the week per group for the summer season and added to obtain the total EDV for the 2016 season. Finally, they were broken down further by calculating the EDV per hour for each day group.

3.3.2. Submerged Aquatic Vegetation Analysis

3.3.2.1. Units of analyses

The submerged aquatic vegetation of the San Marcos River subsection within City Park was analyzed using square meters to estimate the total areal coverage of Texas wild-rice inhabiting the study areas. The limited size of the subsection area was more efficiently analyzed using square meters instead of the hectare unit previously used for measuring the study area. The previously mapped polygons of the vegetation of the San Marcos River were further broken down according to species of each type of vegetation found in the river. The dominant species consisted of *Hydrilla spp.*, *Hygrophila spp.*, *Sagittaria spp.*, *Ludwigia spp.*, *Potamogeton spp.*, and Texas wild-rice. Each of the polygons represented areas of vegetation and were further categorized by percentages of each species as found in each polygon drawn. Exact locations of each species were not depicted.

3.3.2.2. Vegetation Differences

The analysis comparing the submerged aquatic vegetation differences between April and October focused on the study area's subsection spanning the reach from below Sewell Park to City Park. The total study area, total vegetation area, percentage of Texas wild-rice in the study area, and the percentage of Texas wild-rice out of the total vegetation area for April and October were calculated and entered onto the respective shapefiles' attribute tables. The total percentage of Texas wild-rice for April and October was calculated excluding the sections of no change. The two shapefiles were then compared with the intersect tool in ArcMap to find the shared areas (those with no change) for both months. The new intersected shapefile was cut to the April vegetation shapefile to separate the areas only visible during the month. The same procedure was done to the October month shapefile. Areas visible during April but not October were considered as being areas of contraction (i.e., loss). Those areas visible during October but previously not visible in April were considered as areas of new growth. The intersected area shapefile representing no change was analyzed in Microsoft Excel by comparing differences in the measure of Texas wild-rice percentages per polygon for 102 polygons. A negative number when subtracting October's values from April's represented an area of discernible Texas wild-rice contraction from the April to October timespan while a positive number represented an area of growth.

3.3.3. Submerged Aquatic Vegetation and Visitor Interaction Analysis

The submerged aquatic vegetation and visitor interaction analysis from Dataset B were compared to one another. Analysis of visitor interaction with the submerged aquatic vegetation assumes that the patterns of visitor traffic on the river during the summer stays relatively constant over the months for the season. The visitor counts recorded in Dataset B were chosen because they contained geographic locations unlike the visitor counts recorded in Datasets A and C. For this analysis, interactions between visitors and submerged aquatic vegetation were defined as contact by visitors on the vegetation whether by direct overlap, tubing over areas with submerged aquatic vegetation present, or canoeing or kayaking in areas with submerged aquatic vegetation present. The point maps created from the Dataset B analysis were overlain on the submerged aquatic vegetation polygon maps to visualize the interactions with visitors. Each of the polygons depicted submerged aquatic vegetation with percentages of Texas wild-rice per polygon. The percentages were applied to the submerged aquatic vegetation polygon maps showing the Texas wild-rice percent coverage in 2016. Another map was created to show the areas of loss, areas of growth, and the percent changes of Texas wild-rice per polygon for the season from April to October with and without visitors. However, because the interaction analysis was based on point-in-time aerial imagery, the analysis can only be considered as a generalized representation of visitor interactions on the river.

4. Results and Discussion

4.1. Visitor Counts Results

4.1.1. Dataset A – Lion's Club

Calculating the estimated total of visitors relied on using a coefficient for the party-size groups used in Dataset A Worksheet 2. *Table 3* lists the months and the party-size groups with the results of the calculations. The coefficients for the corresponding party-size groups for each month were relatively similar. Party-size groups of 1 were all 1. The party-size group 2 to 5 were within a 0.1 range for each month, and the party-size group 5+ was within a range of 0.1 - 0.4. The estimated sums resulted in values like the original sums collected from Dataset A Worksheet 1, making them sufficient for use in calculating any missing sums for the month of May from Worksheet 2. The coefficients for the months were then summed respectively and divided to derive the new average monthly coefficient. The new coefficients were 1, 3.2, and 8.6, which were used for the missing variables in May.

Table 3. Party-size group statistics for June, July, and August 2016 including estimated sum totals and monthly averages.

MONTH and PARTY-SIZE GROUP	AVERAGE (Coefficients)	COUNT	SUM	ESTIMATED SUM
June 1	1	12	12	12.0
June 2 to 5	3.1	420	1,318	1,302.0
June 5+	8.3	108	896	896.4
June Total			2,226	2,210.4
July 1	1	37	37	37.0
July 2 to 5	3.2	748	2,426	2,393.6
July 5+	8.7	190	1,697	1,653.0
July Total			4,160	4,083.6
August 1	1	44	44	44.0
August 2 to 5	3.1	802	2,518	2,486.2
August 5+	8.8	216	1,905	1,900.8
August Total			4,467	4,511.2

Overall Coefficients	
1	1
2 to 5	3.2
5+	8.6

4.1.2. Dataset B – Aerial Imagery

A similar pattern was reflected in the point density analyses using Dataset B's visitor counts with location points. Each time of day (9:00 a.m., 1:00 p.m., 5:00 p.m.) and separate ones for days of the week (Mondays, Wednesdays, Thursdays, Fridays, and Saturdays) all had concentrations of visitors at the areas where the three parks were located whether in or along the river. The point densities for each differentiation is visible in *Figures 3* and *4.* The patterns for Saturday differ from Friday as surveys were not consistently taken on this day of the week. The early morning surveys' (9:00 a.m.) density reflected less traffic, particularly in City Park, compared to the other survey times. Based on the data, 9:00 a.m. proved to be the least popular time of day to be in the river recreationally and the most popular time of day was 1:00 p.m. When reviewing point densities based on the day of the week, weekend days had the highest traffic with large increases in areas seldom crowded during the week, such as the area below City Park.

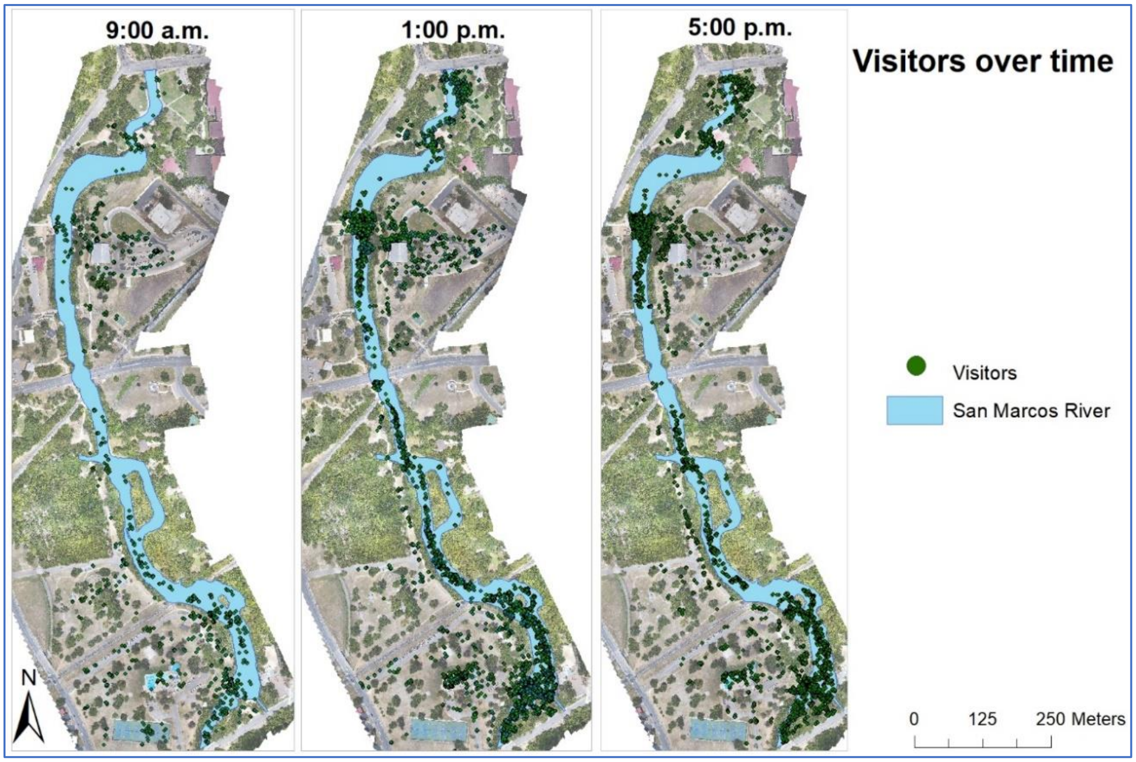

Figure 3. Density analysis based on times of the day: 9:00 a.m., 1:00 p.m., and 5:00 p.m. (left to right).

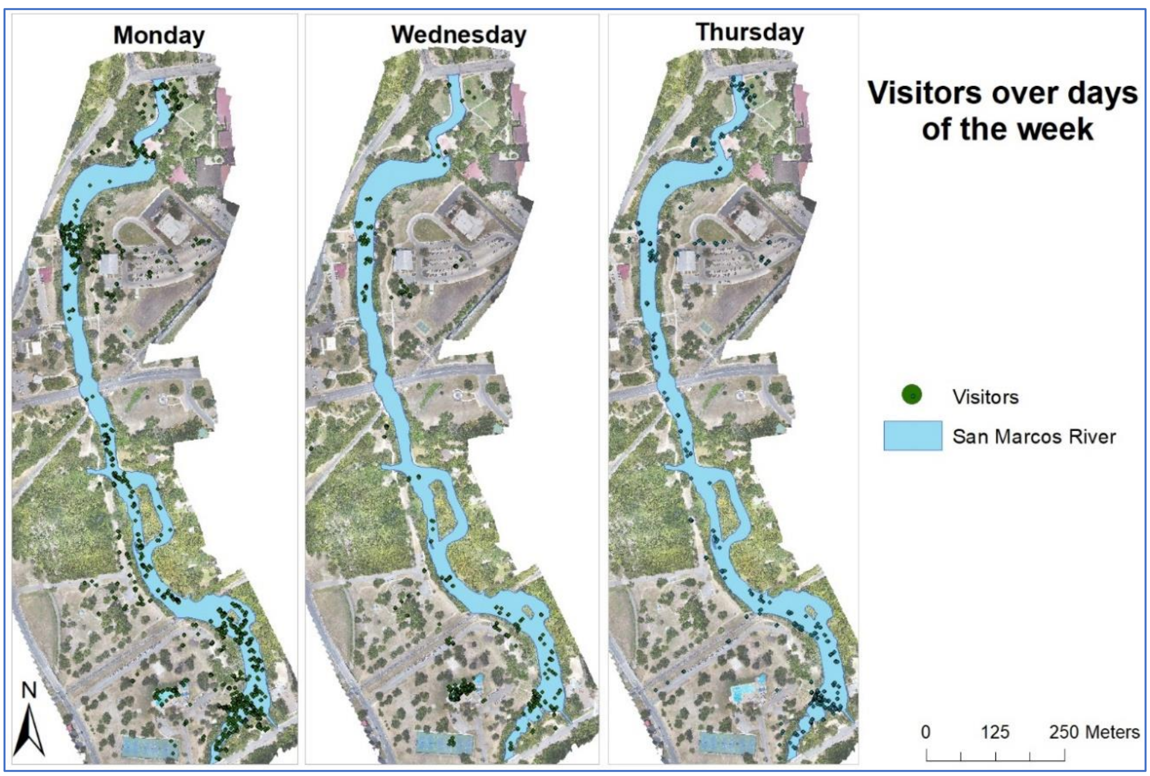

Figure 4. Density analysis for days of the week. Monday, Wednesday, and Thursday (from left to right)

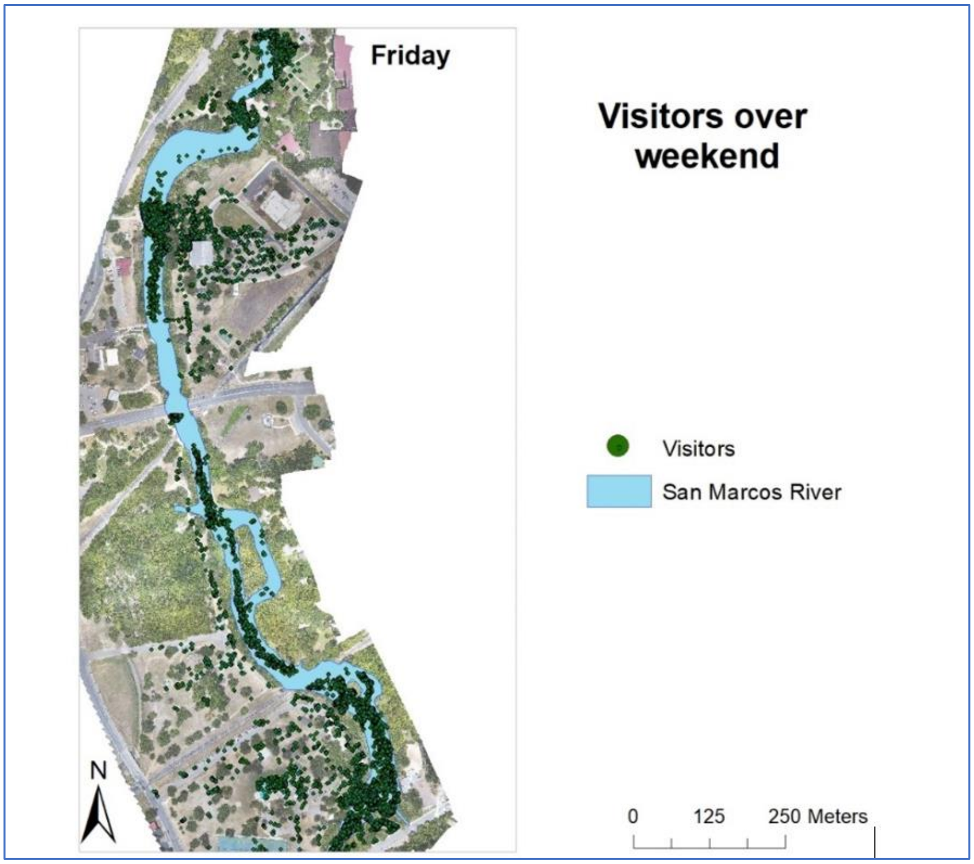

Figure 4.cont. Friday density analysis. Saturday was excluded as there was not sufficient data for accurate comparisons.

4.1.3. Dataset C – River Watch

Dataset C's data was listed with the assumption that the devices represented one visitor each. The visitor count sums were calculated for each day and then totaled by month for June, July, August, and September. Survey hours were from 9:00 a.m. to 7:00 p.m. amounting to ten hours a day. The last weekend of July had the highest total amounting to 4,506 visitors on one day. It was an average of 451 visitors every hour on July 30, 2016 (*Table 4*).

Table 4. Dataset C: River Watch 2016 survey data calculated within hours between 9:00 a.m. to 7:00 p.m.

Date	Day	Survey hours	Visitor total	Visitors per hour
6/11/2016	Saturday	10	3,558	356
6/18/2016	Saturday	10	4,092	409
6/25/2016	Saturday	10	4,295	430

7/02/2016	Saturday	10	4,383	438
7/09/2016	Saturday	10	3,257	326
7/16/2016	Saturday	10	3,958	396
7/23/2016	Saturday	10	4,452	445
7/30/2016	Saturday	10	4,506	451
8/06/2016	Saturday	10	3,490	349
8/13/2016	Saturday	10	2,015	202
8/20/2016	Saturday	10	541	54
8/27/2016	Saturday	10	1,303	130
9/2/2016	Friday	10	2,063	206

4.1.4. Estimated Daily Visitation (EDV)

The bar graph begins with May 2016 and ends in September 2016 (*Figure 5*). July 2016 had the highest visitor traffic with an estimated total of 24,718 visitors. The highest visitor traffic was recorded on June 30th with approximately 4,500 visitors and the lowest visitor traffic was recorded on June 4th with an estimated total of 63 visitors. Visitor counts were plotted according to the day and dataset onto a bar graph for visualization.

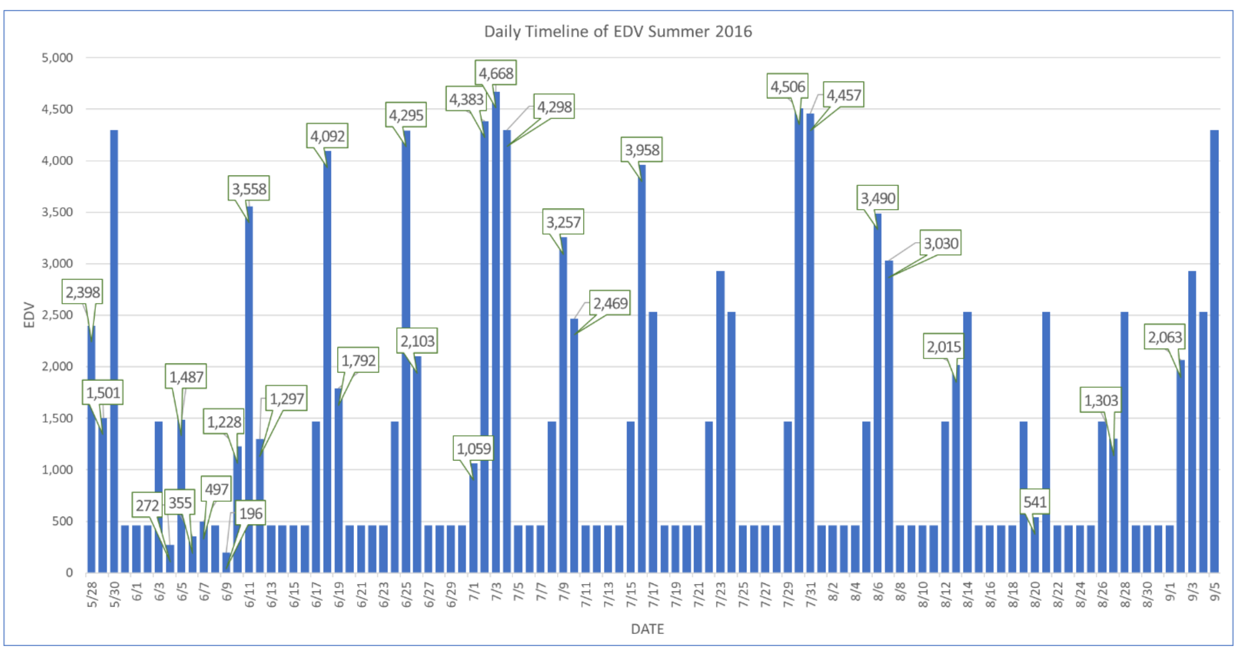

Figure 5. Graph representation of the daily timeline for the estimated daily visitation for Summer 2016. The numbers in call-out boxes are empirical values.

After visitor counts were tallied from each organized dataset, the overall estimated daily visitation for the season was calculated. The average multiplier for comparing Dataset A to Dataset C was calculated as four, meaning that Dataset A visitor counts on average are four times smaller than that of Dataset C (*Table 5*). The newly added table column included the new estimated visitor counts for Dataset C. Each day group's final EDV was calculated and added to obtain the EDV for the 2016 season. *Table 6* shows the day groups EDVs broken down further by hours.

Table 5. Estimated daily visitation combining the three datasets.

DATE	DAY	DATASET A	DATASET B	DATASET C	multiplier	Dataset A * 4	Estimated Dataset C
5/28/16	Saturday	600				2,398	2,398
6/4/16	Saturday	68				272	272
6/11/16	Saturday	559		3,558	6		3,558
6/18/16	Saturday	1,330		4,092	3		4,092
6/25/16	Saturday	812		4,295	5		4,295
7/2/16	Saturday	1,142		4,383	4		4,383
7/9/16	Saturday	795		3,257	4		3,257
7/16/16	Saturday	1,244		3,958	3		3,958
7/30/16	Saturday	1,689		4,506	3		4,506
8/6/16	Saturday			3,490			3,490
8/13/16	Saturday			2,015			2,015
8/20/16	Saturday			541			541
8/27/16	Saturday			1,303			1,303
5/29/16	Sunday	375				1,501	1,501
6/5/16	Sunday	372				1,487	1,487
6/12/16	Sunday	324				1,297	1,297
6/19/16	Sunday	448				1,792	1,792
6/26/16	Sunday	526				2,103	2,103
7/3/16	Sunday	1,167				4,668	4,668
7/10/16	Sunday	617				2,469	2,469
7/31/16	Sunday	1,114				4,457	4,457
8/7/16	Sunday	757				3,030	3,030

6/6/16	Monday	89				355	355
7/4/16	Monday	1,075				4,298	4,298
8/1/16	Monday		792				
6/7/16	Tuesday	124				497	497
6/9/16	Thursday	49				196	196
6/10/16	Friday	307				1,228	1,228
7/1/16	Friday	265				1,059	1,059
7/29/16	Friday		1,679				
8/5/16	Friday		1,397				
8/12/16	Friday		1,387				
9/2/16	Friday			2,063			2,063

Table 6. EDV, total visitation, and total observed hours. Days were grouped into five groups: Saturdays, Sundays, Holidays, Mondays-Thursdays, and Fridays.

Day	Number of Days	EDV	Total Visitation	Total Observed Hours
Saturdays	15	2,928	43,920	150
Sundays	14*	2,534	35,476	140
Holidays	4**	4,298	17,192	40
Monday-Thursday	54	460	24,840	540
Friday	14	1,469	20,566	140
Total Estimated Visitation for 2016 Season			141,994	1,010

***There was one less Sunday than Saturdays and Fridays because June 19, 2016 was Father's Day and grouped with holidays instead of Sundays.**

****Holidays were Memorial Day, Father's Day, Independence Day, and Labor Day**

4.2. Submerged Aquatic Vegetation

4.2.1. Areal measurements of submerged aquatic vegetation for April and October 2016

The calculation of species percentages per polygon shows that in April 2016, the total vegetation area consisted of 1,977.51 m^2 with a Texas wild-rice area of 1,194.13 m^2 for a coverage percentage of 60.39% (*Table 7*). The total vegetation area in October 2016 was 1,912.60 m^2 with a Texas wild-rice area of 1,204.54 m^2 for a coverage percentage of 62.98% (*Table 7*). Although the total vegetation area decreased from April to October, the total amount of Texas wild-rice increased proportionately.

Table 7. Vegetation and Texas wild-rice statistics for months of April and October.

Total subsection area	6,427.67 m^2
April total vegetation	1,977.51 m^2
April TWR	1,194.13 m^2
October total vegetation	1,912.60 m^2
October TWR	1,204.54 m^2
April vegetation out of subsection area	30.77%
October vegetation out of subsection area	29.76%
TWR in April vegetation	60.39%
TWR in October vegetation	62.98%

4.2.2. Vegetation Differences

The resulting shapefiles from the submerged aquatic vegetation analysis depict vegetation contraction (i.e., areas of loss) between April to October, vegetation expansion (growth) between April to October, and area of no change in the vegetation coverage between April and October (*Figures 6 and 7*). *Figure 6* shows the overall change of the total submerged aquatic vegetation area, encompassing the areas that grew, areas that died off, and the area of no change from month to month. *Figure 7* shows the same variables for both April and October with each month isolated. The map for April allows for easier viewing of the areas where contraction occurred, and the October map shows the areas where expansion occurred.

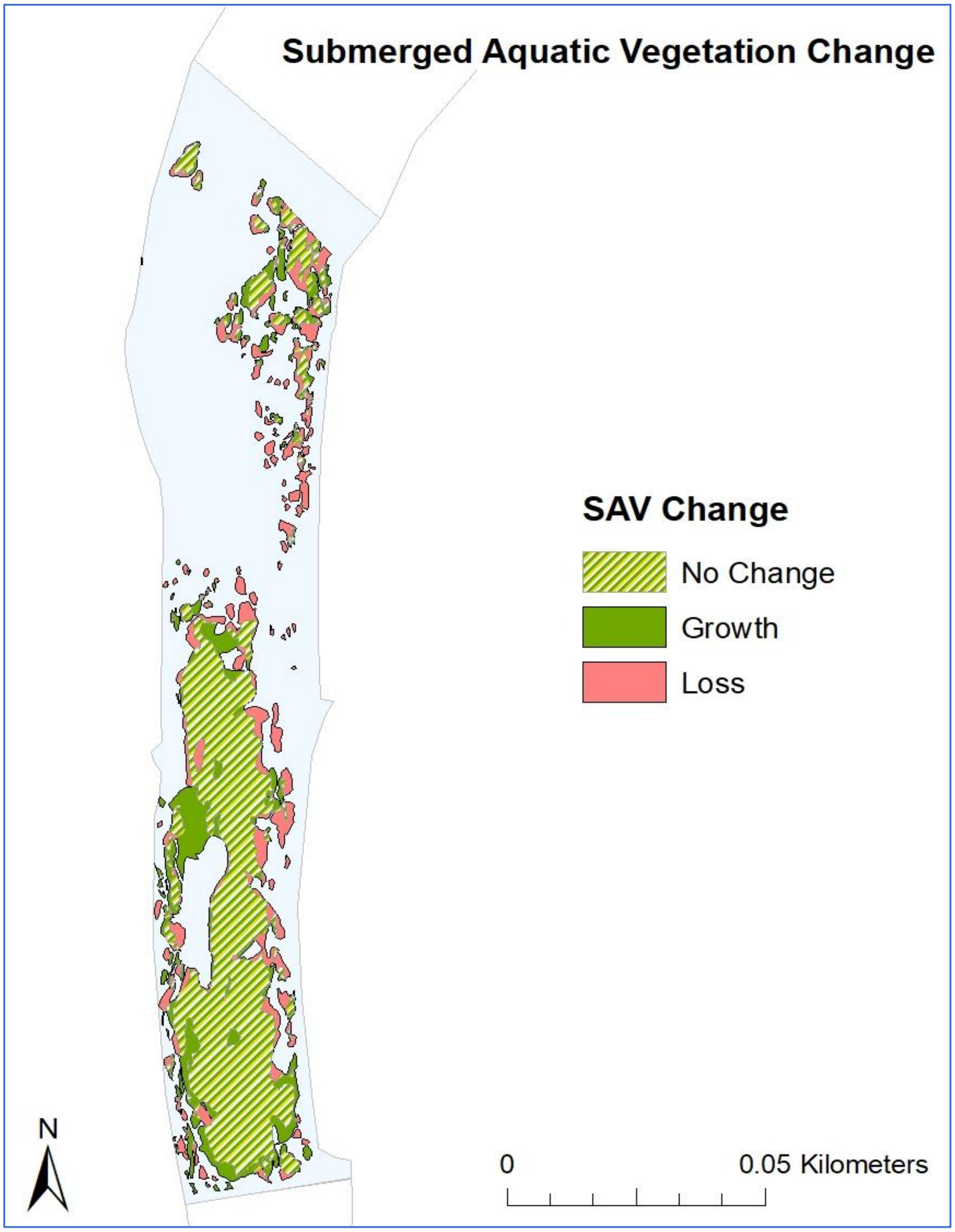

Figure 6. Map of SAV change in City Park subsection between April and October 2016.

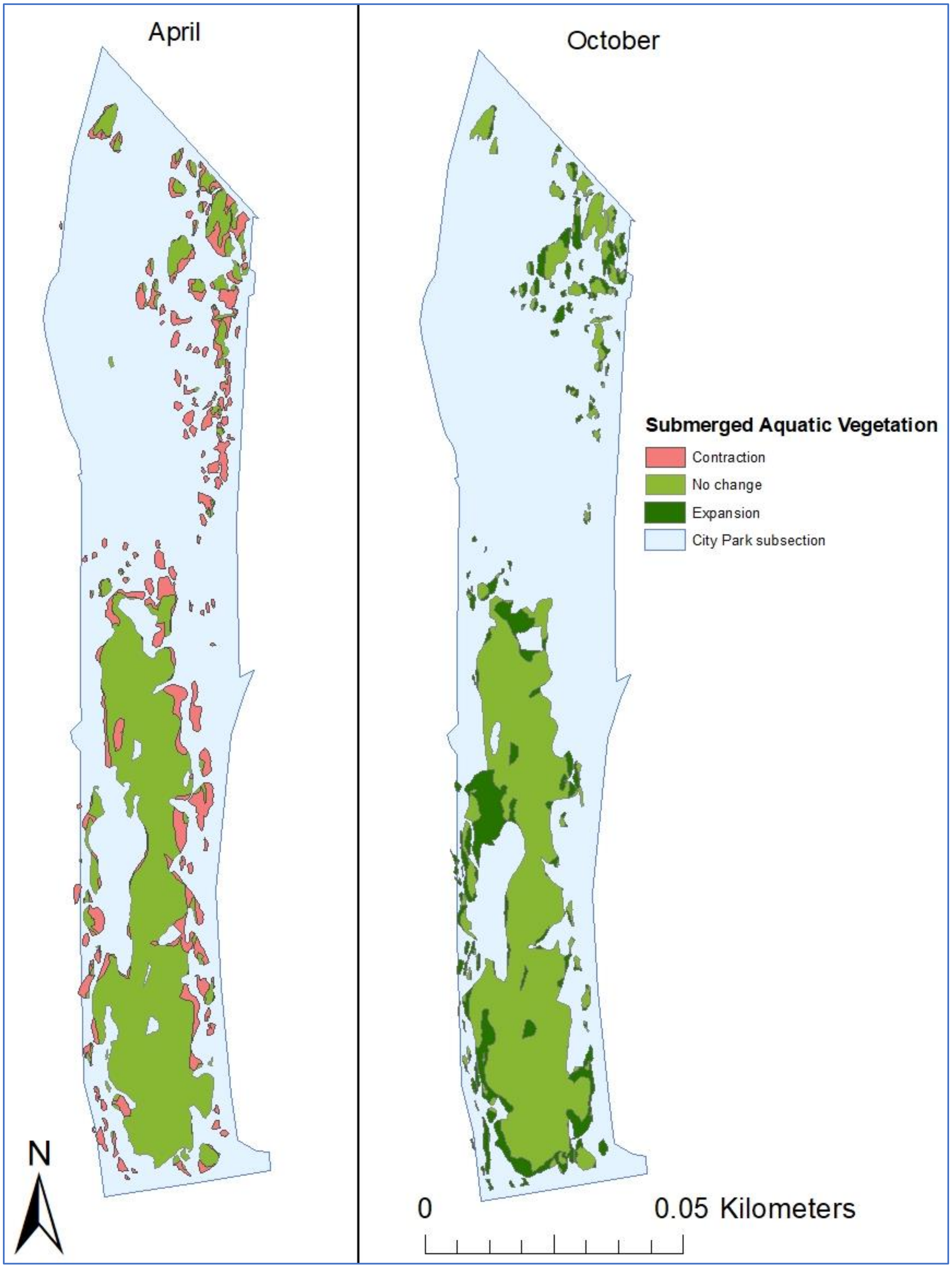

Figure 7. Separate views of the submerged aquatic vegetation during April including the areas that contracted (left) and October submerged aquatic vegetation including areas of expansion (right).

The calculated area change in contraction and expansion of Texas wild-rice yields negative values indicating loss between and positive values indicating growth over the April to October timeframe (Table 8).

Table 8. Percentage differences for Texas wild-rice between April and October to determine overall percentage of growth or loss.

Polygon ID	Polygon Area in SqM	April TWR%	April TWR in SqM	Oct. TWR %	Oct. TWR in SqM	Area Difference in SqM	% TWR Change
1	15.90	90	14.31	85	13.51	-0.79	-5
2	3.02	80	2.41	90	2.72	0.30	10
3	4.59	90	4.13	90	4.13	0.00	0
4	0.33	80	0.27	90	0.30	0.03	10
5	2.42	90	2.18	90	2.18	0.00	0
6	0.25	80	0.20	100	0.25	0.05	20
7	0.07	70	0.05	90	0.07	0.01	20
8	1.36	90	1.22	80	1.09	-0.14	-10
9	0.70	100	0.70	80	0.56	-0.14	-20
10	21.30	80	17.04	90	19.17	2.13	10
11	0.48	100	0.48	90	0.43	-0.05	-10
12	2.04	80	1.63	100	2.04	0.41	20
13	0.41	90	0.37	100	0.41	0.04	10
14	4.50	80	3.60	100	4.50	0.90	20
15	1.53	90	1.38	100	1.53	0.15	10
16	4.53	90	4.08	100	4.53	0.45	10
17	0.29	80	0.23	85	0.24	0.01	5
18	0.01	80	0.01	95	0.01	0.00	15
19	28.46	80	22.77	90	25.62	2.85	10
20	5.15	80	4.12	90	4.64	0.52	10
21	3.38	80	2.71	80	2.71	0.00	0
22	7.17	90	6.45	90	6.45	0.00	0
23	0.06	90	0.05	90	0.05	0.00	0
24	0.35	80	0.28	90	0.31	0.03	10
25	0.11	80	0.09	90	0.10	0.01	10
26	4.92	80	3.94	90	4.43	0.49	10
27	0.04	80	0.03	90	0.03	0.00	10
28	0.00	90	0.00	80	0.00	0.00	-10
29	0.16	100	0.16	100	0.16	0.00	0
30	7.00	80	5.60	90	6.30	0.70	10
31	0.09	100	0.09	90	0.08	-0.01	-10
32	0.81	80	0.65	90	0.73	0.08	10

33	0.01	90	0.00	90	0.00	0.00	0
34	1.67	90	1.50	90	1.50	0.00	0
35	1.14	90	1.02	90	1.02	0.00	0
36	1.36	80	1.08	90	1.22	0.14	10
37	1.19	80	0.95	90	1.07	0.12	10
38	0.21	80	0.17	90	0.19	0.02	10
39	0.19	70	0.14	80	0.16	0.02	10
40	0.35	80	0.28	90	0.32	0.04	10
41	1.48	80	1.19	90	1.34	0.15	10
42	0.48	70	0.34	90	0.43	0.10	20
43	2.76	80	2.21	90	2.49	0.28	10
44	0.14	80	0.11	90	0.12	0.01	10
45	0.22	80	0.18	90	0.20	0.02	10
46	0.40	90	0.36	100	0.40	0.04	10
47	0.32	90	0.29	90	0.29	0.00	0
48	10.84	80	8.67	90	9.75	1.08	10
49	0.61	90	0.55	90	0.55	0.00	0
50	1.55	80	1.24	80	1.24	0.00	0
51	0.49	90	0.44	100	0.49	0.05	10
52	0.77	90	0.69	100	0.77	0.08	10
53	0.57	90	0.51	90	0.51	0.00	0
54	0.04	100	0.04	100	0.04	0.00	0
55	0.02	100	0.02	90	0.02	0.00	-10
56	0.02	90	0.02	90	0.02	0.00	0
57	0.15	90	0.14	90	0.14	0.00	0
58	5.36	80	4.29	80	4.29	0.00	0
59	0.43	100	0.43	80	0.35	-0.09	-20
60	0.38	80	0.30	60	0.23	-0.08	-20
61	19.18	80	15.34	80	15.34	0.00	0
62	1235.12	80	988.10	80	988.10	0.00	0
63	2.19	100	2.19	80	1.75	-0.44	-20
64	0.24	90	0.21	80	0.19	-0.02	-10
65	0.78	100	0.78	80	0.62	-0.16	-20
66	0.35	90	0.32	80	0.28	-0.04	-10
67	0.62	80	0.50	80	0.50	0.00	0
68	10.42	80	8.34	80	8.34	0.00	0
69	0.60	60	0.36	80	0.48	0.12	20
70	1.03	90	0.93	80	0.83	-0.10	-10
71	0.77	80	0.61	80	0.61	0.00	0
72	1.98	80	1.58	80	1.58	0.00	0
73	0.42	90	0.38	80	0.33	-0.04	-10
74	0.08	90	0.08	80	0.07	-0.01	-10
75	0.04	80	0.03	90	0.04	0.00	10

76	0.07	90	0.06	90	0.06	0.00	0
77	0.09	90	0.08	90	0.08	0.00	0
78	0.09	90	0.08	90	0.08	0.00	0
79	0.90	80	0.72	90	0.81	0.09	10
80	1.35	80	1.08	90	1.22	0.14	10
81	0.68	80	0.54	90	0.61	0.07	10
82	0.02	80	0.02	80	0.02	0.00	0
83	1.00	80	0.80	90	0.90	0.10	10
84	0.12	80	0.09	90	0.10	0.01	10
85	0.36	90	0.32	90	0.32	0.00	0
86	0.33	90	0.30	90	0.30	0.00	0
87	6.07	90	5.46	80	4.86	-0.61	-10
88	1.53	100	1.53	80	1.22	-0.31	-20
89	2.00	80	1.60	90	1.80	0.20	10
90	1.41	90	1.27	90	1.27	0.00	0
91	2.88	80	2.31	90	2.59	0.29	10
92	1.95	80	1.56	90	1.76	0.20	10
93	4.75	90	4.27	90	4.27	0.00	0
94	0.21	90	0.18	90	0.18	0.00	0
95	0.25	100	0.25	90	0.23	-0.03	-10
96	0.01	90	0.01	90	0.01	0.00	0
97	11.80	90	10.62	90	10.62	0.00	0
98	0.02	100	0.02	90	0.02	0.00	-10
99	0.23	90	0.20	90	0.20	0.00	0
100	14.24	80	11.39	80	11.39	0.00	0
101	0.11	100	0.11	80	0.09	-0.02	-20
102	1.40	80	1.12	90	1.26	0.14	10

4.3. Vegetation and Visitor Interaction Results

After visitor counts and vegetation were analyzed separately, the final analysis focused on the comparison of visitor counts to vegetation coverage to determine the interaction of visitors with vegetation in the subsection study area. For the vegetation and visitor interaction analysis, the visitors in the river subsection study area were isolated from visitors outside the river perimeter and subsection study area. A point density analysis was performed in ArcMap using the isolated visitors with a mask applied in the environment settings to show the results within the subsection polygon (*Figure 8*).

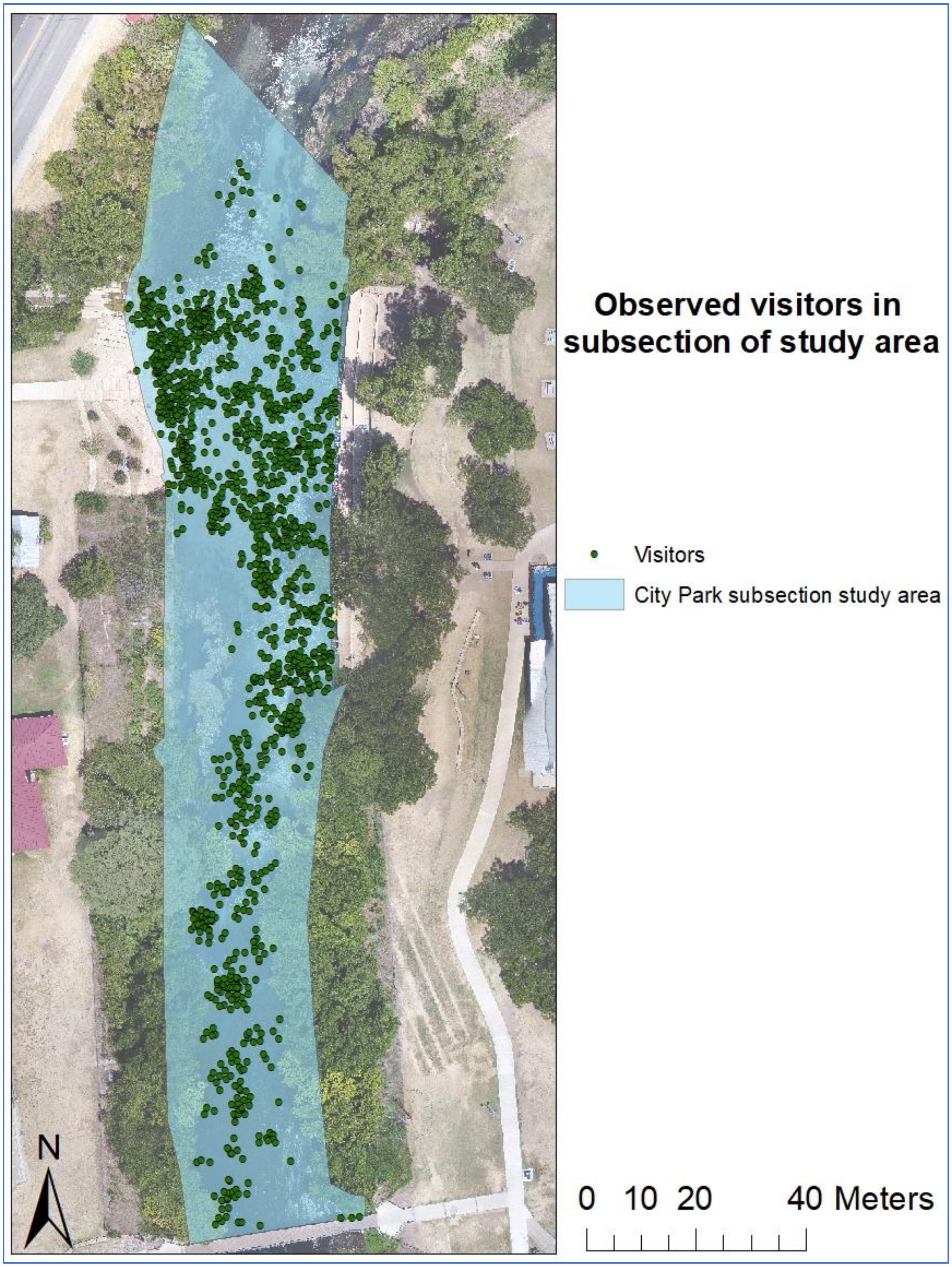

Figure 8. Visitor density for City Park subsection of the study area.

Visitor interaction with vegetation was characterized by counting the number of visitors located above the vegetation from Dataset B. Since distinct location points were not available for all days of the season, I assumed visitor density and usage patterns were consistent during the season. Vegetation present in April but not present in October was interpreted as vegetation loss while vegetation present in October but otherwise not present in April was interpreted as growth (*Figures 9* and *10*). The total number of visitors in proximity to April vegetation was 352 and the amount close to areas of loss was 97. An estimated 281 visitors interacted with the total October vegetation area and an estimated 30 visitors interacted near areas of growth. Out of the total 2016 season visitors observed, 9.7% interacted with submerged aquatic vegetation in the subsection area.

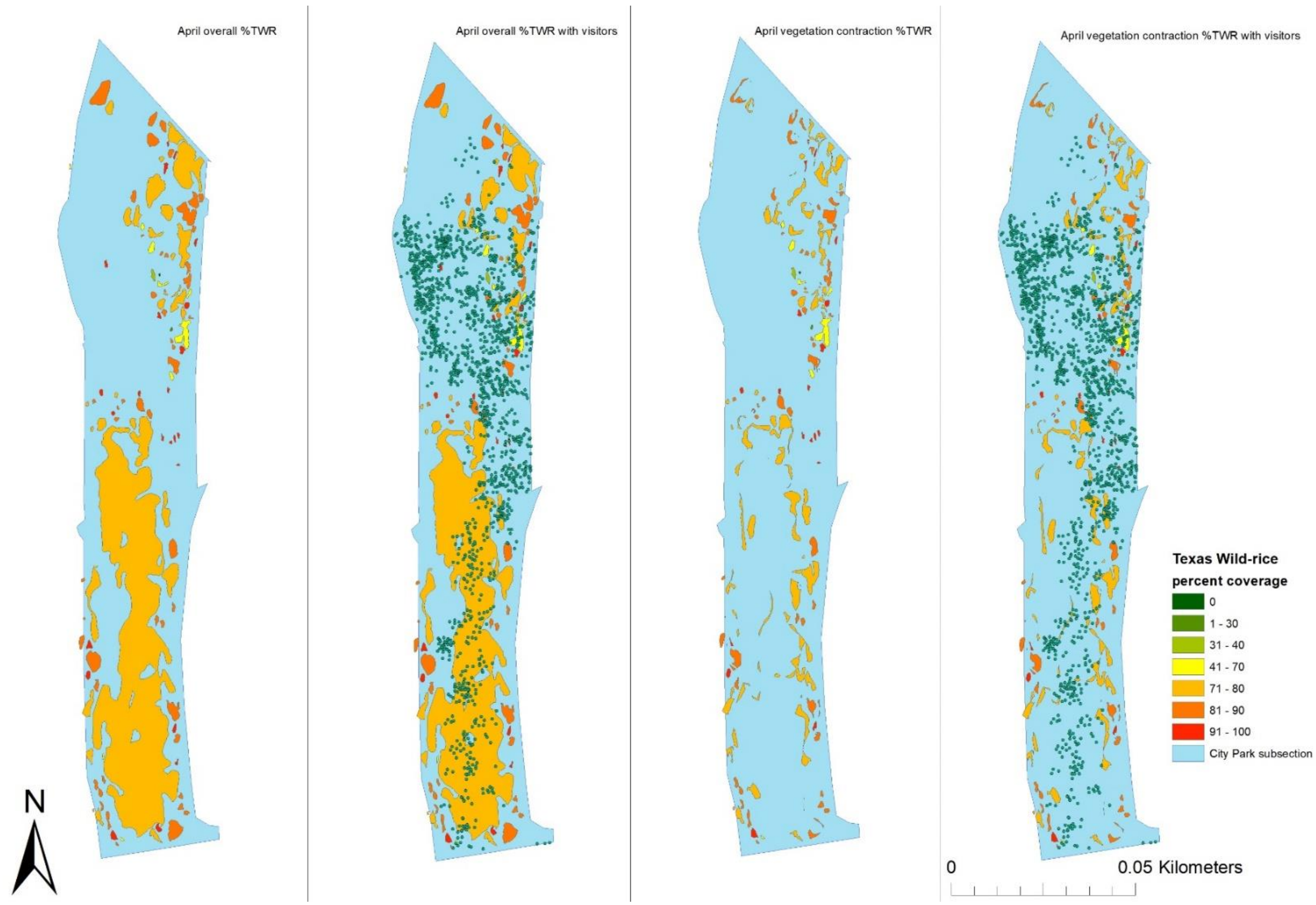

Figure 9. April Texas wild-rice percentages as seen with and without visitors. Left two maps show the overall total and the right two maps show the percent of Texas wild-rice that contracted between the months of April and October.

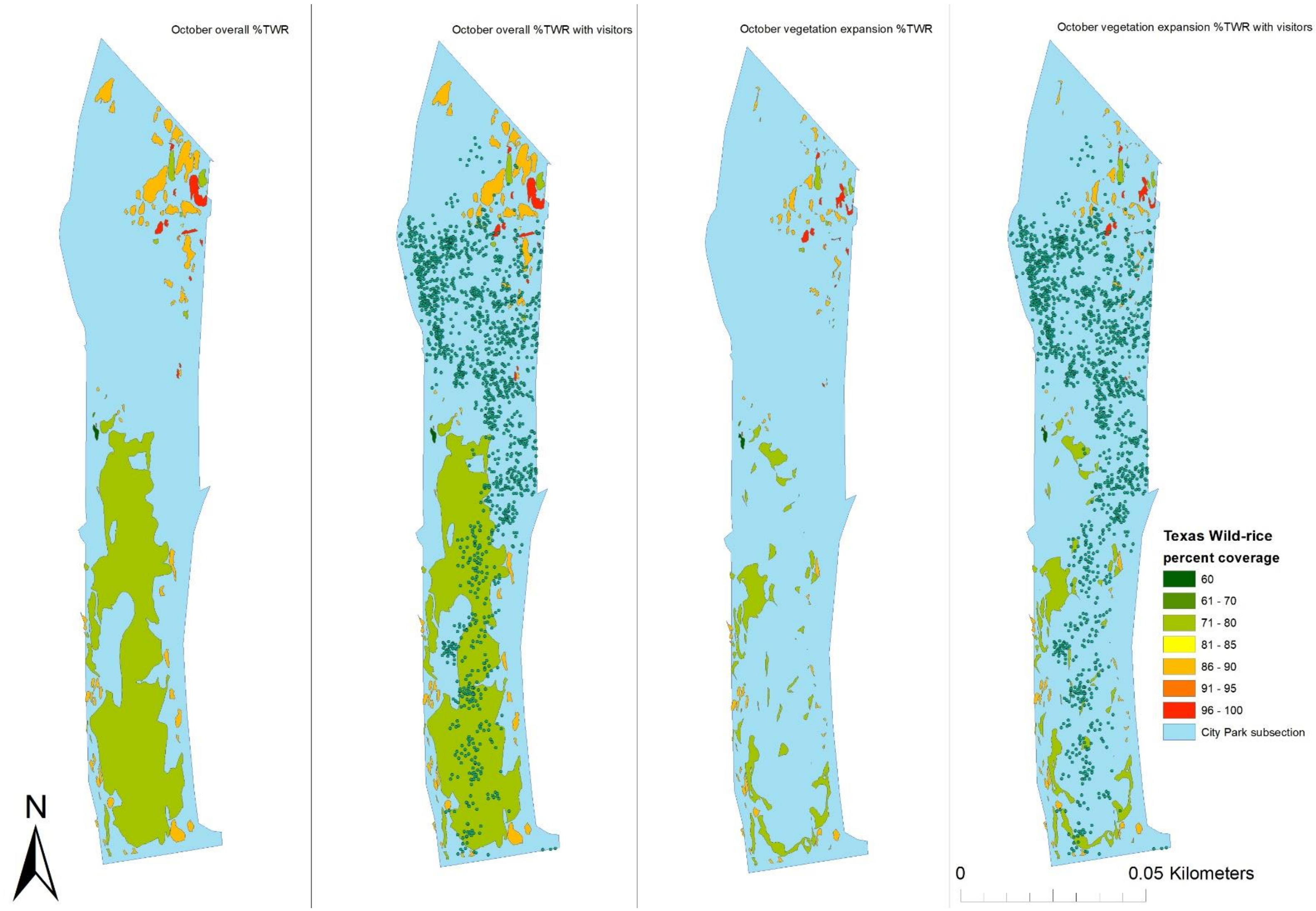

Figure 10. October Texas wild-rice percentages as seen with and without visitors. Left two maps show the overall total and the right two maps show the percent of Texas wild-rice that expanded between the months of April and October.

The percent change in Texas wild-rice was calculated from April to October 2016 using data from the vegetation differences analysis reported in Table 8. *Figures 11 and 12* depict the percent change in Texas wild-rice.

There are four large polygons of Texas wild-rice of interest in the submerged aquatic vegetation shapefiles. Polygons 1, 10, 19, and 62 make up the largest areas in the intersected (no area change) shapefiles with respective areas of 15.90, 21.30, 28.46, and 1,235.12 m^2. Polygons 10 and 19 reveal the highest percentage change with a growth of 2.13 and 2.85 m^2. Polygon 62 by far is the largest area of any polygon with 1,235.12 m^2. Visitors were prevalent on the upper reaches of the river with concentrations located near the edges of these stands. Coincidentally, these areas are where the most vegetation loss occurred. Most of the loss polygons of SAV disappeared on the east side of the river. About 27 out of about 50 polygons by City Park that were lost had interaction of some type with documented visitors as indicated by the people point overlay from Dataset B.

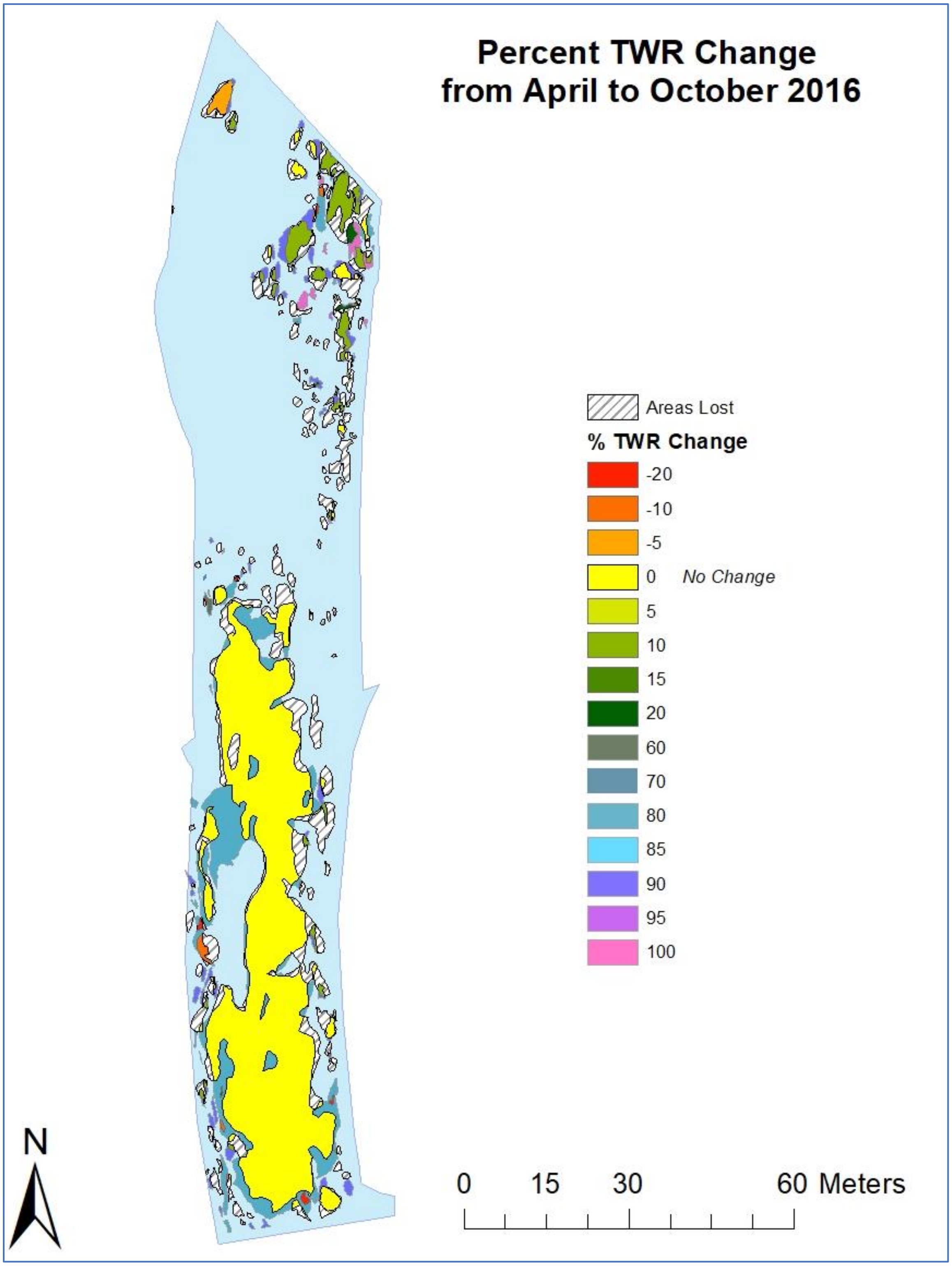

Figure 11. Percent change of Texas wild-rice map. Areas of no change are in yellow. Areas with a red, red-orange, or orange color showed areas where Texas wild-rice percent change decreased whereas green colors represented areas with a positive percent change. Areas where no percent change was detected were left blank.

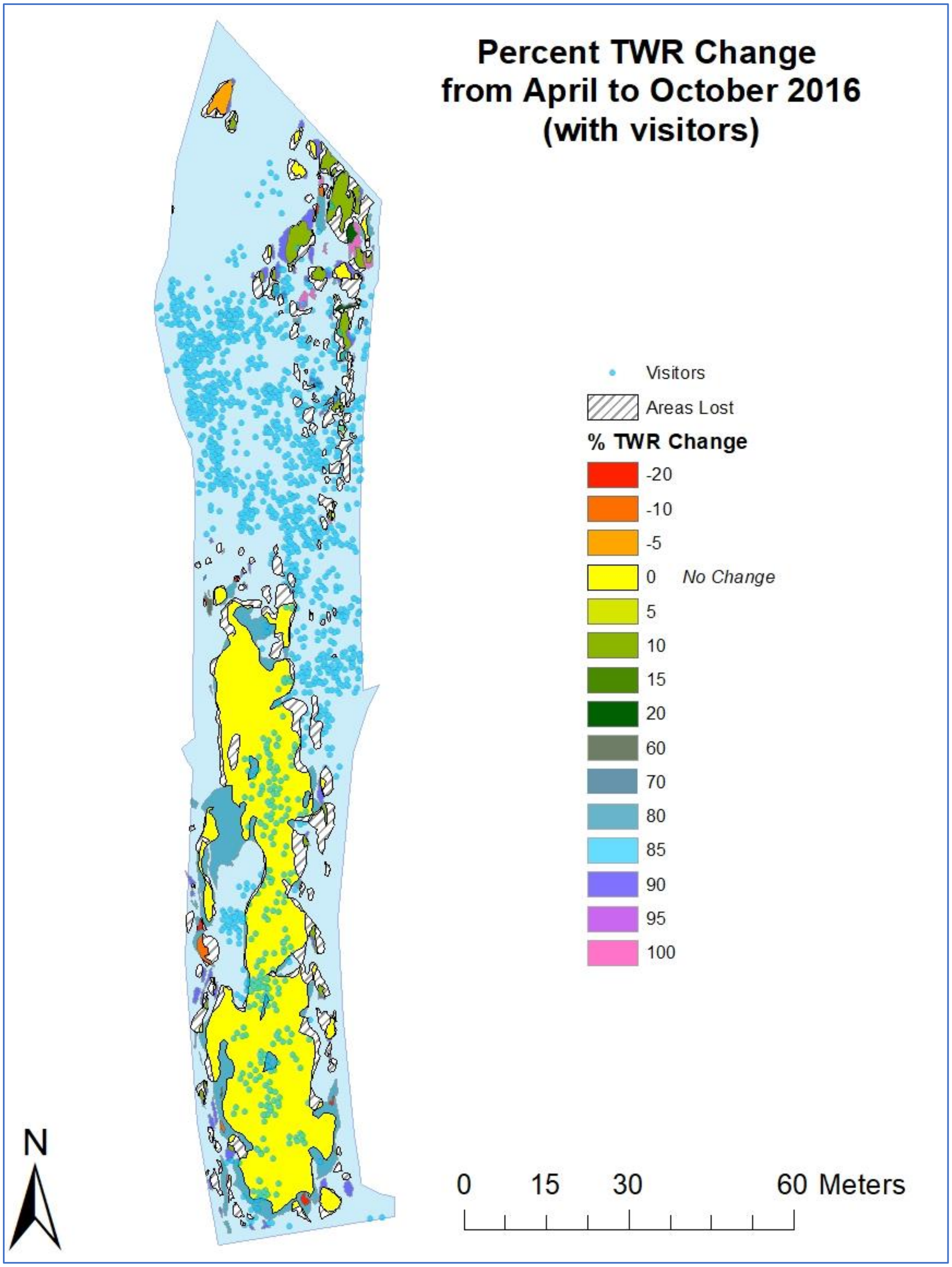

Figure 12. Percent change of Texas wild-rice map including visitors. Areas of no change are in yellow. Areas with a red, red-orange, or orange color showed areas where Texas wild-rice percent change decreased whereas green colors represented areas with a positive percent change. Areas where no percent change was detected were left blank.

4.4. Discussion

Dataset A vastly underrepresented total visitor counts in the river, as Lion's Club recorded only those visitors renting tubes through their facility and not those coming in with their own tubes or entering the river from locations other than City Park. Further, data was collected for weekends only and Dataset A also did not record recreationists that were not tubing. For these reasons Dataset A, as a single dataset, was considered an unreliable source of data for Estimated Daily Visitation (EDV). Dataset C was viewed as the best indicator of EDV when compared to Dataset A since it recorded all devices upon the river (kayaks, canoes, tubes, and paddle boards). However, since it was assumed each device recorded in Dataset C would represent one visitor apiece, it is also an underrepresentation of the total visitors per day. Devices like kayaks and canoes can support more than one person at a time, and some tubes had multiple people. Further, Dataset C did not account for people recreating near City Park that did not float downstream. Families gather in the City Park area for easier access for younger or less able-bodied persons. Staying in this area would be ideal and safer for these groups. Thus, Dataset C is an underrepresentation of visitation as well.

Dataset B represented a point in time and assumptions were that the same pattern was consistent regardless of the day during the peak season. The variations of visitor count point analyses all followed a similar pattern with concentrations at the three parks along the San Marcos River. However, the assumption that all days follow the similar pattern displayed by Dataset B makes it difficult to discern a more accurate representation of river use. I also did not account for weather effects on visitation, such as cool days, thunderstorms, and high water events that may have resulted in fewer visitors. More observations, ideally daily, would need to be conducted to get a truer representation.

Comparing the three datasets was difficult with the lack of days containing data for more than one dataset. Only one day included visitor counts from all three datasets but that day was excluded for having one observed hour for Dataset B and could not be compared to the other datasets. Another difficulty in estimating EDV was calculating the hours for each dataset based on the assumption they had similar observed hours. There was not enough data from all three datasets to make more accurate estimations.

Based on the available data, July 2016 produced the highest usage of the river and was near the peak of the hot summer season in the Hill Country at a time when a majority of students were on break for the summer (U.S. Climate Data, 2020). Sewell Park, City Park, and Rio Vista Park all depicted the areas of densest visitor counts. The City Park subsection's lower area coverage of Texas wild-rice and other submerged aquatic vegetation is relatively absent most likely from the extensive visitor traffic occuring there. Hardened riverbank access at this location and Sewell Park provides an easy route for people to directly enter the river. Rio Vista Park is also accessible from different locations and is the designated shuttle pick-up area for Lion's Club. An estimated total of visitor counts for the 2016 summer season was calculated at 141,994 visitors. Holidays averaged 4,298 visitors a day, Saturdays averaged 2,928, Sundays 2,534, weekdays averaged 460, and Fridays averaged 1,469. These values were much higher than the previous estimations in Bradsby's (1994) study, reflecting increasing visitation and recreation over time. Bradsy estimated 56 visitors a day on weekdays, 461 visitors on weekends, and holidays averaged 475. July 4th had the highest estimated visitor count with 753 visitors on that day. It should also be noted that my estimate of approximately 140,000 visits is only for my small study area near City Park. This estimate would be much higher, likely more than double, if the entire Upper San Marcos River was considered. Indeed, Halff (2010) reported that the Upper San Marcos River receives about 500,000 visits per year.

The lack of data for visitor location points for Datasets A and C justified why the submerged aquatic vegetation polygons were checked against visitor location points from Dataset B. Because no location data was available for Datasets A and C, the analyses were conducted under the assumption the patterns of visitor traffic in the river are constant. Therefore, a true estimation of the level of interaction between visitors and the aquatic vegetation was not feasible. However, results depicting the overall reduced numbers of submerged aquatic vegetation for the month of October when compared to those of April is suggestive of recreation impacting rivers from previous studies mentioned in this paper.

Positive growth changes in submerged aquatic vegetation and Texas wild-rice occurred despite the recreation impacts. The spatial patterns showed most of these areas of growth occurred away from the wadable hardened access points. Increases in submerged aquatic vegetation coverage could be attributed in part to the removal of non-native species from the study area and planting of the species in accordance with the biological goals. Without the efforts of the Habitat Conservation Plan, it can be assumed recreation may have had more substantial effects on the growth and loss of submerged aquatic vegetation.

Overall, the areas of Texas wild-rice contraction are distributed along the outer edges of vegetation clumps and near the riverbank, which is characterized by shallow areas where people usually access the river. From 2015 to 2016 Texas wild-rice coverage decreased from 5,511.1 m^2 to 5,482.8 m^2. In comparison, since the implementation of the first EACHP survey in 2013, Texas wild-rice coverage has increased dramatically from 2,467.6 m^2 (Edwards Aquifer Authority, 2016). A closer look at the spatial patterns of percent change in Texas wild-rice coverage suggests recreation was impactful in the 2016 season. Unfortunately, without the exact locations of Texas wild-rice stands within the polygons, it was difficult to measure the changes. All estimations relied on the assumption that the percentage of Texas wild-rice did not change when there was a change in the total area of submerged aquatic vegetation. Larger contiguous, intact patches tended to stay the same or grow in comparison to the areas that consisted of smaller, somewhat clustered, yet fragmented patches. The changes in the four largest polygons (1,10,19, and 62) suggested that larger patches are more resilient. Out of the four largest polygons, the largest (Polygon 62) had a 0% change in the percentage of Texas wild-rice.

The location of Polygon 62 in the middle of the river in part explains the lack of change. Polygon 62's location was closer to the thalweg as the currents merge into the center of the channel. Polygon 62 is also less susceptible to trampling by being located downstream and away from direct riverbank access of where visitors enter the river at City Park. By the time visitors traveled over the channel center after entering through the shallower areas, they would usually be floating on tubes and the deeper water likely protected the larger stands of Texas wild-rice.

On the contrary, most of the smaller fragmented patches near the access areas were lost from April to October. Almost half of the small, fragmented patches of submerged aquatic vegetation were lost in the area of City Park and Lion's Club tubers' main access point. The lost patches coincided with areas of high visitor use near the shallower banks of the river.

We can expect Texas wild-rice biomass to increase during the growing season and the large areas with higher percent change in growth, like Polygons 10 and 19, could have benefitted from supplemental plantings, offsetting the detrimental effects of recreation. There are other factors accounting for the continual growth of Texas wild-rice. Breslin's study (1997) mentioned instances in which students that were aware of the importance of Texas wild-rice took it upon themselves to inform those impacting the plant of its importance. Educational organizations, signposts, and social media relating to the San Marcos River have contributed to the growing awareness of the role of Texas wild-rice in the local aquatic biosystem. For example, the Meadows Center for Water and the Environment conducts glass-bottom boat tours, where visitors are educated about the unique aquatic ecosystem. To educate students, some courses at Texas State University require students to take this tour. Additionally, signs have been posted along large swaths of Texas wild-rice stating their endangered status and related conservation efforts in action.

During the summer of 2016, the San Marcos River also experienced a higher-than-normal median flow of 7.65 m^3/s instead of the typical median of 5.10 m^3/s (USGS Waterdata, 2016). A higher flow may have limited the area of wadable riverbed leading to less trampling of submerged aquatic vegetation. Another hypothesis to Texas wild-rice's resiliency is the effect from flash flooding. The direct physical effects of flooding (shearing, uprooting, tearing) are detrimental to Texas wild-rice growth. However, if the plant withstands the flood's initial impact, it may benefit from the higher, silt-flushing flows which remove fine sediment accumulation, providing more suitable substrate for Texas wild-rice expansion.

A drawback of conducting this analysis was how the polygons did not show specific locations of each vegetation type but were generalized for the vegetation community. Percentages of submerged aquatic vegetation were calculated per polygon. This meant several vegetation species occupied a polygon with no demarcation as to where each species was located within the polygon. Determining the specific areas of Texas wild-rice affected by recreational activities is a difficult task given continuous plant growth and loss, planting efforts, and invasive removal efforts which open new habitats. The presence of tree canopies over portions of the river can also hamper proper identification of some submerged aquatic vegetation when using only aerial imagery. Although underwater observers would sometimes be deployed to verify the species within a large polygon, environmental factors could disrupt positions, presence, or absence. Distinguishing cause and effect among these variables is challenging when using data from only two static time steps.

Another challenge to this analysis is the multitude of different entities collecting river user data. Most created their own data sets for different sections of the river covering different time frames, making it difficult to find continuous overlapping data that can be compared to each other. Due to these circumstances, many assumptions were made in this report to calculate the estimated daily visitation (EDV) from three different datasets.

Conclusion

This study provided a short-term analysis of temporal and spatial recreational use patterns of the 2016 summer recreation season on the San Marcos River and examined the potential implications of river-related recreation on Texas wild-rice distribution changes. Small, fragmented areas near heavy visitor traffic experienced contraction while larger connected areas experienced growth or no change. Visitor traffic in my study area for the summer season of 2016 was estimated at approximately 140,000 visitors.

The endangered and endemic Texas wild-rice, with a habitat range unique to the San Marcos River, requires continued conservation of its habitat, as is occurring through the EAHCP, to prevent further ecosystem degradation. There are many factors involved in the management of Texas wild-rice in the San Marcos River including invasive plant removal, native species planting, and recreational use monitoring.

Monz et al. (2013) and Bradsby (1994) stated areas that had previously been highly impacted by recreation will not incur much further damage after the initial impacts of recreation. In comparison, areas subjected to many small but continual initial impacts will continue to be damaged. I recommend that larger segments of the San Marcos River be included in a State Scientific Areas (SSA). Exclusive protection zones conserve and preserve the areas with little recreation impact to allow for the aquatic vegetation to grow. In 2015 Texas Parks and Wildlife Department designated a two-mile segment of the San Marcos River's public waters as a SSA to mitigate the impacts of recreation (Edwards Aquifer Authority, 2015). The SSA's are specific areas within the upper river designed to protect Texas wild-rice. They represent areas that people should not enter or float over. During low flow conditions below 3.40 m^3/s, they are bordered with floating exclusion buoys to prevent people from entering them. The spatial pattern of SAV contraction documented in 2016 provide evidence that recreation affects Texas wild-rice coverage.

The planting efforts of the EAHCP likely counter-acted some of these impacts. It is also important to note the subsection area of this study is a very small portion of the San Marcos River. Analyzing the vegetation differences for this area alone is not sufficient in determining the overall state of Texas wild-rice across the full range of the species.

Multiple factors contribute to the success or decline of the Texas wild-rice. Based on this paper's analyses, one can conclude the plant will continue to be successful only if there are designated areas for recreation and those for conservation. Texas wild-rice coverage might stay healthy with continuous planting and removal of non-native species. Population increase, climate change, and pollutants are factors which might prevent Texas wild-rice from continuing its growth pattern. Today an increase in pollutant loads, particularly in City Park (The Meadows

Center for Water and the Environment, 2018), is another factor that may affect the population of Texas wild-rice, but more studies are needed to better understand those effects. Climate change, and particularly the long-term forecast for more intense droughts and lower flows (and hence shallower, wadable area) and the initial impacts of larger floods may threaten the resiliency of Texas wild-rice. Future studies should collect continuous data on river usage and recreation to document the impacts on native submerged aquatic vegetation over the recreation season.

With the ever-growing population and tourism, further steps must be adopted to prevent further degradation. Ideally this analysis will aid stakeholders concerned about impacts of recreation on Texas wild-rice along the San Marcos River. Policies, regulations, and management practices such as those in the EAHCP must continue to be implemented to protect Texas wild-rice and the integrity of the San Marcos River ecosystem.

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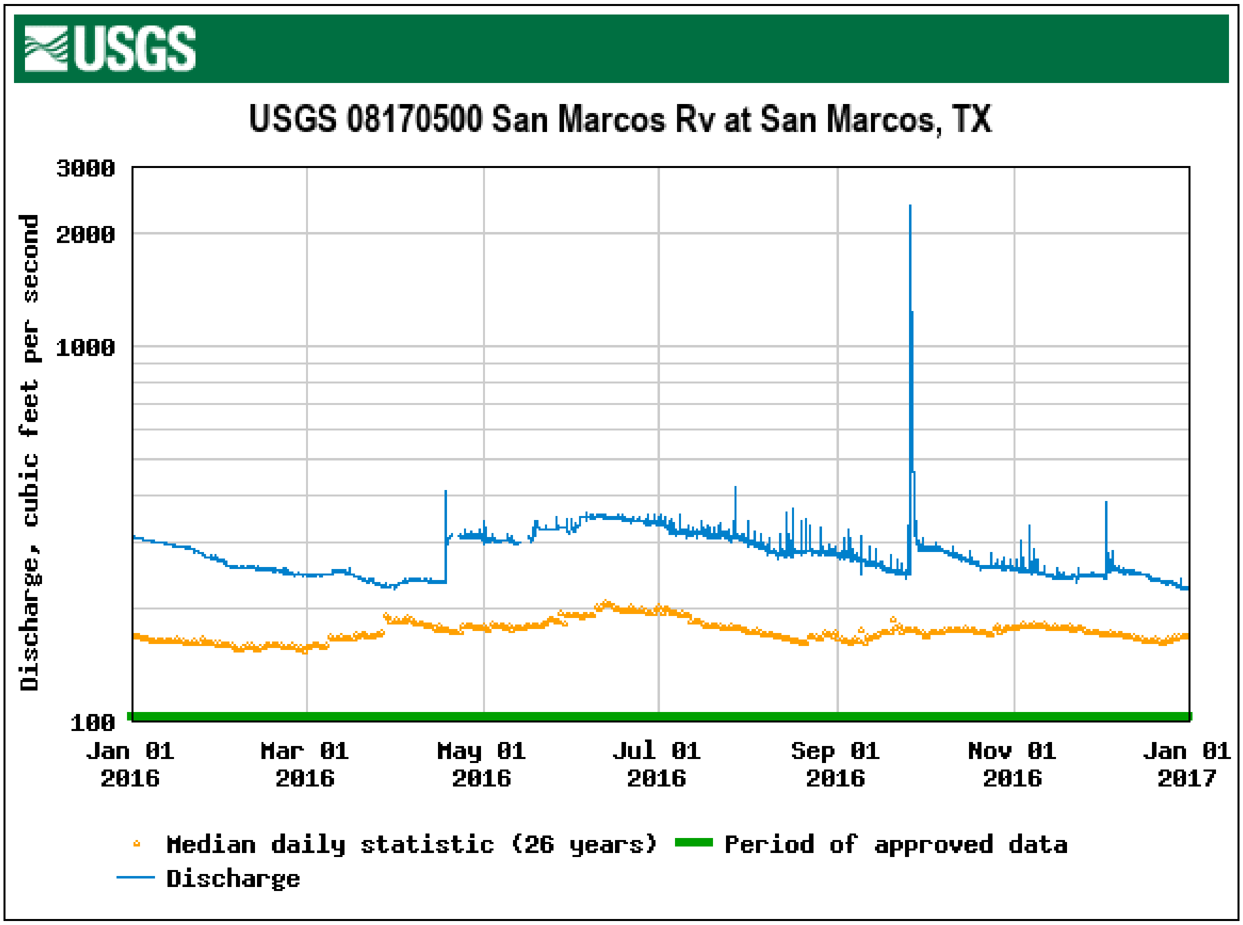
Appendix



Appendix A. USGS hydrograph and median discharge from January 01, 2016 to January 01, 2017 for the San Marcos River.