In Cooperation with Northern Arizona University

2011 Monitoring Tamarisk Foliage Removal by the Introduced Tamarisk Leaf Beetle (*Diorhabda carinulata)*, and its Effects on Avian Habitat Parameters along the Colorado River in Grand Canyon National Park, Arizona

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Conversion Factors

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:°C=(°F-32)/1.8

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Abstract

Six trips to sample for the presence of tamarisk leaf beetles (*Diorhabda carinulata)* along the Colorado River and its tributaries between Lees Ferry and Pearce Ferry, Arizona occurred from May to September 2011. The beetle's presence was sampled at a maximum of 241 sites. At 21 of the sampling sites, thermistors were deployed to measure air temperature and relative humidity throughout the sampling season. The thermistor sampling sites were at Colorado River Management Plan (CRMP) monitoring sites where avian and vegetation data were also collected.

In 2010, leaf beetle was detected in June, though recorded only as a single individual in the late larval state at Lees Ferry (river mile 0). By July, beetles in all life stages were observed upstream and downstream of Lee's Ferry and Kanab Creek, both major Grand Canyon tributaries. The greatest densities were observed during the August sampling period. Localized defoliation was most noticeable during September, with an estimated 50% defoliation of tamarisk cover at some sites. In 2011, the tamarisk leaf beetle in Grand Canyon National Park along the Colorado River became an established population. During 2011, the tamarisk leaf beetle's presence was detected in April at Lees Ferry (river mile 0) where high numbers of adults emerged from diapause. By May, beetles in all life stages were observed at several locations along the river corridor. Beetle densities were greatest between Lees Ferry and river mile 25, and between river mile 108 and 189. The greatest densities for all life stages of the beetle were observed during the June and July sampling periods. Defoliation was at its height during late July and August with an estimated 70% defoliation of tamarisk cover at some sites.

In 2011, our microclimate measurements at CRMP sites found mean temperature in the months of June through August tended to be greater among sites relative to the middle portion of the river corridor (e.g., Hance to 185 mile) than sites at either end of the river corridor.

Comparisons of mean temperatures between 2010 and 2011 indicate that July mean temperatures were significantly different in July with 2010 having warmer mean temperatures than 2011. In 2011, mean relative humidity across sites trended downward most markedly in September with distance from Lees Ferry. The difference in relative humidity across sites was most prominent in August and September of 2011. Comparing mean relative humidity between 2010 and 2011 indicated significant difference existed between years for the months of July and August. Mean humidity in July 2010 was 29.3% while in July 2011 relative humidity was 38.5%, for August relative humidity was greater in 2010 than in 2011.

We also examined the presence of birds at the CRMP sites within Grand Canyon NP where point count surveys were conducted between 2007 through 2011. We examined the mean abundance of bird's species before the presence of the tamarisk leaf beetle and the effects the beetle may have had on abundance of those species after the beetle arrived. In 2010 and 2011, a total of 81 bird species were detected during the CRMP breeding bird surveys within the new high water zone (NHWZ). The bird species detected in the NHWZ riparian habitat using tamarisk-dominated habitat are most likely to be affected by the beetle. Comparison in abundance (unadjusted for detectability) of bird species in the NHWZ before and after beetle presence found significant increases in mean abundance for common yellowthroat (*Geothlypis trichas*), lesser goldfinch (*Carduelis psaltria*) and decreases of house finch's (*Carpodacus mexicanus).* These bird abundance results are based on the presence of the beetle over a two year period, and therefore are preliminary. We highly recommend continued long term monitoring of birds in tamarisk-dominated habitat in Grand Canyon National Park in order to determine long term trends of these species and what affects the tamarisk leaf beetle may have on them.

Introduction

Tamarisk is a highly invasive plant native to Eurasia. It was introduced in the late 19th and early 20th century throughout the southwestern United States as a landscape ornamental plant, and to help stabilize soil (Robinson, 1965). Though capable of establishing along unregulated channels, it is equally successful in regulated channels (Stromberg, 1998; Birkin and Cooper, 2006). Tamarisk is prevalent in riparian habitats throughout the southwest (Friedman and others, 2005), including along the Colorado River in Grand Canyon National Park (GRCA), where it has expanded since river regulation began in 1963 when Glen Canyon Dam became operational (Turner and Karpiskac, 1980; Ralston and others, 2008; Kennedy and Ralston, 2010). Tamarisk's presence can affect native plant diversity, wildlife habitat, and poses an increased wildfire risk where dense stands occur (Busch and Smith, 1993; Bailey and others, 2001; Kennedy and Hobbie, 2004).

In 1999, the tamarisk leaf beetle (*Diorhabda carinulata*) was approved for release as a biological control agent in areas of the southwestern United States, specifically in southern Utah and southwestern Colorado (DeLoach and others, 2000; Dudley, 2005). The beetles (in the larval stage) feed on the leaves of tamarisk and defoliate the plant in the summer months (generally June – early September). Defoliation compromises the plant's ability to photosynthesize and store food resources in its roots. Late season flower and seed production also become limited. The repeated defoliation by the beetle over several years causes the root mass to decrease in size until it can no longer support the plant or reproduce.

The tamarisk leaf beetle has shown signs of successful establishment on the Colorado River from Cisco-West Water to the Colorado/Green River Confluence, and along the Green River from Green River, Utah to the confluence with the Colorado River, on the Dolores River to above the University of Utah Field Station at the Entrada Ranch, and up into southwestern Colorado (Dennison and others, 2009).

In Grand Canyon NP, larvae were detected in 2009 near Navajo Bridge and at river mile 12 (Makarick, unpublished data). In 2010, the leaf beetle was detected in June, but only as a single individual in the late larval state at Lees Ferry (river mile 0), by July, beetles in all life stages were observed at several locations along the river corridor, though not continuously distributed throughout. The greatest densities for all life stages of the beetle were observed in the August sampling period. Localized defoliation was most noticeable during the last survey trip in September, with an estimated 50% defoliation of tamarisk cover at some sites.

Personnel from Grand Canyon National Park conducted breeding bird surveys from 2007 to 2011 along the Colorado River in Grand Canyon as part of the 2006 Colorado River Management Plan Resource Monitoring Program (CRMP; Kearsley 2007). We conducted surveys for TLB at the same sites during the spring and summer of 2010 and 2011. Here we summarize the bird CRMP data (unpublished data, Grand Canyon National Park), compare the distributions of riparian breeding birds and TLB along the river corridor, and discuss the possible effects of TLB on riparian habitat and riparian breeding birds.

The completion of Glen Canyon Dam changed the hydrograph of the Colorado River through the Grand Canyon. Reduction in peak annual flow and the absence of historical floods that removed lower riparian zone vegetation allowed perennial plant species, mainly nonnative species, to colonize these areas. These new areas of riparian vegetation are referred to as the new high-water zone (NHWZ), and are generally dominated by tamarisk. The higher pre-dam riparian habitats are referred to as the old high-water zone (OHWZ) and generally are devoid of tamarisk. The beetle mainly impacts the NHWZ riparian habitat because individuals in its larvae and adult phases feed exclusively on tamarisk and defoliate tamarisk trees. Defoliation of tamarisk trees eliminates physical vegetation cover which can affect riparian breeding bird nest success by increasing exposure of nests to nest predators, and affecting microclimate (temperature and humidity) of nests sites. Repeated defoliation may lead to tamarisk mortality and habitat loss for bird species that nest in the NHWZ.

The expansion of the beetle to riparian areas of Arizona and southern Utah pose a threat to riparian breeding birds that utilize tamarisk for nesting. Bird use of tamarisk is often greater than generally recognized; across the western United States, 49 species have been documented breeding in tamarisk, and in Arizona and New Mexico 11 bird species of regional or national concern frequently breed in tamarisk (*Sogge et al. 2008*). However, there is little research on the ecological ramifications of breeding in tamarisk, and therefore establishing baseline information about nesting sites including bird abundance, ambient temperature and relative humidity data prior to and following the arrival of the beetle provides managers an understanding of the extent and possible consequences of the beetle's presence to changes in plant biomass and diversity, and migratory bird nesting success. A species of concern is the southwestern willow flycatcher *(Empidonax traillii extimus),* a federally-listed endangered species that breeds along the Colorado River in Grand Canyon National Park (Sogge et al. 2007, Johnson and Abeita 2001, Paxton et al. 2007). The flycatcher is one of several Neotropical migrants that breed in tamarisk and may be vulnerable to the effects of the tamarisk leaf beetle (Hultine et al. 2009). One possible adverse effect may occur if beetles defoliate tamarisk trees during the breeding period of the willow flycatcher (Hultine et al. 2009). Defoliation may affect the nest tree foliage cover and structure and expose the nest to direct sunlight, excessive heat, and nest predators, ultimately affecting the breeding success of the flycatcher.

A sampling program to measure the extent and density of beetles at the three life stages (adult, early and late larvae) along the river corridor and the effects of defoliation on temperature and relative humidity was initiated in the summer of 2010. Specifically, the project objectives are:

- Document the presence of the tamarisk leaf beetle approximately every 1.5 km throughout the Colorado River corridor from Glen Canyon Dam to Pearce Ferry.
- Document the presence of the tamarisk leaf beetle at all Colorado River Management Plan (CRMP) monitoring sites along the Colorado River in Grand Canyon National Park.
- Collect microclimate variables (for example, temperature and relative humidity) in beetle-infested and unoccupied sites along the river corridor.
- Examine the microclimate sites where bird point counts will be used to establish a baseline of bird abundance. Data from 2011 will be compared with data from 2007 through 2010 (CRMP data, unpublished) to identify breeding bird species that may be affected by to beetle expansion.
- The results of these sampling efforts will inform resource managers of the extent and possible consequences of the beetles' presence on riparian resources. This report summarizes results from the 2011 field effort.

Methods

Study Area and Sampling Schedule

In 2011, our study area was the 276 miles of the Colorado River between Lees Ferry, located 12 river miles downstream of Glen Canyon Dam and the western boundary of Grand Canyon National Park (Figure 1). Sampling occurred 1.5 km apart along the left and right sides of the channel, as time and logistics allowed, and at monitoring sites used by GRCA in association with their Colorado River Management Program (Appendix 1). Sites that were sampled on the first trip were re-sampled on each subsequent trip (Appendix 2). In order to detect the presence of beetle larvae and the height of adult activity, our sampling time periods spanned April, May, June, late July/early August and early September, 2011.

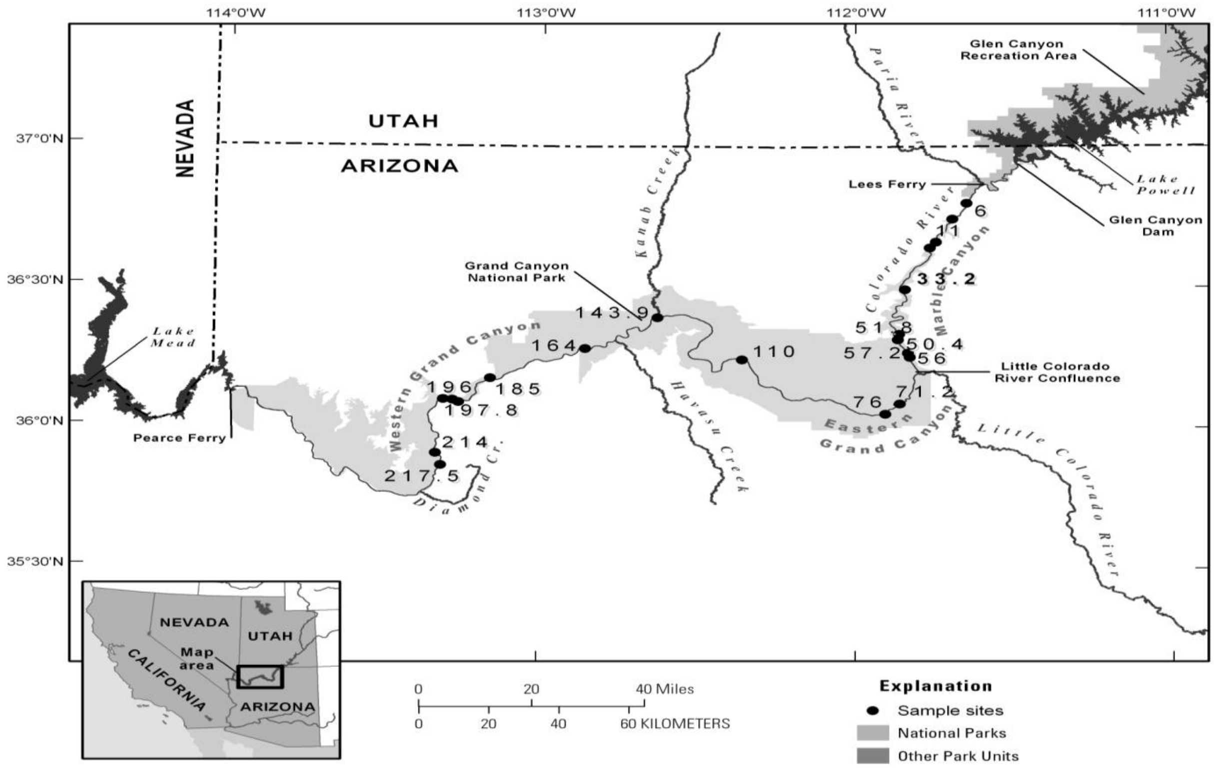


Figure 1. 2011 Map of the Colorado River downstream from Glen Canyon Dam. Large tributaries to the main stem, including the Little Colorado River, are identified. Sample sites numbers are identified as CRMP sites where bird, vegetation, and microclimate (temperature, relative humidity) were collected.

Documenting the Presence of the Tamarisk Leaf Beetle

The beetle sampling methods followed those used by USDA, USDI, Colorado Department of Agriculture, and the Tamarisk Coalition, which are all part of a regional effort to monitor the spread of the tamarisk leaf beetle. At each sampling location, personnel recorded the UTM using NAD 83 datum, and documented vegetation cover and dominance, and other ancillary site information. Beetle sampling involved using standard 38 cm aerial sweep nets. At each sampling location we completed five sweep sets, roughly 5 m away from each previous sweep set. For each sweep set, personnel completed five sweeps in the tamarisk foliage within a 1 m radius, and then emptied and recorded the contents of the net. Each sweep recoded the following information: beetle presence in the early and late larval stages, presence of adult beetles, presence of eggs, percent of defoliation and refoliation, and if ants or lady bugs were present. Both ants and ladybugs prey on larvae and adult tamarisk leaf beetles. For sites along the Colorado River, sampling locations were at least 1.5 km apart, and the sweep sets were done within 50 m of the landing point. A minimum of three sampling visits were completed at each CRMP site. Some of the randomly selected sites were only visited once or twice due time restrictions.

Determining Defoliation Effects on Microclimate Factors

At least three data loggers that record temperature and relative humidity were deployed at each of the 21 CRMP sites (Appendix 1and 2). Each logger was programmed to record an event (T/RH reading) every 30 minutes. Temperature (T) and relative humidity (RH) were recorded with HOBO Pro RH/Temp data loggers (Onset Computer Corporation, Pocasset, MA). HOBO loggers were programmed to collect T (–30°C to 50°C; accurate to ± 0.2° C at 21° C; -22°F to 122°F) and RH (0–100 percent, accurate to ± 3 percent) data. To protect each data logger from direct solar radiation, HOBOs were deployed in the field using a small, inverted plastic container with a sheet of shade cloth covering the top. The open bottom of the bowl was covered with shade cloth to ensure that the HOBO is sampling free-flowing air, and thus can accurately measure T/RH. Each thermistor was deployed within the vegetation on a tamarisk tree branch at 2-m high. The data will also be used to compare with subsequent defoliation events within the canyon.

Breeding Birds and the Effects of the Tamarisk Leaf Beetle

The bird CRMP data are from breeding bird transects conducted from 2007 to 2011 at CRMP study sites along the Colorado River in Grand Canyon. The breeding bird community associated with the riparian habitats along the Colorado River is comprised of bird species generally restricted to riparian habitats (NHWZ (new high water zone) and OHWZ (old high water zone)) and species that can also be found in adjacent upland, non-riparian habitats (Holmes et al. 2005). During the CRMP bird surveys, surveyors noted the type of riparian habitat, NHWZ or OHWZ, in which a bird was detected. We summarized the CRMP bird data by calculating the mean (average) number of detections (unadjusted for detectability) per transect, and standard error (SE), for each bird species detected in the NHWZ and OHWZ. We then compared the abundance and distribution of bird species most likely to be affected by tamarisk leaf beetles and their effects on riparian vegetation with data on the distribution of the beetle. To do this, we used bird data from the subset of study sites where beetles were detected during beetle surveys in 2010 and 2011, and detections made within the tamarisk-dominated NHWZ. We compared mean bird species abundance "pre-beetle invasion" (bird CRMP data from 2007 through 2009) and "post-beetle invasion" (2010 and 2011) using non-parametric tests of differences in the means (Kruskal Wallis test).

Results

Tamarisk Leaf Beetle Distribution and Abundance, 2011

We completed six tamarisk beetle sampling trips between Lee's Ferry and Pearce Ferry (Figure 1). Three survey trips were also conducted between Lee's Ferry and Glen Canyon Dam. The number of sites surveyed varied during each trip in 2011. While conducting vegetation sampling on 2-18 May, 63 sites were sampled for beetles. During the first formal survey on 16-

31 May, 241 sites were sampled. In June, 149 sites were sampled, followed by July (133 sites), August (144 sites) and September (189 sites). Between Lee's Ferry and Glen Canyon Dam, we surveyed 15 sites during each visit.

During the first formal survey (16 May – 31 May), we surveyed for tamarisk beetles and deployed temperature and relative humidity data loggers in tamarisk habitat at 21 CRMP sites between Lees Ferry and Diamond Creek (Appendix 1, Appendix 2).

In 2010, we detected tamarisk leaf beetles (larvae and adults) primarily in areas adjacent to where known beetle populations exist on the north rim of Grand Canyon major tributaries (Paria Canyon and Kanab Creek) that enter the Grand Canyon. In 2011, this same pattern existed, however, beetle populations expanded upstream and downstream of these major tributaries, with the core population detected in the between Mile 127 and Mile 180. (Figures 2 and 3; Appendix 3, Map #1).

When we look at the beetle's monthly distribution within Grand Canyon in 2011, we found beetles had emerged from diapause in mid-April. During this visit, we detected a high number of adult beetles at Lee's Ferry (river mile 0). This was the only site sampled in April. During the month of May, tamarisk leaf beetles were found in large numbers from Lee's Ferry (river mile 0) downstream to Soap Creek Rapid (river mile 12), lower numbers were found downstream to river mile 29 near Silver Grotto, where an increase in numbers were detected, but then lead to the sudden absence of the beetles (Figures 2 and 3; Appendix 3, Map #1). No beetles were found further downstream within Marble Canyon in May. Downstream of Marble Canyon, moderate numbers of beetles were detected between river mile 126 and 151. Beetles became more scattered between river mile 152 and 170, but from river mile 171-180, larger numbers of beetles were consistently found, tapering off into infrequent aggregations between river mile 181 and 192.5.

During June, the distribution of beetles was similar to May's distribution from river mile 0 to river mile 21, though numbers were reduced (Figures 2 and 3; Appendix 3, Map #1). We found a gap between river mile 21 and 26, where no beetles were detected, but were detected consistently between river mile 123 and 190. During June, we conducted our first survey from Lee's Ferry to Glen Canyon Dam and detected high numbers of beetles throughout this section of river (Figures 2 and 3; Appendix 3, Map #2).

During July, tamarisk leaf beetles remained high at river mile -6 and -7 within the Glen Canyon section of our surveys (Figures 2 and 3; Appendix 3, Map #3), however, tamarisk leaf beetle numbers remained low in Marble Canyon, though beetles were found as far downstream as river mile 31, above South Canyon (Appendix 3, Map #1). Downstream, beetles were found further upstream then previously recorded, with one detection at river mile 108.5 near Bass Camp. We detected beetles scattered between river mile 115 and 118, while higher numbers were detected between river miles122 thru 188 (Figures 2 and 3; Appendix 3, Map #1).

During August, the main population of beetle numbers declined throughout the Grand Canyon (Lee's Ferry – Pearce Ferry) and Glen Canyon (Lee's Ferry – Glen Canyon Dam; Figures 2 and 3; Appendix 3 Maps #1 and #4). We detected beetles between river mile -15 and 32, with high numbers at river mile 0 and a small number isolated at river mile 41 and at river mile 60. Downstream, smaller numbers of beetles were scattered between river mile 115 and 117, but detected consistently as far as river mile 199. We also detected 27 beetles isolated at river mile 213 near Pumpkin Springs.

With shortening day lengths in September, fewer beetles were detected throughout the canyon. We only detected very small numbers between river mile 0 and 4; river mile 30 through river mile 33 and 10 adults at river mile 48 (Figures 2 and 3; Appendix 3, Map #1). Downstream the majority of the population had gone into diapause with only six adults detected at river mile 120; no other beetles were detected downstream in September.

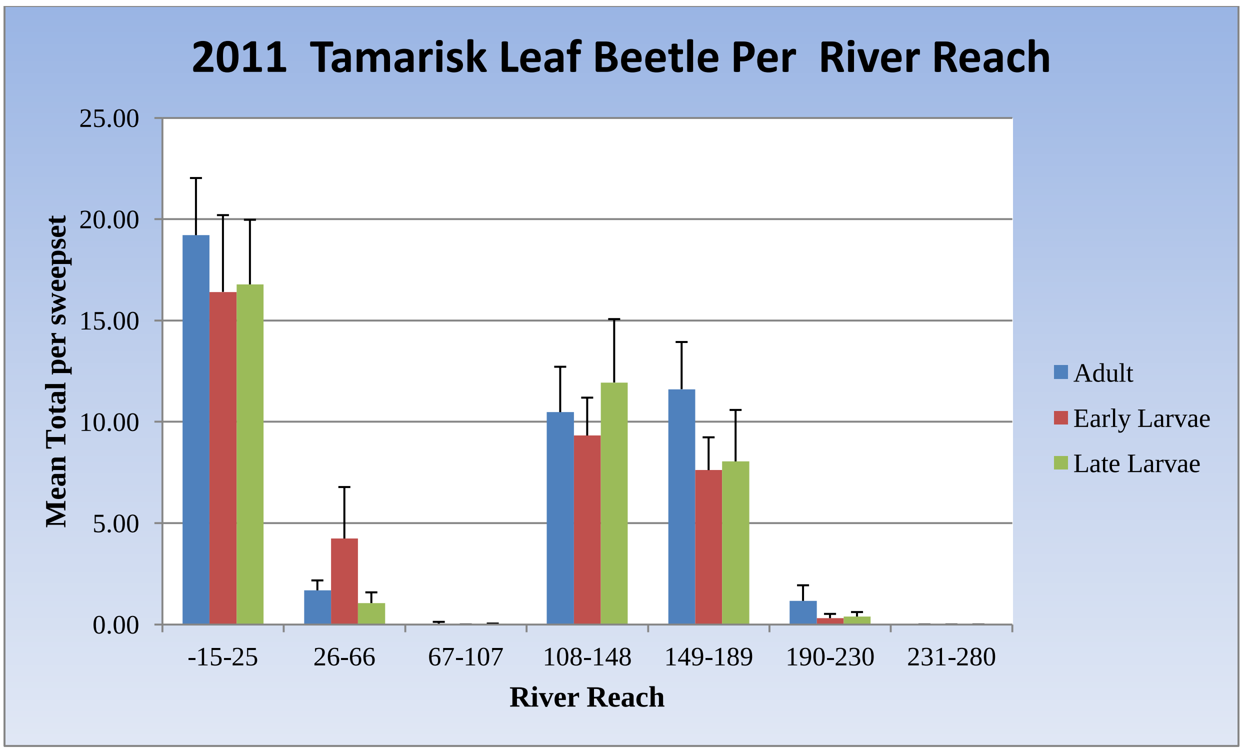


Figure 2. Mean number of tamarisk leaf beetles (early stage larvae, late stage larvae, and adults) by river reach along the Colorado River during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

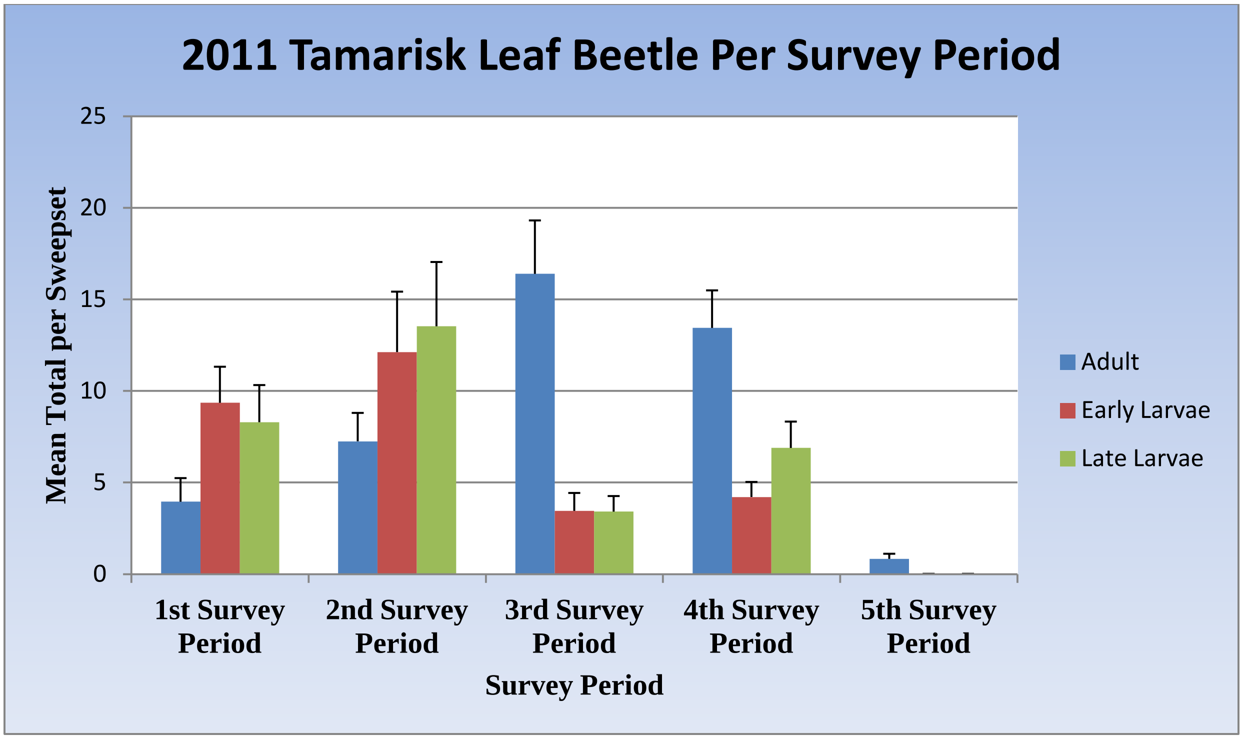


Figure 3. Mean number of tamarisk leaf beetles (early stage larvae, late stage larvae, and adults) per survey period during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

Tamarisk Defoliation, 2011

Defoliation by the tamarisk leaf beetle was observed during all five survey periods (1st survey period = 4/21-5/30; 2nd survey period 6/13-6/22; 3rd survey period = 7/8-7/17; 4th survey period = 8/10-8/23; 5th survey period 9/3-9/18) (Figure 4). Defoliation was particularly high during the third and forth survey periods. Below we will break down the extent of the defoliation by the tamarisk leaf beetle in Grand Canyon by month.

During the April survey at Lee's Ferry and May surveys (1st survey period) in the canyon, we observed very low levels of defoliation by adult beetles between Lee's Ferry and river mile 194 (Appendix 3; Map #5). During June (2nd survey period), high rates of defoliation by tamarisk leaf beetles occurred at river miles -5, -12 and -14 between Lee's Ferry and Glen Canyon Dam (Appendix 3; Map #6) . Tamarisk leaf beetles had also defoliated the full stretch between Lee's (river mile 0) to just below Soap Creek Rapid (river mile 13), with spots of defoliation extending down to Tiger Wash (river mile 27; Appendix 3; Map #6). In the lower sections of Grand Canyon, defoliation was in isolated patches from Forster Canyon (river mile 123) to just above Deer Creek Falls (river mile 136.5). Moderate levels of defoliation were observed along the river corridor from Deer Creek down to Kanab Canyon (river mile 145). Below Kanab Creek in June, defoliation was found in isolated patches downstream to Mohawk Canyon (river mile 172) where defoliation increased. From Mohawk, defoliation covered the whole river corridor downstream to just below Lower Lava rapid (river mile 181; Appendix 3; Map #7). From the Lava area downstream defoliation was again found only in isolated patches to Whitmore Wash (river mile 188), with no defoliation found downstream beyond that point.

During July (3rd survey period), defoliation was observed at a high rate at all sites except river miles -6 and -9 between Lee's Ferry and Glen Canyon Dam (Appendix 3; Map #8). Defoliation covered full stretch between Glen Canyon Dam (river mile -15) to Tiger Wash (river mile 27; Appendix 3; Map #9). In the lower sections of Grand Canyon, defoliation covered entire patches from Forster Canyon (river mile 123) to Kanab Canyon (river mile 145). Below Kanab Creek during July, defoliation covered the whole river corridor from river mile 167 downstream to river mile 171. From river mile 171, defoliation was observed in isolated patches downstream to river mile 199 (Appendix 3; Map #9).

During August (4th survey period) defoliation was moderate to high at half the sites between Lee's Ferry and Glen Canyon Dam (Appendix 3; Map #10). Defoliation had expanded and interconnected the whole canyon from Lee's Ferry down to South Canyon (river mile 32; Appendix 3; Map #11). In the lower Canyon defoliation had grown considerably, covering the river corridor from Blacktail Canyon (river mile 120) downstream to 192 Canyon (river mile

192), defoliation was then found intermittently downstream to Parashant Wash (river mile 199), no defoliation was observed beyond that point(Appendix 3; Map #11).

In September (5th survey period), moderate levels of defoliation was observed from river mile -15 to river mile 32, with low to moderate levels of refoliation observed (Appendix 3; Map #12). Low to no defoliation had occurred downstream of river mile 32 to river mile 120. Many areas downstream of river mile 120 to river mile 199 had low to moderate levels of defoliation during this survey period. Within this section, we observed many of the tamarisk trees that defoliated in July and August showing sign of low to moderate levels of refoliation. Downstream of Parashant Wash (river mile 199) very low levels of defoliation was observed during this survey period.

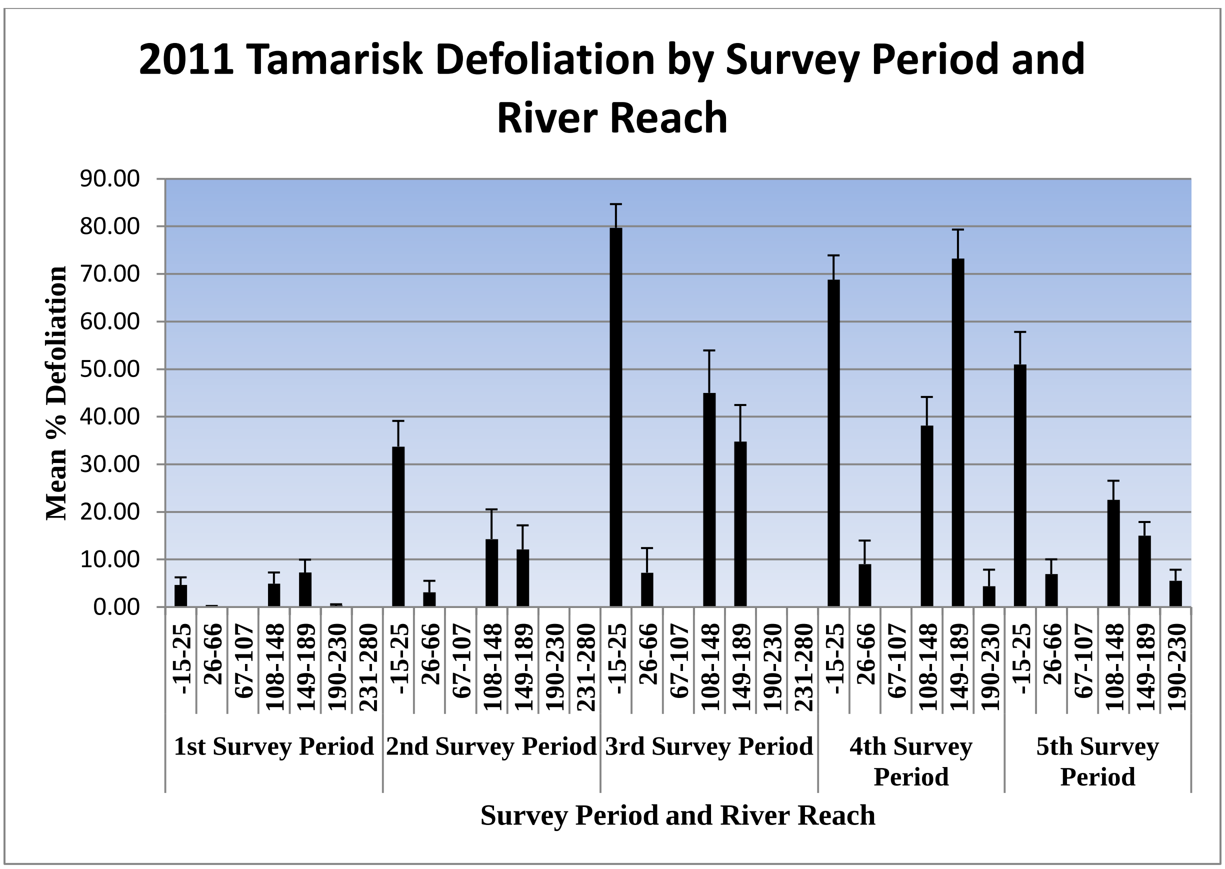


Figure 4. Average tamarisk cover defoliated by tamarisk leaf beetle by survey period and river reach along the Colorado River during 2010 Grand Canyon National Park tamarisk leaf beetle surveys.

Tamarisk Leaf Beetle Distribution and Defoliation in Grand Canyon Tributaries, 2011

In 2011, we surveyed for tamarisk leaf beetles in three tributaries that enter into Grand Canyon National Park (Appendix 3; Maps #13 and #14). The tributaries were Paria Canyon, Buckskin Gulch, and Kanab Creek, Paria Canyon and Buckskin Gulch were surveyed three times while Kanab Creek was surveyed once. During our surveys in Paria Canyon and Buckskin Gulch, we detected beetles at the mouths of the upper and lower sections of each canyon (approximately 3 km) (Figures 5; Appendix 3; Map #13). The largest number of beetles detected were during the May and end of June surveys. We detected very few beetles during our second survey in early June. We documented defoliation during each survey in both the upper and lower section of both canyons, and found high rates of defoliation during the May and end of June surveys (Figure 6; Appendix 3; Map #14). The survey in Kanab Creek accessed from the river occurred in mid-July where we detected beetles continuously for 6 km (Figure 5; Appendix 3; Map #13). The survey of Kanab Creek from the rim of the canyon was not conducted until early-September due to logistical complications. This survey detected few beetles due to the time of the survey, but documented defoliation throughout this section of the Kanab Creek (Figure 6; Appendix 3; Map #14).

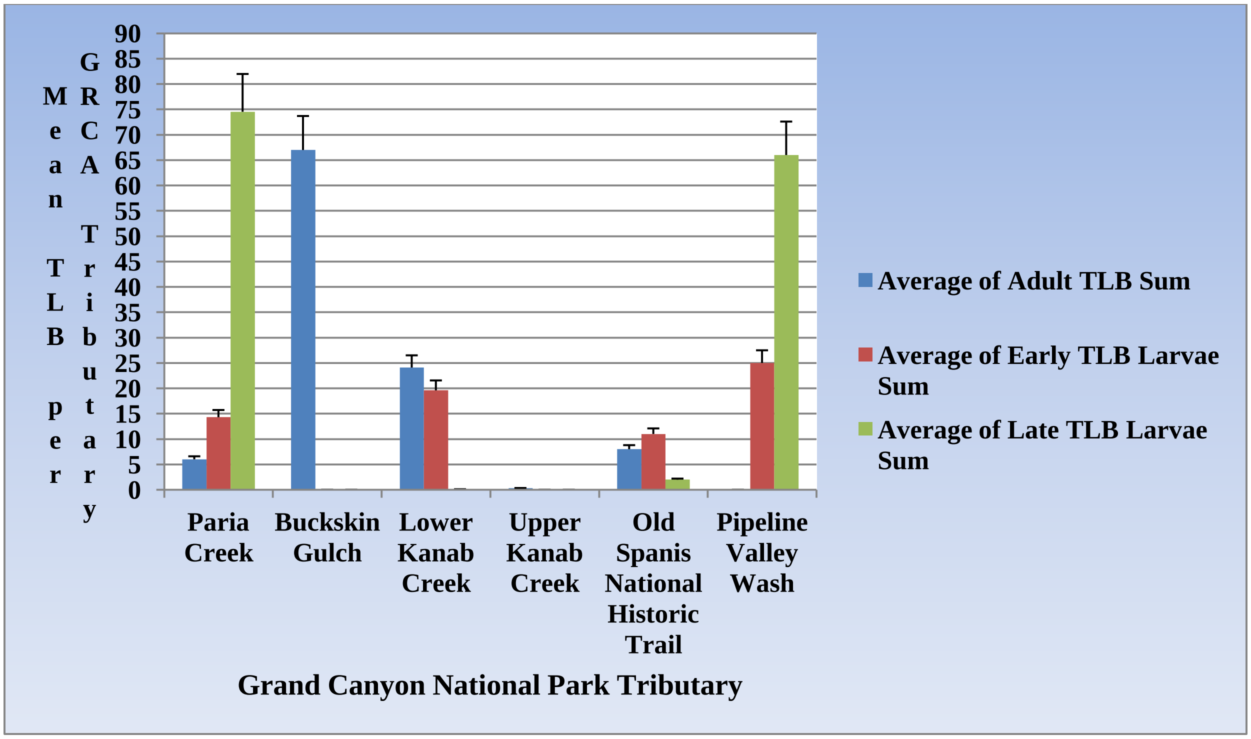


Figure 5. Mean number of tamarisk leaf beetles (early stage larvae, late stage larvae, and adults) by during tamarisk leaf beetle surveys in tributaries in Grand Canyon National Park.

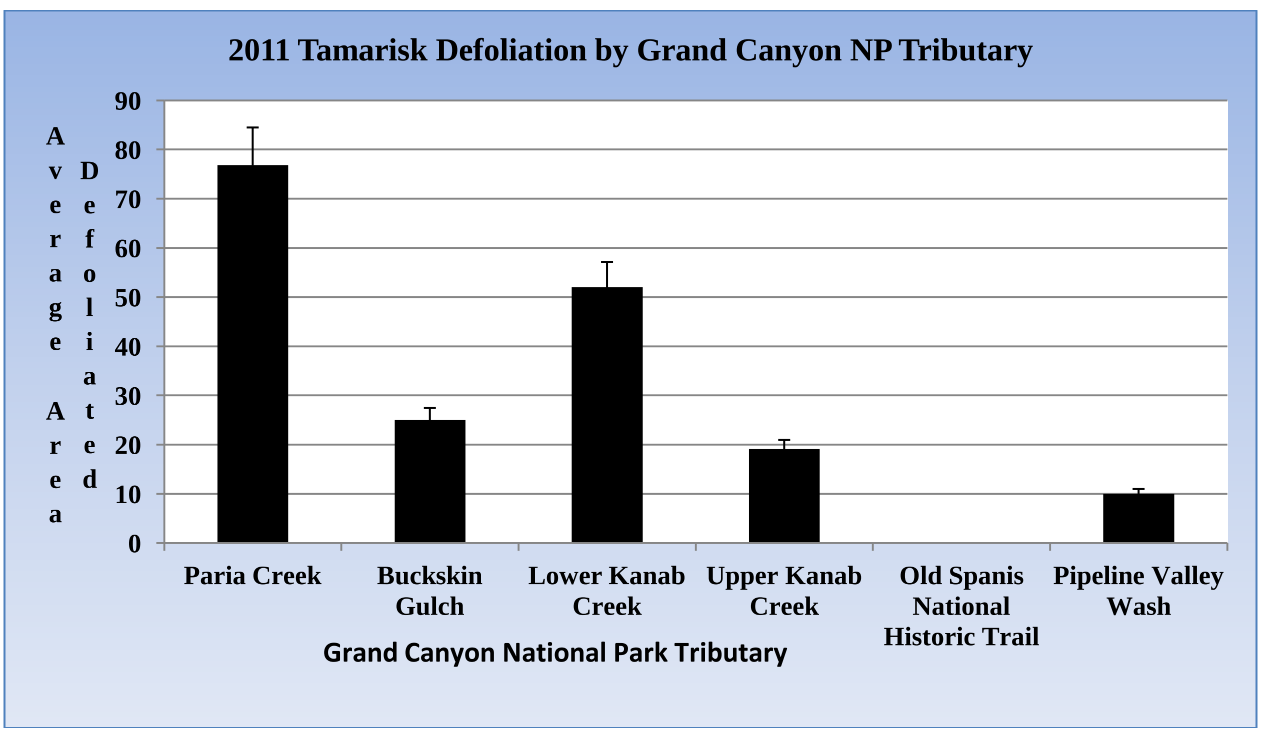


Figure 6. Average tamarisk cover defoliated by tamarisk leaf beetle observed during tamarisk leaf beetle surveys within tributaries (Paria, Buckskin and Kanab Creeks) in Grand Canyon National Park.

Microclimate at Grand Canyon NP CRMP Sites, 2011

Temperature

Results are based on combined temperature and relative humidity data from three thermistors at each site and are represented in figs 7 - 9. Data from May are from May 17 through May 30 and September is from September 1 through September 9th. SigmaPlot 11.0 was used to develop the descriptive statistical information.

Mean temperatures across sites increased with distance from Lees Ferry in 2011, but most obviously in May and September (Figures 7a, and 9e). Mean temperature in the months of June through August tended to be greater among sites relative to the middle portion of the river corridor (e.g., Hance to 185 mile; Figures 7b, 8c, 8d) than sites at either end of the river corridor. The pattern of temperature variability among sites is different from that observed in 2010 where the differences in June temperature were 6.2 °C while in August the greatest difference between sites was 9.1°C. T-statistic to compare of mean temperatures between years indicate that July mean temperatures were statistically significantly different in July with 2010 having warmer mean temperatures than 2011 ($p<0.001$, $X_{(July\ 2010)} = 32.2$ °C, $X_{(July\ 2011)} = 29.45$ °C.

In 2011, Maximum temperatures were more variable among sites rather than showing an upward trend with distance downstream. The site “above Kanab Creek” consistently had the highest mean and maximum temperatures for all months (Figures 7a – 9e). Maximum temperatures in the months of June through September tended to be greatest among sites within the river corridor rather than at the farthest downstream sites along the river corridor (Figures 7b – 9e). Minimum temperatures were least variable among all sites in May and September (Figures 7a, 9e) and were more variable in June, July and August (Figures 7b, 8c, 8d). The greatest minimum temperatures were associated with sites within the river corridor rather than sites on either end of the river corridor.

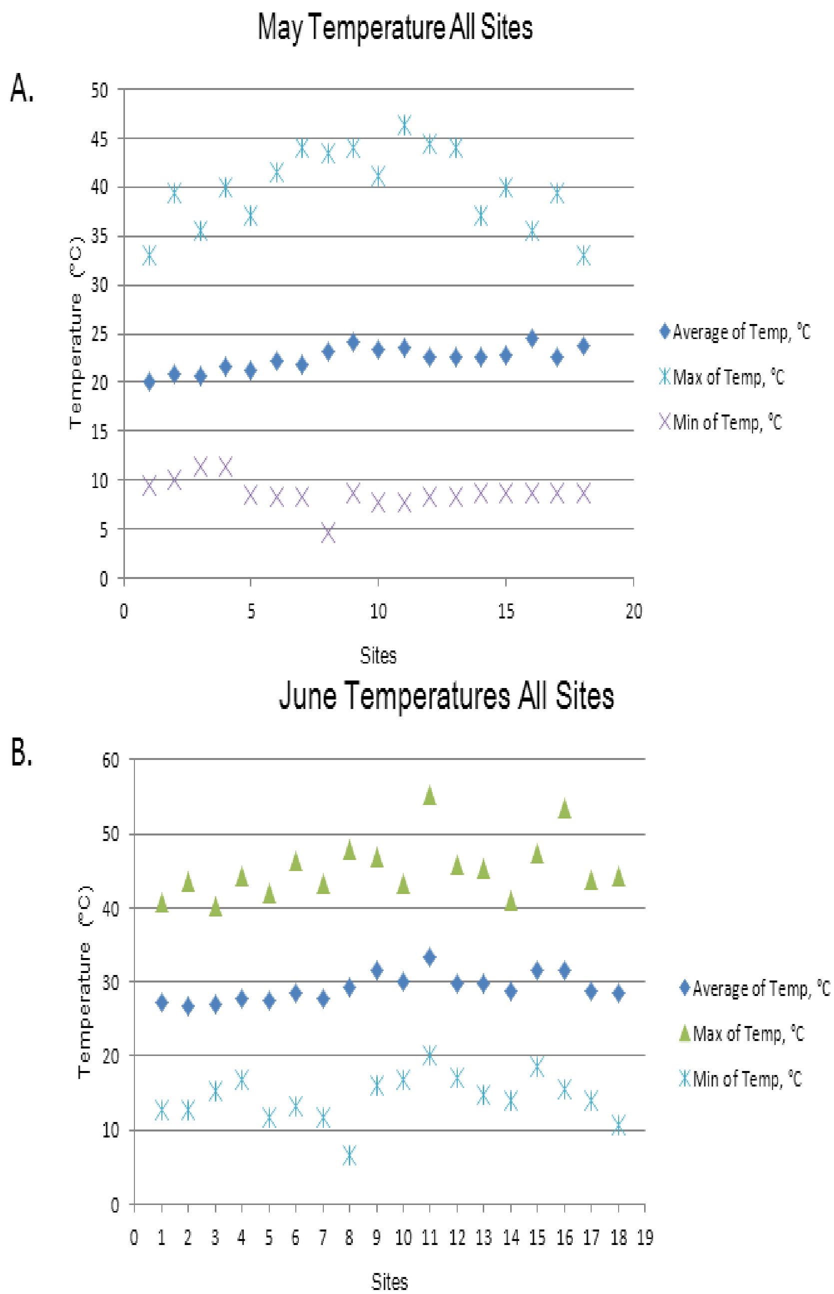


Figure 7A,B. Mean, maximum mean and minimum mean monthly air temperatures for (A) May and (B) June, 2011 for sites along the Colorado River between Lees Ferry and Diamond Creek at CRMP monitoring sites during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

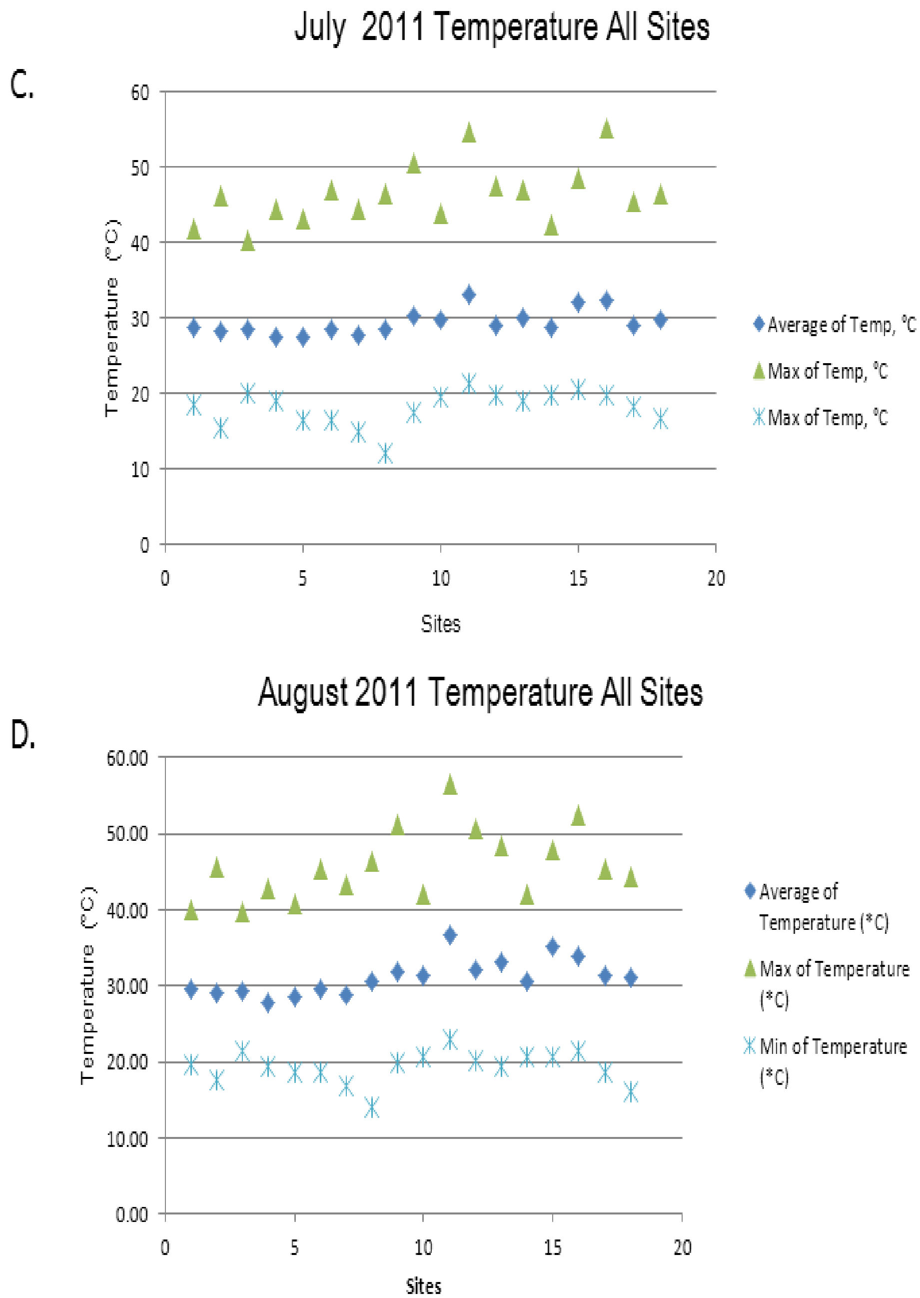


Figure 8C,D. Mean, maximum mean and minimum mean monthly air temperatures for (A) July and (B) August, 2011 for sites along the Colorado River between Lees Ferry and Diamond Creek at CRMP monitoring sites during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

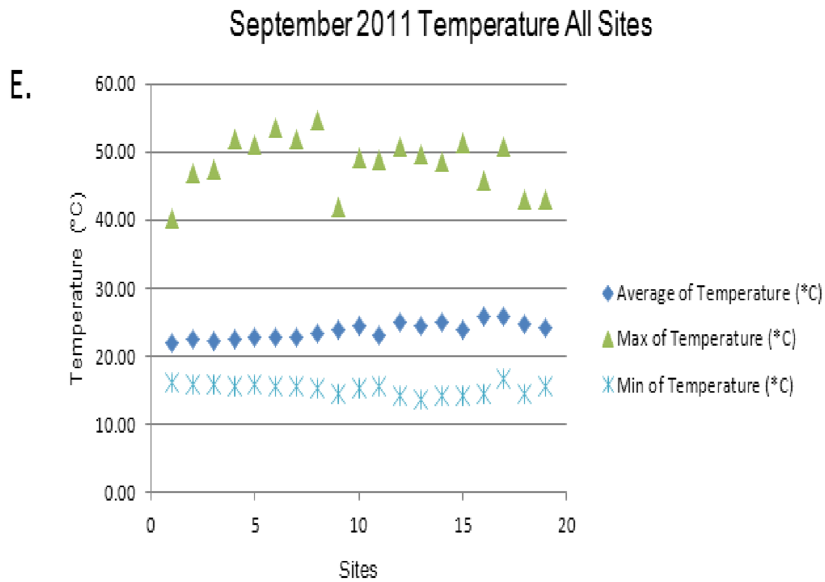
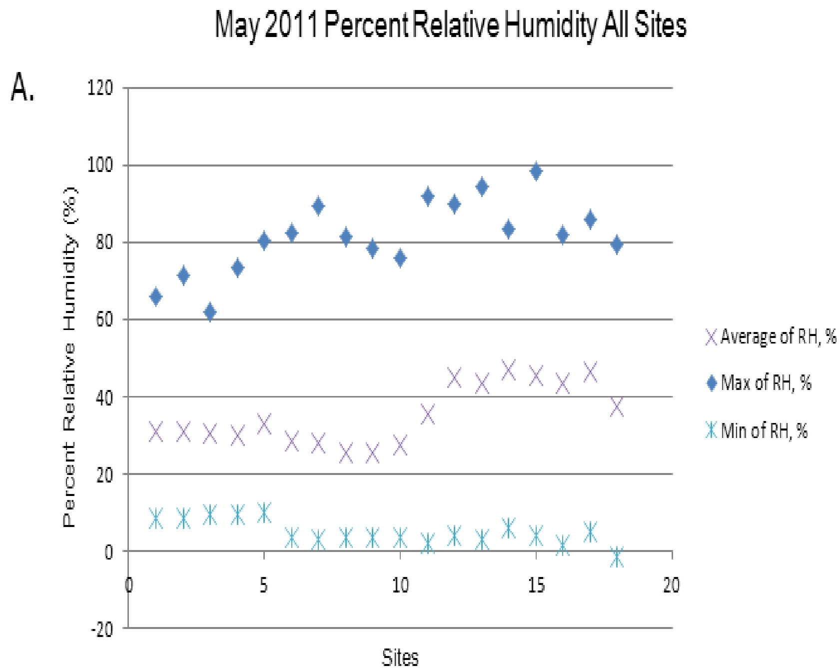


Figure 9E. Mean, maximum mean and minimum mean monthly air temperatures for (A) September, 2011 for sites along the Colorado River between Lees Ferry and Diamond Creek at CRMP monitoring sites during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

Relative Humidity

Mean relative humidity across sites trended downward most markedly in September 2011 with distance from Lees Ferry (Figures 10a – 12e). The difference in relative humidity across sites was most prominent in August and September (Figures 11d, 12e). In September relative humidity varied between 89 - 80% for sites in Marble Canyon (e.g., Soap Creek) and 61 – 54% in western Grand Canyon (Figure 12e). T-statistic that compared mean relative humidity between 2010 and 2011 indicated significant difference existed between years for the months of July and August. Mean humidity in July 2010 was 29.3% while in July 2011 relative humidity was 38.5% ($t_{df=37}$ =-5.043, P=<0.001). For August relative humidity was greater in 2010 than in 2011 ($X_{(RH2010)}$ = 52.2%, $X_{(RH2011)}$ = 32.5%).

Maximum values for relative humidity were most consistent among sites in July and August where many sites recorded 100% relative humidity (Figures 11c and 11d). The greatest variability among sites for maximum relative humidity occurred in June (Figure 10b). Minimum values for relative humidity were similar among sites and months (Figures 10a – 12e).



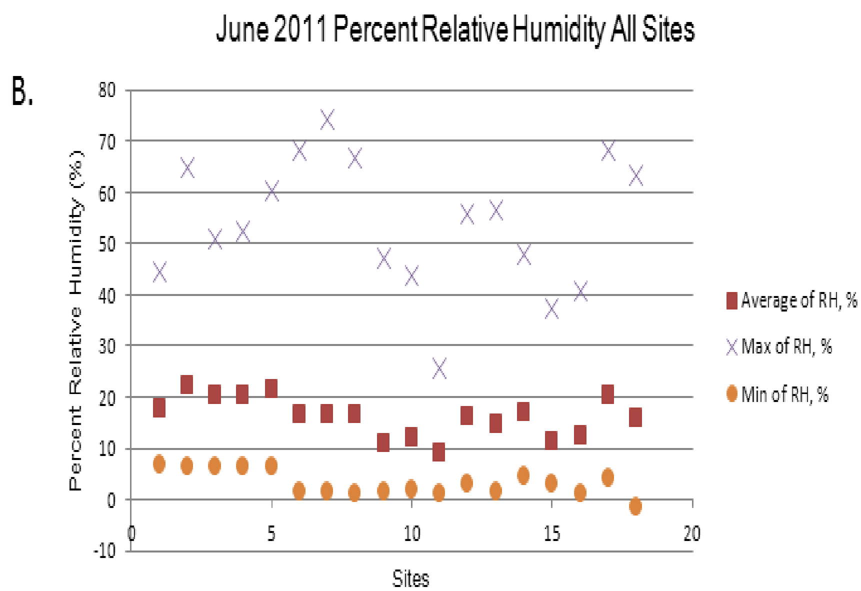
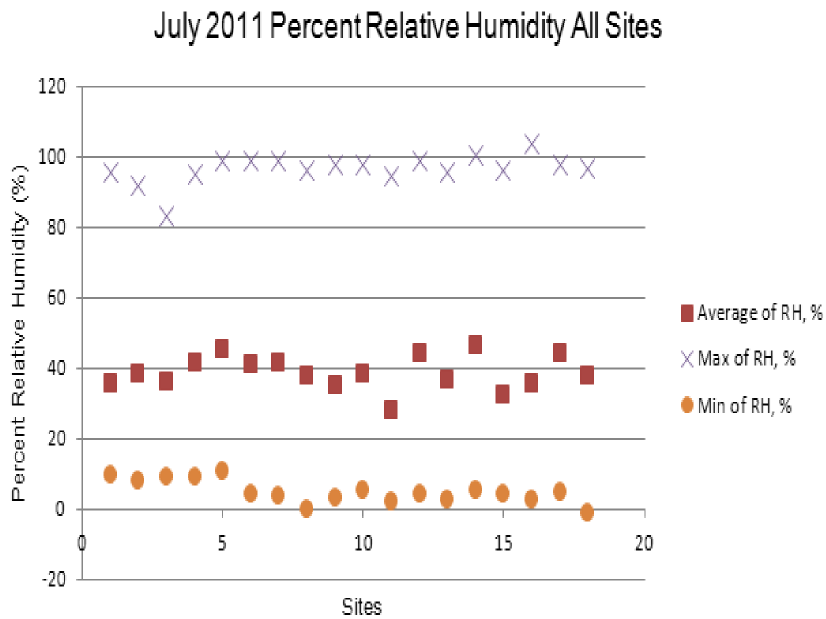


Figure 10A, B. Mean, maximum mean and minimum mean relative humidity for (A) May and (B) June, 2011 for sites along the Colorado River between Lees Ferry and Diamond Creek at CRMP monitoring sites during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

C.



D.

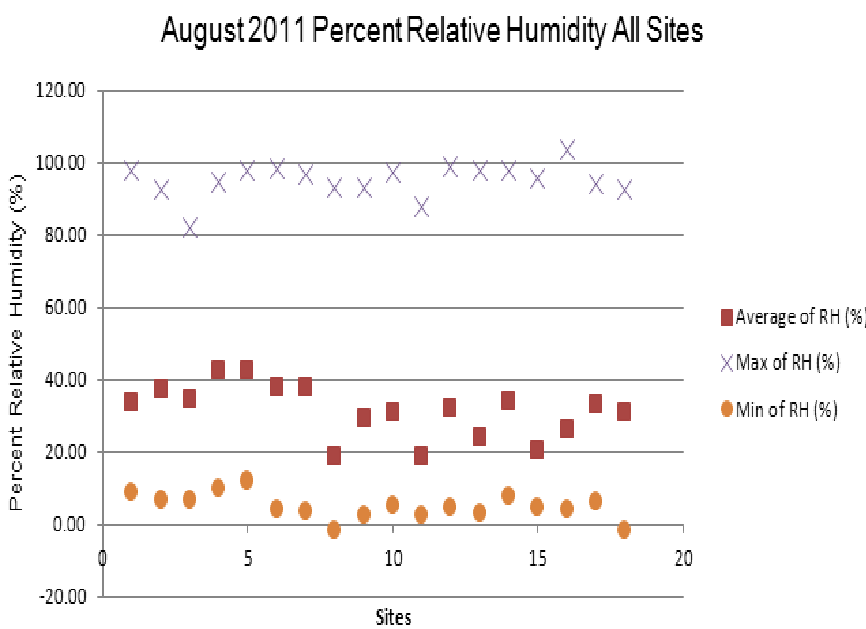


Figure 11C, D. Mean, maximum mean and minimum mean relative humidity for (A) July and (B) August, 2011 for sites along the Colorado River between Lees Ferry and Diamond Creek during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

E.

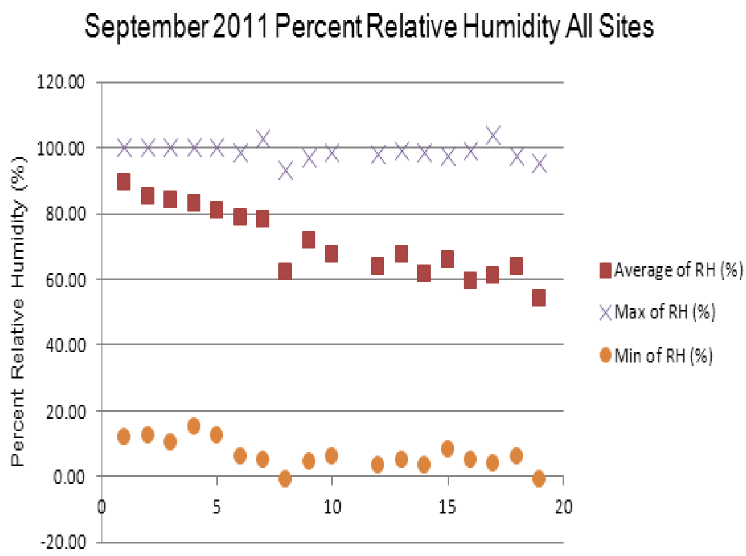


Figure 12E. Mean, maximum mean and minimum mean relative humidity for (A) September, 2011 for sites along the Colorado River between Lees Ferry and Diamond Creek during 2011 Grand Canyon National Park tamarisk leaf beetle surveys.

Breeding Birds and Effects of Tamarisk Leaf Beetle and Defoliation, 2011

A total of 81 bird species were detected during the 2010 and 2011 CRMP breeding bird surveys (Table 1). Of these species, those detected in the NHWZ riparian habitat, and thus using tamarisk-dominated habitat, are most likely to be affected by the tamarisk leaf beetle (Table 2). We used data from sites where beetles were detected during the 2010 to 2011 beetle surveys (Appendix 4) and compared the mean abundance (unadjusted for detectability) of these bird species before and after beetle presence of Grand Canyon NP (Figure 13; Appendix 4). A non-parametric test of the mean abundances pre and post tamarisk leaf beetle presence found differences in mean abundance at $p \leq .05$ for common yellowthroat (*Geothlypis trichas*) and house finch (*Carpodacus mexicanus*), and $p \leq .01$ for lesser goldfinch (*Carduelis psaltria*).

Table 1. Bird species mean number of detections per transect in New High Water Zone (NHWZ) and Old High Water Zone (OHWZ) riparian habitats at CRMP sites, 2007-2011. Species listed from the highest number detected in the NHWZ to the lowest. Shaded species are generally the most common terrestrial breeding bird species found in riparian habitats along the Colorado River in Grand Canyon (Spence 2004, Holmes et al. 2005).

		Mean number detected per transect	
Species	**Species Code**	**NHWZ**	**OHWZ**
Violet-green Swallow	VGSW	19.39	4.25
White-throated Swift	WTSW	18.19	11.70
Green-winged Teal	GWTE	9.00	0.00
Mallard	MALL	3.67	2.00
Dark-eyed Junco	DEJU	3.00	1.00
White-crowned Sparrow	WCSP	2.53	3.50
Red-winged Blackbird	RWBL	2.50	0.00
Lucy's Warbler	LUWA	2.44	3.65
House Finch	HOFI	2.21	2.64
Cooper's Hawk	COHA	2.00	0.00
Hermit Warbler	HEWA	2.00	0.00
Olive-sided Flycatcher	OSFL	2.00	1.00
White-throated Sparrow	WTSP	2.00	0.00
Black-throated Sparrow	BTSP	1.80	2.11
Chipping Sparrow	CHSP	1.80	1.50
Turkey Vulture	TUVU	1.76	1.33
Yellow Warbler	YEWA	1.73	1.47
Warbling Vireo	WAVI	1.67	1.50
Bell's Vireo	BEVI	1.66	1.58
Lincoln's Sparrow	LISP	1.66	1.56

Table 1 cont.

Species	Species Code	Mean number detected per transect NHWZ	OHWZ
Canyon Wren	CNWR	1.65	1.70
Phainopepla	PHAI	1.63	1.25
Blue-gray Gnatcatcher	BGGN	1.56	1.88
Cactus Wren	CAWR	1.52	2.00
Black-chinned Sparrow	BCSP	1.50	1.00
Great-tailed Grackle	GTGR	1.50	1.00
Indigo Bunting	INBU	1.50	0.00
Bewick's Wren	BEWR	1.49	1.94
Common Yellowthroat	COYE	1.45	1.39
Yellow-rumped Warbler	YRWA	1.45	1.00
Blue Grouse	BLGR	1.40	1.00
Common Raven	CORA	1.35	1.55
Brown-crested Flycatcher	BCFL	1.33	1.50
Ring-billed Gull	RBGU	1.33	1.00
Song Sparrow	SOSP	1.33	1.44
Say's Phoebe	SAPH	1.31	1.53
Lazuli Bunting	LABU	1.25	1.00
Peregrine Falcon	PEFA	1.25	0.00
Rock Wren	ROWR	1.25	1.24
Western Tanager	WETA	1.24	1.25
Wilson's Warbler	WIWA	1.21	1.00
Lesser Goldfinch	LEGO	1.20	1.38
Western Wood-Pewee	WWPE	1.20	1.00
Black-chinned Hummingbird	BCHU	1.18	1.15
Hooded Oriole	HOOR	1.17	1.00
Marsh Wren	MAWR	1.17	1.00
Mourning Dove	MODO	1.16	1.00
Ash-throated Flycatcher	ATFL	1.14	1.24
Costa's Hummingbird	COHU	1.14	1.20
MacGillivray's Warbler	MGWA	1.14	1.00
Black Phoebe	BLPH	1.13	1.05
Spotted Sandpiper	SPSA	1.13	0.00
Yellow-breasted Chat	YBCH	1.13	1.11
Summer Tanager	SUTA	1.05	1.21
Belted Kingfisher	BEKI	1.00	0.00
Black-headed Grosbeak	BHGR	1.00	1.00
Blue Grosbeak	BLGR	1.00	1.00
Brewer's Blackbird	BRBL	1.00	0.00
Brewer's Sparrow	BRSP	1.00	4.00
Broad-tailed Hummingbird	BTHU	1.00	1.00
Bullock's Oriole	BUOR	1.00	0.00
Great Blue Heron	GBHE	1.00	0.00
Greater Roadrunner	GRRO	1.00	0.00
Green-tailed Towhee	GTTO	1.00	1.00
Hammond's Flycatcher	HAFL	1.00	0.00
House Sparrow	HOSP	1.00	0.00
Loggerhead Shrike	LOSH	1.00	3.00

Table 1 cont.

Species	Species Code	Mean number detected per transect NHWZ	OHWZ
Northern Mockingbird	NOMO	1.00	1.00
Rose-breasted Grosbeak	RBGR	1.00	2.00
Ruby-crowned Kinglet	RCKI	1.00	1.00
Rufous-crowned Sparrow	RCSP	1.00	0.00
Red-tailed Hawk	RTHA	1.00	1.00
Sage Sparrow	SASP	1.00	1.00
Scott's Oriole	SCOR	1.00	0.00
Snowy Egret	SNEG	1.00	0.00
Spotted Towhee	SPTO	1.00	0.00
Southwestern Willow Flycatcher	SWFL	1.00	0.00
Tree Swallow	TRSW	1.00	0.00
Willow Flycatcher	WIFL	1.00	0.00
Magnolia Warbler	MAWA	0.00	1.00
Northern Rough-winged Swallow	NRSW	0.00	1.00

Table 2. Riparian breeding bird species most likely to be affected by the TLB. Mean number of detections per transect in New High Water Zone (NHWZ) and Old High Water Zone (OHWZ) riparian habitats at CRMP sites, 2007-2011. Shaded species have been found to build their nests in tamarisk trees (Spence et al. unpublished data; J. Holmes, pers. obs.).

	Mean number detected per transect	
Species	NHWZ	OHWZ
Red-winged Blackbird	2.50	0.00
Lucy's Warbler	2.44	3.65
House Finch	2.21	2.64
Yellow Warbler	1.73	1.47
Bell's Vireo	1.66	1.58
Blue-gray Gnatcatcher	1.56	1.88
Great-tailed Grackle	1.50	1.00
Indigo Bunting	1.50	0.00
Bewick's Wren	1.49	1.94
Common Yellowthroat	1.45	1.39
Brown-crested Flycatcher	1.33	1.50
Song Sparrow	1.33	1.44
Lazuli Bunting	1.25	1.00
Lesser Goldfinch	1.20	1.38
Black-chinned Hummingbird	1.18	1.15
Hooded Oriole	1.17	1.00
Mourning Dove	1.16	1.00
Ash-throated Flycatcher	1.14	1.24
Yellow-breasted Chat	1.13	1.11
Summer Tanager	1.05	1.21
Black-headed Grosbeak	1.00	1.00
Blue Grosbeak	1.00	1.00
Bullock's Oriole	1.00	0.00
Great Blue Heron	1.00	0.00
Northern Mockingbird	1.00	1.00

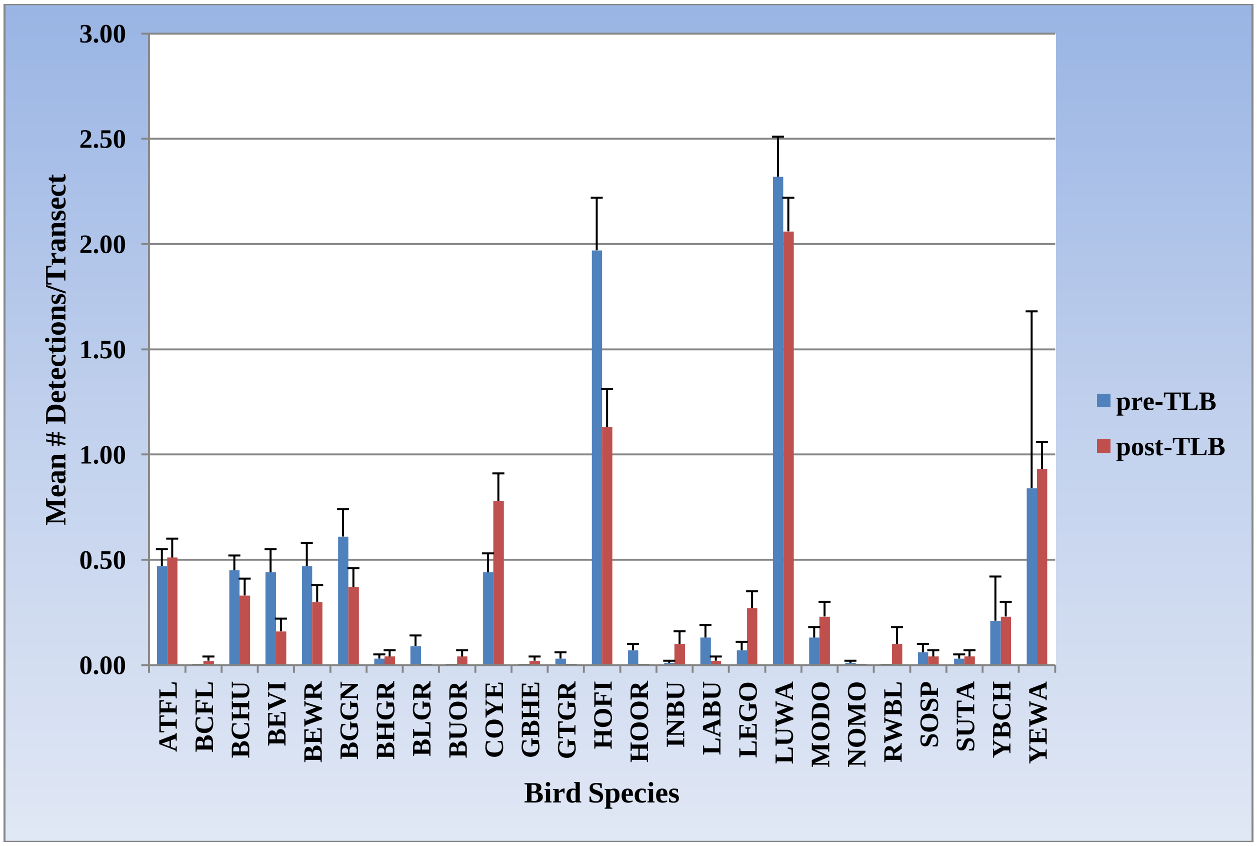


Figure 13. Mean number of detections per transect of species detected in CRMP sites' New High Water Zone (NHWZ), pre-TLB (2007-2009) and post-TLB (2010-2011) invasion. See Table X for a list of bird species common names and 4-letter codes.

Discussion

Tamarisk Leaf Beetle Distribution and Defoliation Affects on Riparian Ecosystems

In 2010, we detected tamarisk leaf beetles (late stage larvae) during the second visit (12 June -26 June) at Lees Ferry, which was the first detection of any form of tamarisk leaf beetle detected in 2010. In 2011, we detected a high numbers of adult beetles at Lee's Ferry during our first visit in April. In 2010, surveys in July, August and September detected tamarisk leaf beetles (larvae and adults) primarily in areas adjacent to where known beetle populations existed on the north rim of Grand Canyon's major tributaries (Paria Canyon and Kanab Creek) that enter the Grand Canyon. In 2011, this same pattern existed, however, beetle populations expanded upstream and downstream of these major tributaries, with the core populations detected between river mile -15 and river mile 27; and between river mile 127 and river mile 180. In 2010, we observed isolated defoliation of tamarisk cover by the tamarisk leaf beetle upstream and downstream of Lee's Ferry and Kanab Creek (river mile 144) with localized defoliation during September. In 2011, tamarisk leaf beetles had defoliated the full stretch of canyon from Lee's Ferry to just below Soap Creek Rapid (river mile 13), and by August defoliation had interconnected the canyon from Lee's Ferry down to South Canyon (river mile 32). Defoliation on the lower portion of the Grand Canyon was spread out in isolated patches from Forster Canyon (river mile 123) to above Deer Creek Falls (river mile 136.5) and encompassed the entire river corridor from Deer Creek down to below Kanab Canyon (river mile 145). Below Kanab Creek, defoliation covered the whole river corridor downstream to below Lower Lava rapid (river mile 181) and by August, defoliation had grown considerably extending across the river corridor from Blacktail canyon (river mile 120) downstream to river mile 192 Mile Canyon.

The expansion of the tamarisk leaf beetle and it's affects on the tamarisk trees in Grand Canyon along the Colorado River in 2011 had dramatically increased. Through these observations in 2011, we have concluded that the beetle is well established in Grand Canyon NP and will have short term and long term affects on vegetation and wildlife.

In the short term, beetle establishment may have positive and negative impacts on food resources for birds. A positive affect may be on birds that readily feed on tamarisk beetles, which may provide an abundant food resource, thereby increasing habitat quality for birds (Kuehn and Dudley 2010). The negative affect could see healthy, flowering tamarisk that attract a variety of native pollinating insects disrupted by beetle defoliation, which may lead to a lower abundance of native insects that birds are known to consume.

Pronounced changes in habitat structure and composition as a result of the beetle could also have notable long term affects. Many systems in the Colorado Basin have broad expanses of monotypic tamarisk stands, while other areas have a mixed tamarisk-native plant composition (van Riper et al., 2008). While tamarisk leaf beetle biocontrol is not expected to eradicate tamarisk, the introduction of beetles to these systems will reduce plant vigor and increase mortality, ultimately leading to a system where tamarisk persists at lower frequencies (Shafroth et al. 2005). The change in avian productivity in these systems as a result of this type of biocontrol will depend heavily on what plant species are present and what will replace tamarisk. Because tamarisk is capable of growing in areas with little water and high salinity, desired native plants may not naturally replace tamarisk habitats that are lost to mortality from beetles (Shafroth et al. 2005). A major concern is that these areas will be colonized by non-native plants (e.g., Russian Thistle, *Salsola tragus* or Russian Olive, *Elaeagnus angustifolia*) that provide poorer quality habitat to birds than tamarisk (Paxton et al. 2011).

Tamarisk Leaf Beetle and Additional Affects on Breeding Birds

In 2011, the tamarisk leaf beetle was widely distributed across the CRMP bird monitoring sites. Tamarisk leaf beetle’s, is expected to primarily impact the tamarisk-dominated NHWZ riparian habitat. Defoliation of tamarisk trees by the beetle is expected to eliminate physical vegetation cover, which can, in turn, affect riparian breeding bird nest success by increasing exposure of nests to nest predators, and affecting microclimate (temperature and relative humidity) of nests sites (Paxton et al. 2011). Vegetation density and canopy cover are important components to avian communities in southwestern riparian ecosystems. In low-elevation desert riparian areas, such as the Colorado River in Grand Canyon NP, tamarisk dominates the vegetation cover and plays an important role in the microclimate at the nest *(*Tieleman et al. 2008*)*. Many areas in the Grand Canyon exceed ambient air temperatures of 43–44 °C (Webb 1987) and are lethal to eggs. These high summer daytime temperatures can also quickly stress bird's ability to dissipate heat and balance their water demands *(*Wolf and Walsberg 1996*)*.

There is also an indirect link with vegetative cover and density and the occurrence and/or productivity of southwestern riparian breeders such as the Southwestern Willow Flycatcher (Paxton et al 2011). These changes in vegetative cover and density due to defoliation by the tamarisk leaf beetle could also affect many riparian breeding bird species detected in Grand Canyon at the CRMP sites within the NHWZ riparian habitat in 2010 and 2011and are also using the densest tamarisk-dominated habitat. In particular, Lucy's warbler, House Finch, Bewick's Wren, Black-chinned Hummingbird, Mourning Dove and Blue Grosbeak, are known to breed in the tamarisk dominated habitat in Grand Canyon NP (Table 2; Spence et al., unpublished data; J. Holmes, pers. obs.). Defoliation by the beetle could reduce cover around these species nests, increasing exposure to nest predators and high temperatures, affecting humidity around the nest, and ultimately lowering nest success. Yet, when we compared mean abundances of birds during pre-and post-beetle invasion, only three bird species (common yellowthroat, house finch, and lesser goldfinch) differed. The house finch nests in tamarisk (and on rock ledges) in the canyon, and its decrease in abundance may be, at least in part, due to changes in tamarisk cover resulting from defoliation. But if that were the case we would expect to also see changes in abundance of Lucy's warbler, Bewick's wren, black-chinned hummingbird, mourning dove and blue grosbeak, which did not differ. The bird data we analyzed for this report were unadjusted for detectability (i.e., detectability was not modeled using program Distance), and the observed differences in abundance may be due to differences in detectability, observer experience, or other unknown factors between years.

Along the Colorado River in Grand Canyon, many of the sites that birds breed in are dominated by tamarisk. This is particularly evident in the NHWZ where we examined differences between pre-tamarisk leaf beetle data from 2007 to 2009, and data from post-beetle invasion for 2010 and 2011. The post-beetle data constitutes data from the initial leaf beetle invasion of sites along the Colorado River in Grand Canyon and the full impacts of repeated defoliation by the leaf beetle on the NHWZ in these areas had yet to occur. In the future, the majority of bird species that use tamarisk likely have populations large enough or are widespread enough in other habitats to withstand large-scale loss of tamarisk, however, species in the Grand Canyon that use tamarisk extensively and distributions are confined to areas dominated by tamarisk may experience significant population declines (Paxton et al. 2011).

Over the next few years, repeated defoliation may lead to tamarisk mortality and habitat loss for bird species that nest in the NHWZ. Therefore, we recommend continued monitoring of bird species in order to adequately track the effects of the tamarisk leaf beetle on the riparian bird community in the Grand Canyon. We also suggest tracking the presence of the tamarisk leaf beetle at all Colorado River Management Plan (CRMP) monitoring sites along the Colorado River, and continue to collect microclimate variables (temperature and relative humidity) in beetle-infested and un-infested sites along the river corridor.

We also suggest Grand Canyon National Park specifically conduct research of tamarisk beetle and bird interactions that examine: (1) tamarisk beetles as a food source for riparian birds; (2) effects of loss of vegetation cover on other native and non-native insect prey; (3) examine the effects of vegetation cover loss on nest success and annual productivity on riparian bird species;

and (4) compare the rate at native vegetation recovery after tamarisk beetle's infiltrate areas of mixed vegetation versus monotypic stands of tamarisk.

Literature Cited

Allison, L. J., C. E. Paradzick, J. W. Rourke, and T. D. McCarthey. 2003. A characterization of vegetation in nesting and non-nesting plots for Southwestern Willow Flycatchers in central Arizona. Studies in Avian Biology 26:81–90.

Bailey, J. K., J. A. Schweitzer, and T. G. Whitham. 2001. Salt cedar negatively affects biodiversity of aquatic macroinvertebrates. Wetlands 21:442-447.

Birkin, A. S. and D. J. Cooper. 2006. Processes of *Tamarix* invasion and floodplain development along the Lower Green River, Utah. Ecological Applications 16:1103-1120.

Brown, B. T. 1992. Nesting chronology, density and habitat use of Black-chinned Hummingbirds along the Colorado River, Arizona. Journal of Field Ornithology 63:393–400.

Busch, D. E. and S. D. Smith. 1993. Effects of Fire on Water and Salinity Relations of Riparian Woody Taxa. Oecologia 94:186-194.

Cohan D.R., Anderson B.W., and Ohmart R.D. 1978. Avian population responses to salt cedar along the Lower Colorado River. In: Johnson RR and McCormick JF (Eds). Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Washington, DC: USDA Forest Service. General technical report WO-12.

Durst, S. L., T. C. Theimer, E. H. Paxton, and M. K. Sogge. 2008. Temporal variation in the arthropod community of desert riparian habitats with varying amounts of saltcedar (Tamarix ramosissima). Journal of Arid Environments 72:1644–1653.

DeLoach C.L., Carothers, R. I., Lovich, J.E., Dudley, T.L., and Smith, S.D., 2000, Ecological interactions in the biological control of saltcedar (*Tamarix spp*.) in the United States: toward a new understanding. In: N.R. Spencer, Editor, Proceedings of the X International Symposium on Biological Control of Weeds, Montana State University, Bozeman, MT (2000), pp. 819–873.

Dudley, T.L., 2005, Progress and pitfalls in the biological control of saltcedar (*Tamarix spp*.) in North America: Proceedings of the 16th U.S. Department of Agriculture Interagency Research Forum on Gypsy Moth and Other Invasive Species (2005) GTR-NE-337.

Fleishman, E., N. McDonal, R. MacNally, D. D. Murphy, J. Walters, and T. Floyd. 2003. Effects of floristics, physiognomy and non-native vegetation on riparian bird communities in a Mojave Desert watershed. Journal of Animal Ecology 72:484–490.

Friedman, J. M., G. T. Auble, P. B. Shafroth, M. L. Scott, M. F. Merigliano, M. D. Freehling, and E. R. Griffin. 2005. Dominance of non-native riparian trees in western USA. Biological Invasions 7:747-751.

Holmes, J. J., J. Spence, and M. K. Sogge. 2005. Birds of the Colorado River in Grand Canyon: a synthesis of status, trends, and dam operation effects, p. 123–138. *In* S. P. Gloss, J. E. Lovich, and T. E. Melis [EDS.], The state of the Colorado River ecosystem. U.S. Geological Survey Circular 128. U.S. Geological Survey, Reston, VA.

Hultine, K.R., Belnap, J., van Riper, C, III, Ehleringer, J.R., Dennison, P.E., Lee, M.E., Nagler, P.E., Snyder K.A., Uselman, S.M., and West, J.B., 2009, Tamarisk biocontrol in the western United States: ecological and societal implications; Frontiers in Ecology and the Environment e-View. doi: 10.1890/090031.

Hunter, W., R. Ohmart, and B. Anderson. 1988. Use of exotic saltcedar (*Tamarix chinensis*) by birds in arid riparian systems. Condor 90:113–123.

Johnson, M.J., and L.C. Abeita. 2001. Southwestern Willow FlycatcherIinventory and Monitoring along the Colorado River in Grand Canyon National Park, 2000 Summary Report. USGS Colorado Plateau Field Station, Northern Arizona University, Flagstaff. 19 pp.

Kearsley, M. 2007. Vegetation, avifauna, campsite and cultural resource monitoring plan for the 2006 Colorado River Management Plan Resource Monitoring Program. Draft report, Northern Arizona University / National Park Service, Colorado Plateau Cooperative Ecosystems Studies Unit. Updated by M. McMaster.

Kuehan, M. J. and T. Dudley. 2010. Evaluating the Importance of Tamarisk versus Native Plants as Breeding Habitat for Birds on the Virgin River of Clark County, Nevada: An Assessment of the Potential Impacts of Biocontrol on the Avian Community. Report submitted to Clark County. pp. 23.

Kennedy, T. A. and S. E. Hobbie. 2004. Saltcedar (*Tamarix ramosissima*) invasion alters organic matter dynamics in a desert stream. Freshwater Biology 49:65-76.

Kennedy, T. A. and B. E. Ralston. 2010. Regulation leads to increases in riparian vegetation, but not direct allochthonous inputs, along the Colorado River in Grand Canyon, Arizona. River Research and Applications.

Paxton, E.H., Sogge, M.K., Durst, S.L., Theimer, T.C., and Hatten, J.R., 2007, The ecology of the

southwestern willow flycatcher in central Arizona; a 10-year synthesis report: U.S. Geological Survey Open-File Report 2007-1381, 143 p. [http://pubs.usgs.gov/of/2007/1381/].

Paxton, K. L., C. van Riper III, and O'Brien, C. 2008. Movement patterns and stopover ecology of Wilson's Warblers during spring migration on the lower Colorado River in southwestern Arizona. Condor 110(4): 672-681.

Paxton, E. H., Theimer, T.C. and Sogge, M.K. 2011. Tamarisk Biocontrol using Tamarisk Beetles: Potential Consequences for Riparian Birds in the Southwestern United States. Condor 113(2): 255-265.

Ralston, B. E., Davis, P. A., Weber, R M., and Rundall, J M., 2008, A vegetation database for the Colorado River ecosystem from Glen Canyon Dam to the western boundary of Grand Canyon National Park, Arizona: U.S. Geological Survey Open-File Report 2008–1216, 37 p.

Robinson, T. W. 1965. Introduction, spread, and areal extent of saltcedar (*Tamarix*) in the western states. Geological Survey Professional Paper 491-A.

Shafroth P.B., Cleverly J.R., Dudley T.L., *et al.* 2005. Control of Tamarix in the western United States: implications for water salvage, wildlife use, and riparian restoration. Environ Manage 35: 231–46.

Sogge, M. K., D. L. Felley, and M. Wotawa. 2005. A quantitative model of avian community and habitat relationships along the Colorado River in the Grand Canyon, p. 161–192. *In* C. van Riper III and D. Mattson [EDS.], The Colorado Plateau II: biophysical, socioeconomic, and cultural research. University of Arizona Press, Tucson.

Sogge, M.K., T.J. Tibbitts, and J. Petterson. 1997. Status and ecology of the Southwestern Willow Flycatcher in the Grand Canyon. Western Birds 28:142-157.

Spence, J. R. 2004. The riparian and aquatic bird communities along the Colorado River from Glen Canyon Dam to Lake Mead, 1996-2002. Draft 2.0, Final report submitted to Grand Canyon Monitoring and Research Center, USGS, Flagstaff, Arizona.

Stromberg, J., 1998, Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix chinensis*) populations along the San Pedro River, Arizona: Journal of Arid Environments, v. 40, p. 135-155.

Tieleman, B. I., H. J. Van Noordwijk, and J. B. Williams. 2008. Nest site selection in a hot desert: trade-off between microclimate and predation risk? Condor 110:116–124.

van Riper, C., III, K. Paxton, C. O’Brien, P. Shafroth and L. McGrath. 2008. Rethinking avian response to tamarisk on the lower Colorado River: A threshold hypothesis. Restoration Ecology 16 (1):155-167(March issue).

Webb, D. R. 1987. Thermal tolerance of avian embryos: a review. Condor 89:874–898.

Wolf, B. O., and G. E. Walsberg. 1996. Thermal effects of radiation and wind on a small bird and implications for microsite selection. Ecology 77:2228–2236.

Appendices 1-4

Appendix 1. 2011 tamarisk microclimate sites along the Colorado River, Grand Canyon National Park. Sites were selected in coordination with the Grand Canyon NP CRMP program.

Site Name	Data Logger Number	Point Name	River Mile	River Side	UTM Easting	UTM Northing
6 mile camp	1132144	Gc6.7DL2	6.7	R	442365	4071665
6 mile camp	1132147	Gc6.7DL1	6.7	R	442360	4011659
6 mile camp	1132148	Gc6.7DL3	6.7	R	442374	4071689
6 mile camp	1132164	Gc6.7DL4	6.7	R	442394	4071732
Soap Creek camp	1137650	Gc11.2DL3	11.2	R	438226	4066854
Soap Creek camp	1132159	Gc11.2DL4	11.2	R	438241	4066495
Soap Creek camp	1137652	Gc11.2DL1	11.2	R	438304	4066542
Soap Creek camp	1137651	Gc11.2DL2	11.2	R	438281	4066522
18 mile wash	1132157	Gc18.2DL4	18.2	L	433510	4057119
18 mile wash	1137646	Gc18.2DL2	18.2	L	433516	4057089
18 mile wash	1132151	Gc18.2DL3	18.2	L	433554	4057156
18 mile wash	1137642	Gc18.2DL1	18.2	L	433531	4057114
20 mile camp	1132158	Gc19.6DL2	19.6	L	431858	4055744
20 mile camp	1137658	Gc19.6DL3	19.6	L	431855	4055713
20 mile camp	1132153	Gc19.6DL1	19.6	L	431866	4055762
20 mile camp	1137653	Gc19.6DL4	19.6	L	431857	4055728
Nautiliod	1137657	Gc35.4DL1	35.4	L	424904	4035653
Nautiliod	1137655	Gc35.4DL4	35.4	L	424760	4035884
Nautiliod	1137647	Gc35.4DL3	35.4	L	424688	4035916
Nautiliod	1132154	Gc35.4DL2	35.4	L	424620	4035819
Upper Saddle	1132155	Gc48.2DL1	48.2	R	420711	4024235
Upper Saddle	1137637	Gc48.2DL2	48.2	R	420740	4024204
Upper Saddle	1132149	Gc48.2DL3	48.2	R	420761	4024180
Upper Saddle	1010144	Gc48.2DL4	48.2	R	420771	4024158
50.4 SWWFL	1010176	Gc50.4DL2	50.4	L	422969	4021400
50.4 SWWFL	1010154	Gc50.4DL3	50.4	L	422978	4021369
50.4 SWWFL	1010129	Gc50.4DL1	50.4	L	422960	4021432
50.4 SWWFL	1010173	Gc50.4DL4	50.4	L	422982	4021342
Little Nankoweap	1010124	Gc52DL3	52	R	422288	4018937
Little Nankoweap	1010142	Gc52DL4	52	R	422206	4018995
Little Nankoweap	1014565	Gc52DL2	52	R	422339	4018896
Little Nankoweap	1010140	Gc52DL1	52	R	422330	4018878
Kwagunt	1010141	Gc56.7DL3	56.7	R	425795	4013044
Kwagunt	1010136	Gc56.7DL4	56.7	R	425768	4013004
Kwagunt	1010145	Gc56.7DL1	56.7	R	425809	4013079
Kwagunt	1010157	Gc56.7DL2	56.7	R	425794	4013061
60 mile	1014566	Gc59.9DL2	59.9	R	427031	4008331
60 mile	855846	Gc59.9DL1	59.9	R	427038	4008314
60 mile	1010143	Gc59.9DL3	59.9	R	427015	4008294
60 mile	1010128	Gc59.9DL4	59.9	R	427040	4008360

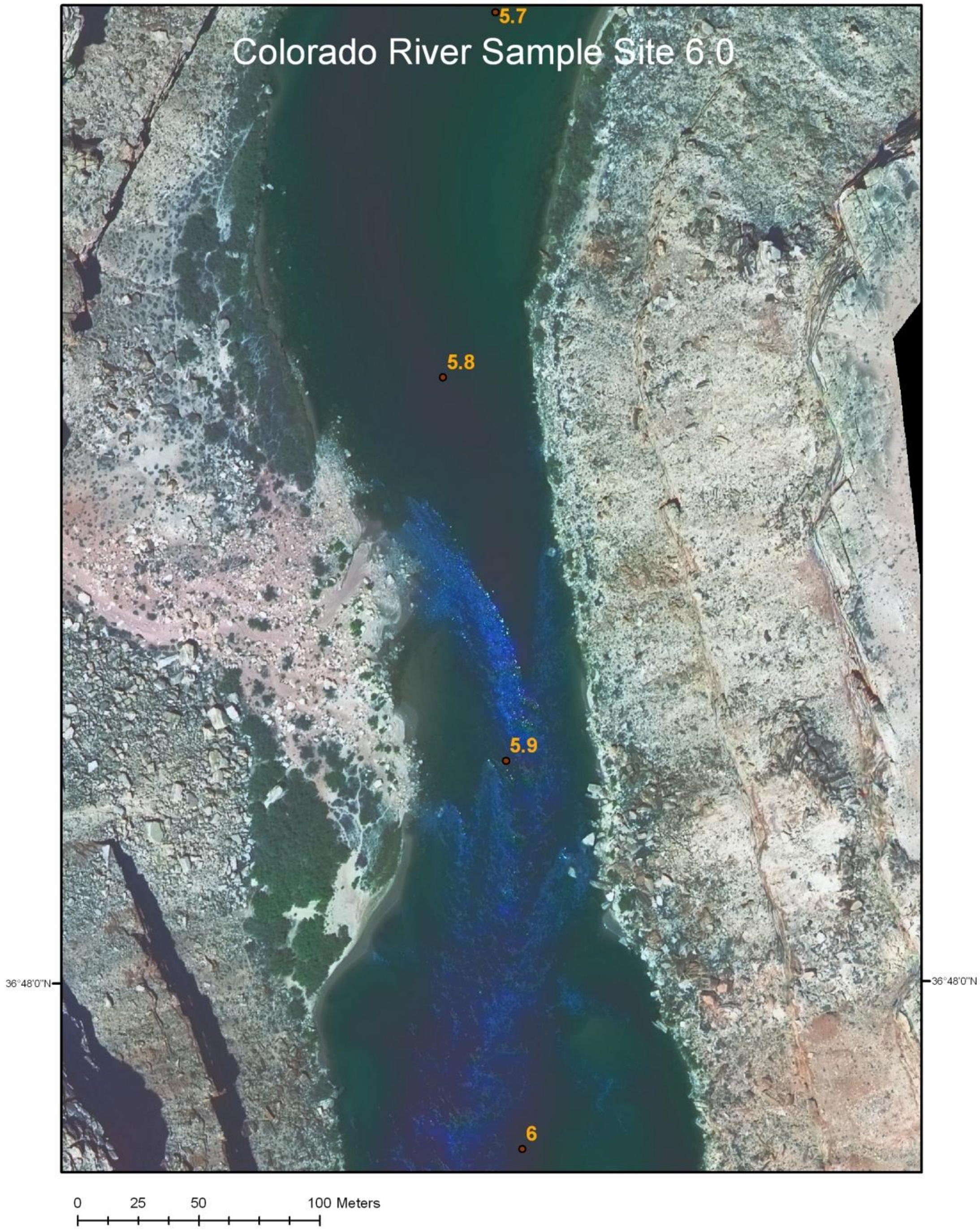
Appendix 1 cont.

Site Name	Data Logger Number	Point Name	River Mile	River Side	UTM Easting	UTM Northing
Cardenas	1010132	Gc71.4DL3	71.4	L	422414	3993860
Cardenas	1010158	Gc71.4DL1	71.4	L	422446	3993822
Cardenas	1010160	Gc71.4DL2	71.4	L	422427	3993822
Cardenas	1010163	Gc71.4DL4	71.4	L	422380	3993855
Hance	1010138	Gc76.9DL2	76.9	L	417746	3989270
Hance	1014561	Gc76.9DL1	76.9	L	417827	3989270
Hance	1014553	Gc76.9DL4	76.9	L	417718	3989243
Hance	1010125	Gc76.9DL3	76.9	L	417733	3989250
110 mile	1010150	Gc110DL1	110	R	377640	4011791
110 mile	1014556	Gc110DL4	110	R	377702	4011607
110 mile	1010152	Gc110DL3	110	R	377674	4011777
110 mile	1010131	Gc110DL2	110	R	377665	4011779
Kanab	1010139	Gc143.4DL3	143.4	L	353978	4028680
Kanab	1010162	Gc143.4DL2	143.4	L	354025	4028606
Kanab	1010149	Gc143.4DL1	143.4	L	354072	4028620
Kanab	1010134	Gc143.4DL4	143.4	L	353906	4028927
Tuckup	1010135	Gc165.4DL2	165.4	R	331106	4015893
Tuckup	1010146	Gc165.4DL1	165.4	R	331106	4015935
Tuckup	1010123	Gc165.4DL3	165.4	R	331095	4015884
Tuckup	1014564	Gc165.4DL4	165.4	R	331100	4015841
185 mile	1010177	Gc185DL2	186	R	304730	4004373
185 mile	1014555	Gc185DL1	186	R	304737	4004379
185 mile	1010169	Gc185DL4	186	R	304734	4004350
185 mile	1010175	Gc185DL3	186	R	304713	4004375
Whitmore Trailhead	1014554	Gc187.5DL2	187.5	R	301973	4002940
Whitmore Trailhead	1010174	Gc187.5DL3	187.5	R	301958	4002903
Whitmore Trailhead	1010167	Gc187.5DL4	187.5	R	301993	4003101
Whitmore Trailhead	1014559	Gc187.5DL1	187.5	R	301972	4112936
SWFL survey 194.8	1010127	Gc193DL2	194.8	L	296843	3996045
SWFL survey 194.8	1010161	Gc193DL4	194.8	L	296867	3996088
SWFL survey 194.8	1010153	Gc193DL3	194.8	L	296862	3996060
SWFL survey 194.8	1010159	Gc193DL1	194.8	L	296826	3996037
Froggy Fault	1010164	Gc197DL1	197.5	L	292961	3997257
Froggy Fault	1010148	Gc197DL4	197.5	L	292769	3997075
Froggy Fault	1010168	Gc197DL3	197.5	L	292814	3997069
Froggy Fault	1010172	Gc197DL2	197.5	L	292812	3997029
214 mile	1010178	Gc214DL1	215.1	R	290800	3974855
214 mile	1010147	Gc214DL2	215.1	R	290829	3974840
214 mile	1014563	Gc214DL3	215.1	R	290867	3974836

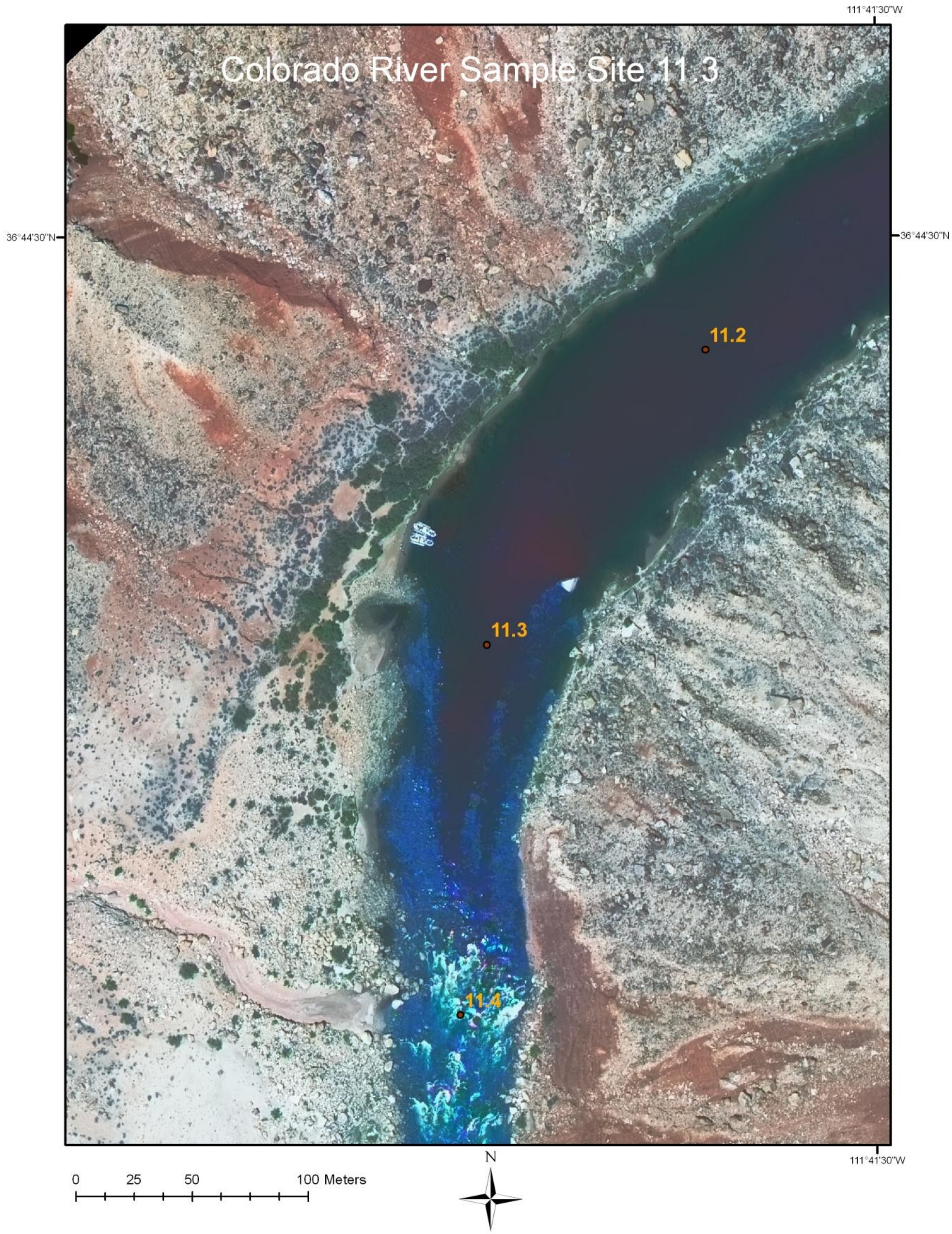
Appendix 1 cont.

Site Name	Data Logger Number	Point Name	River Mile	River Side	UTM Easting	UTM Northing
214 mile	1014560	Gc214DL4	215.1	R	290892	3974822
217 mile	1010151	Gc217DL1	217.7	L	291425	3971136
217 mile	1014558	Gc217DL4	217.7	L	291443	3971232
217 mile	1010171	Gc217DL3	217.7	L	291442	3971194
217 mile	1014552	Gc217DL2	217.7	L	291434	3971166
217 mile	1014562	Gc217DL1	217.7	L	291424	3971210

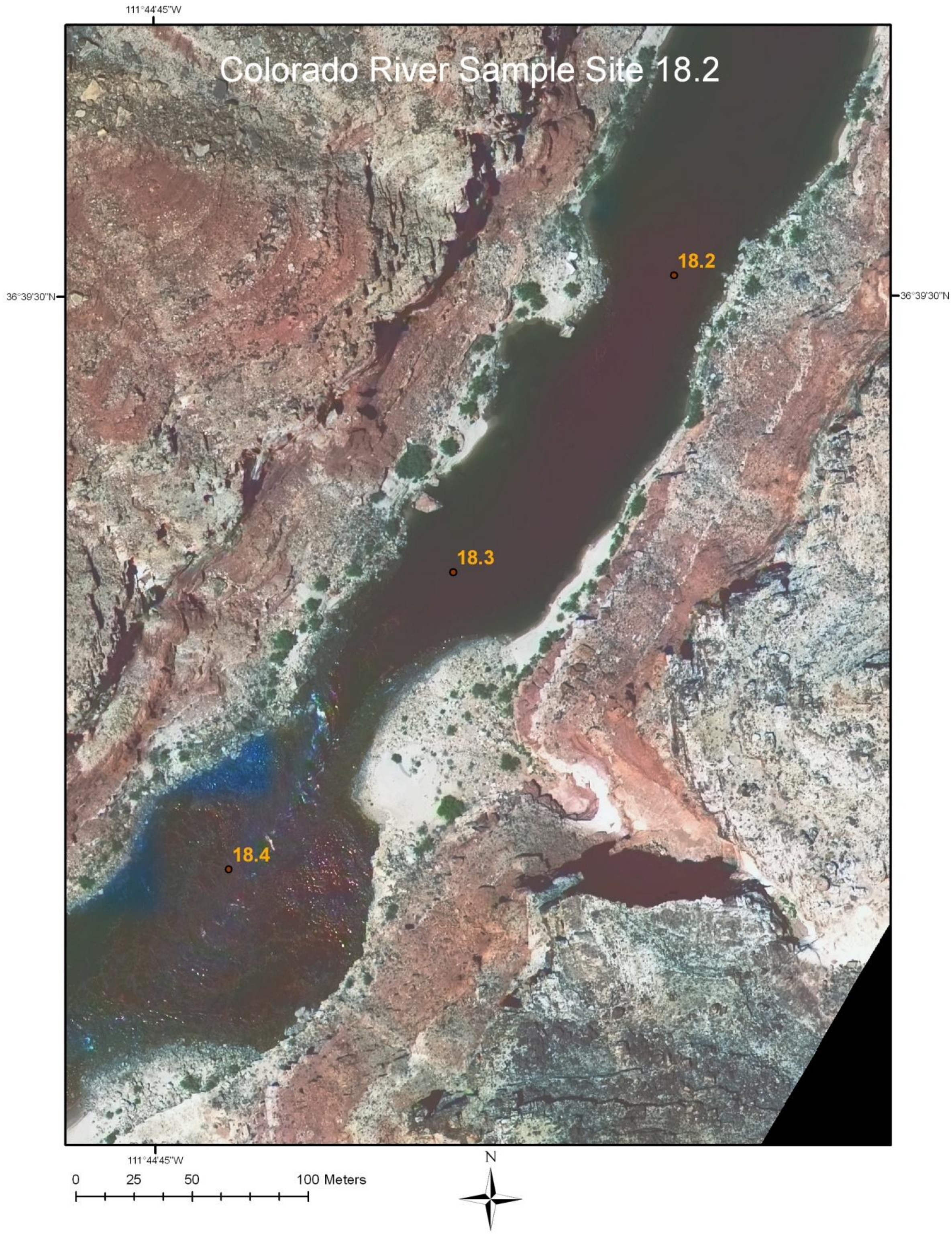
Appendix 2. 2011 aerial photographs of CRMP sites where bird, vegetation, microclimate (Temperature, Relative Humidity) and tamarisk leaf beetle sweeps were completed along the Colorado River in Grand Canyon National Park. Colorado River, River Right, River Mile 6.



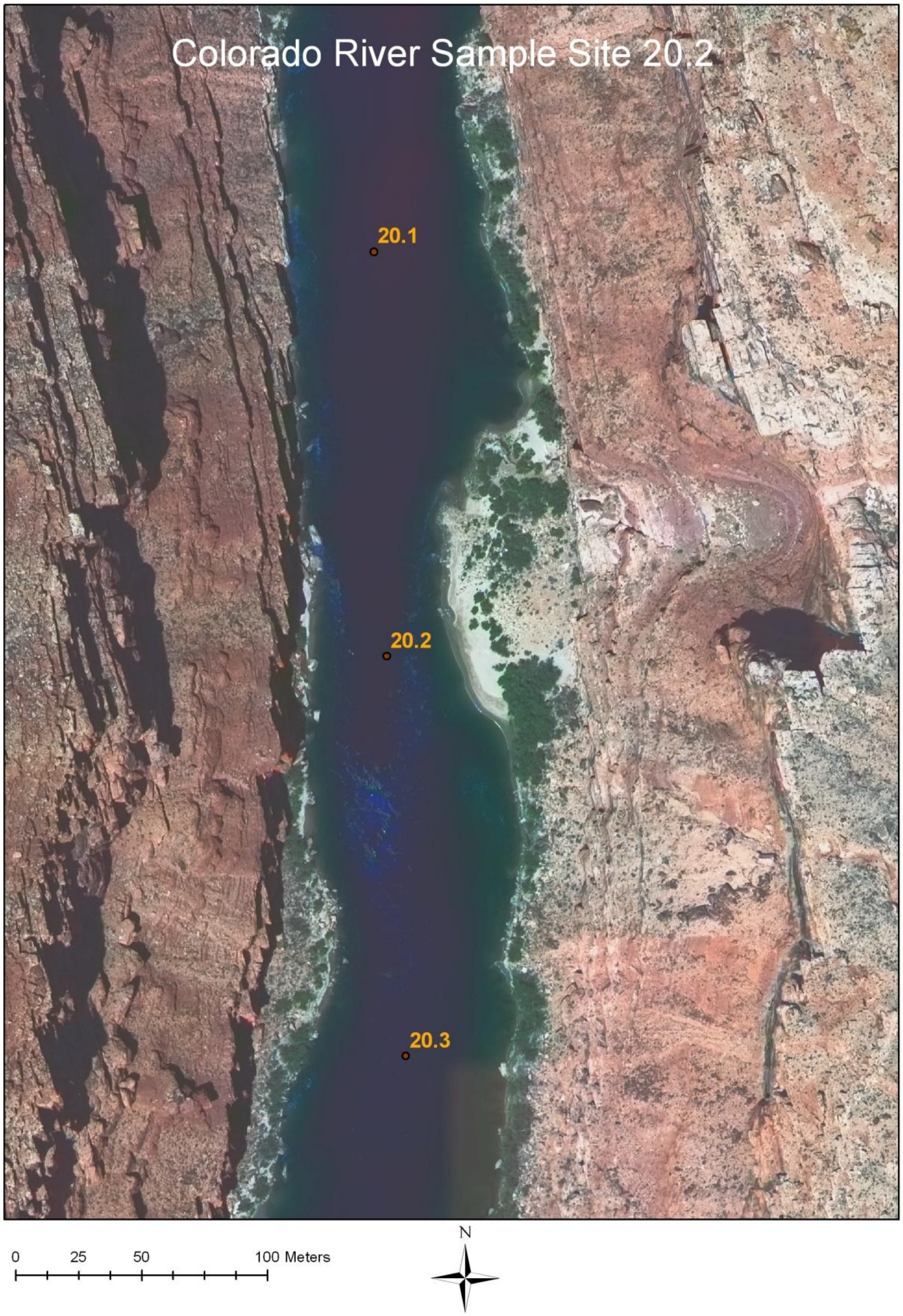
Appendix 2 cont. (Colorado River, River Right, River Mile 11.3)



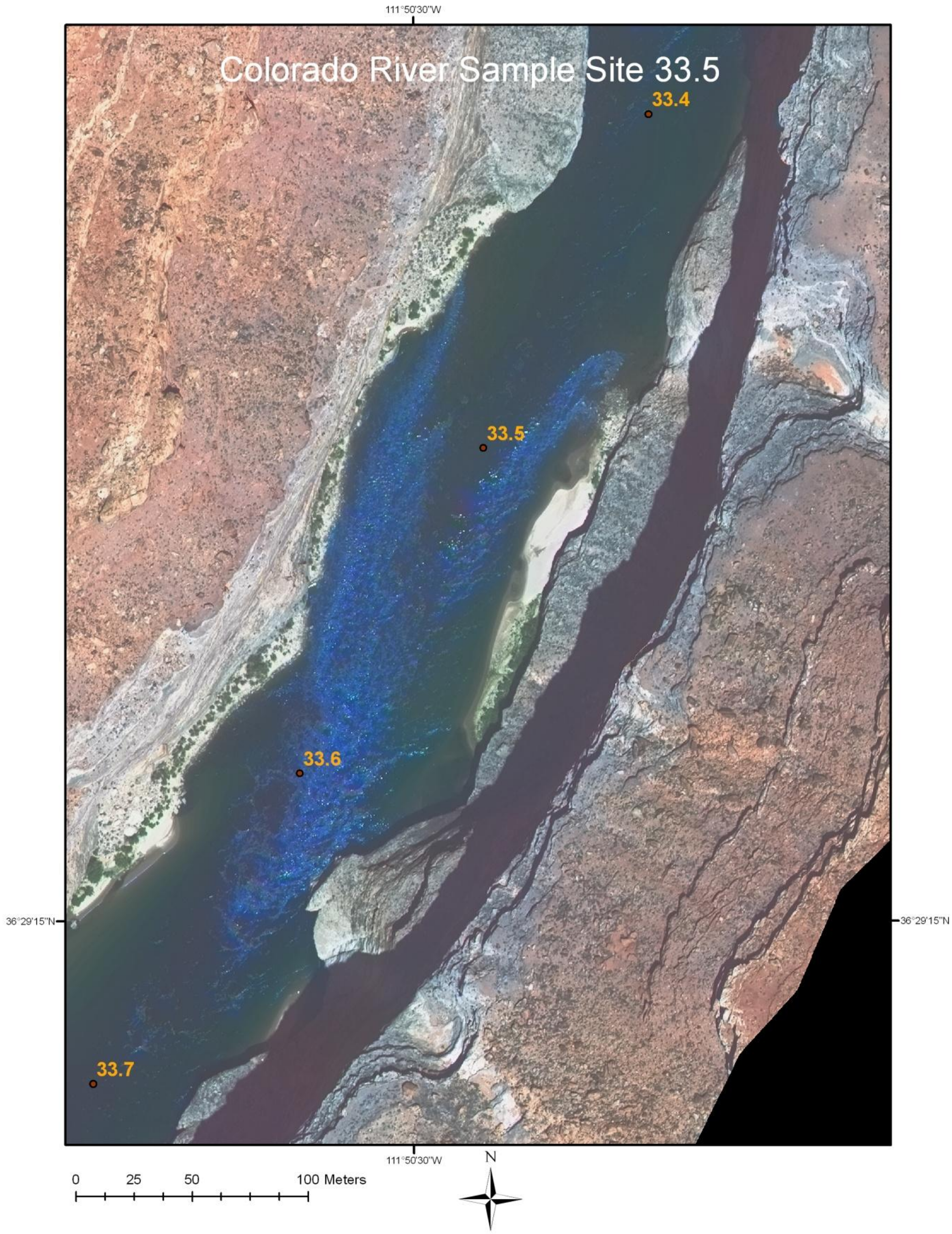
Appendix 2 cont. (Colorado River, River Right, River Mile 18.2)



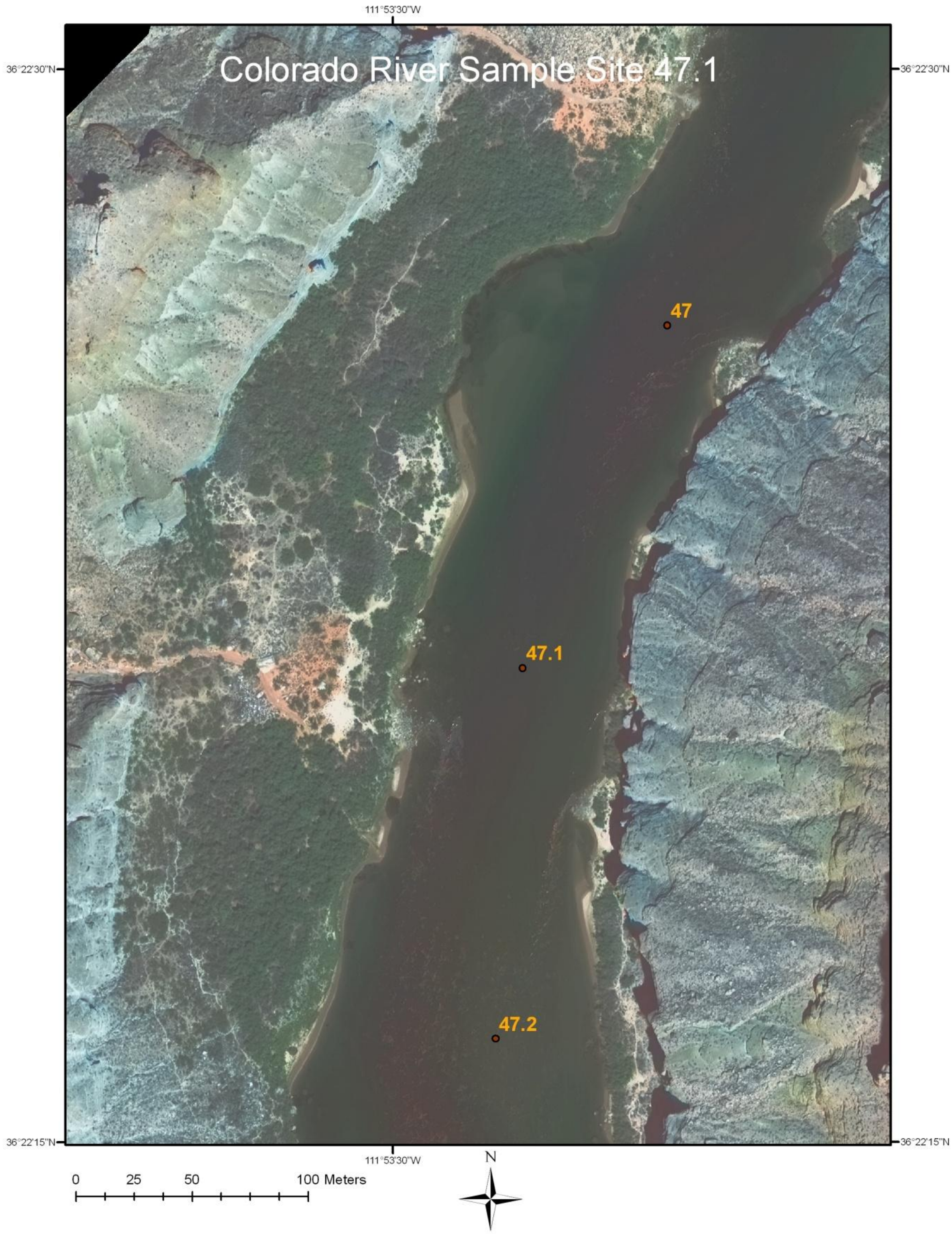
Appendix 2 cont. (Colorado River, River Left, River Mile 20.2)



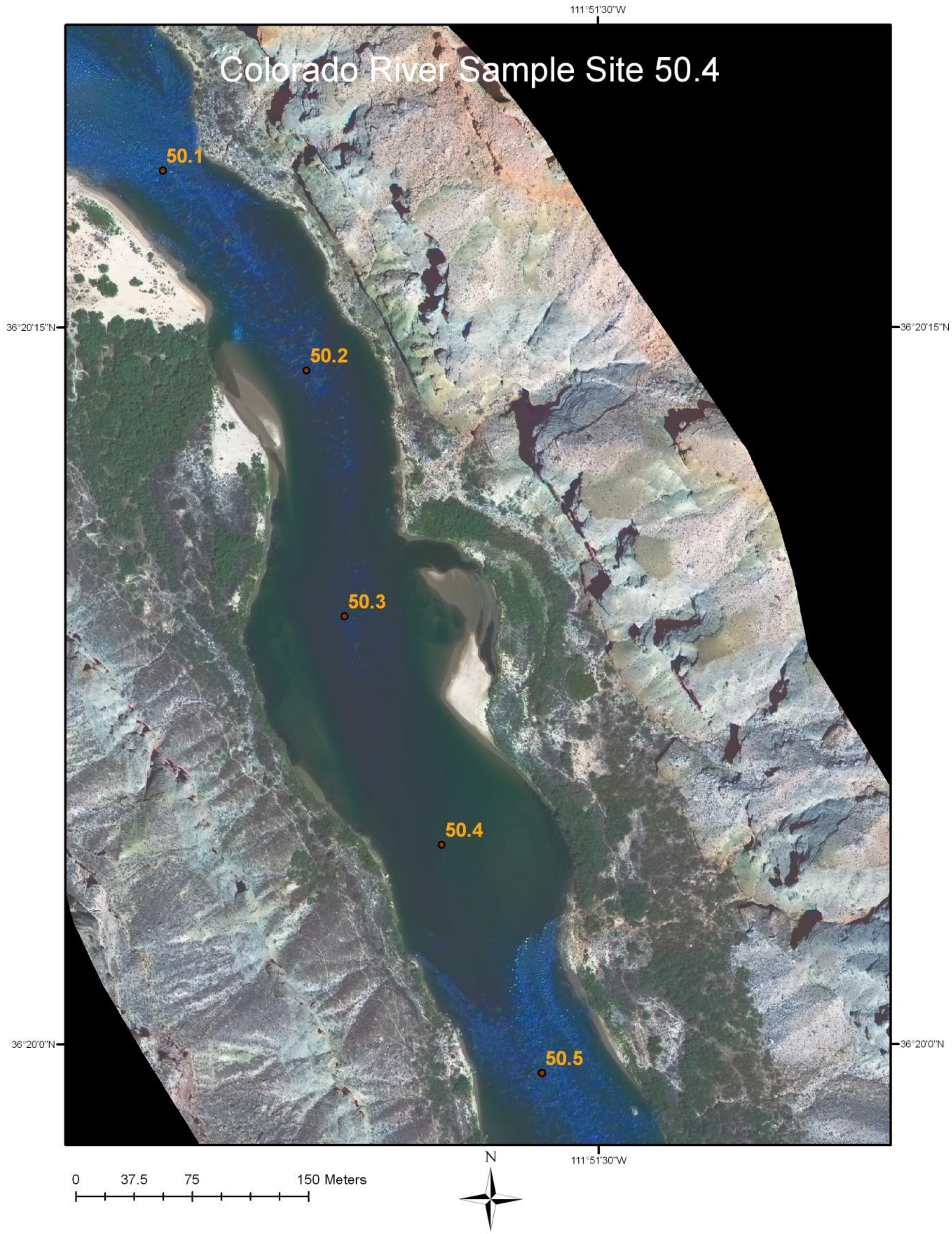
Appendix 2 cont. (Colorado River, River Left, River Mile 33.5)



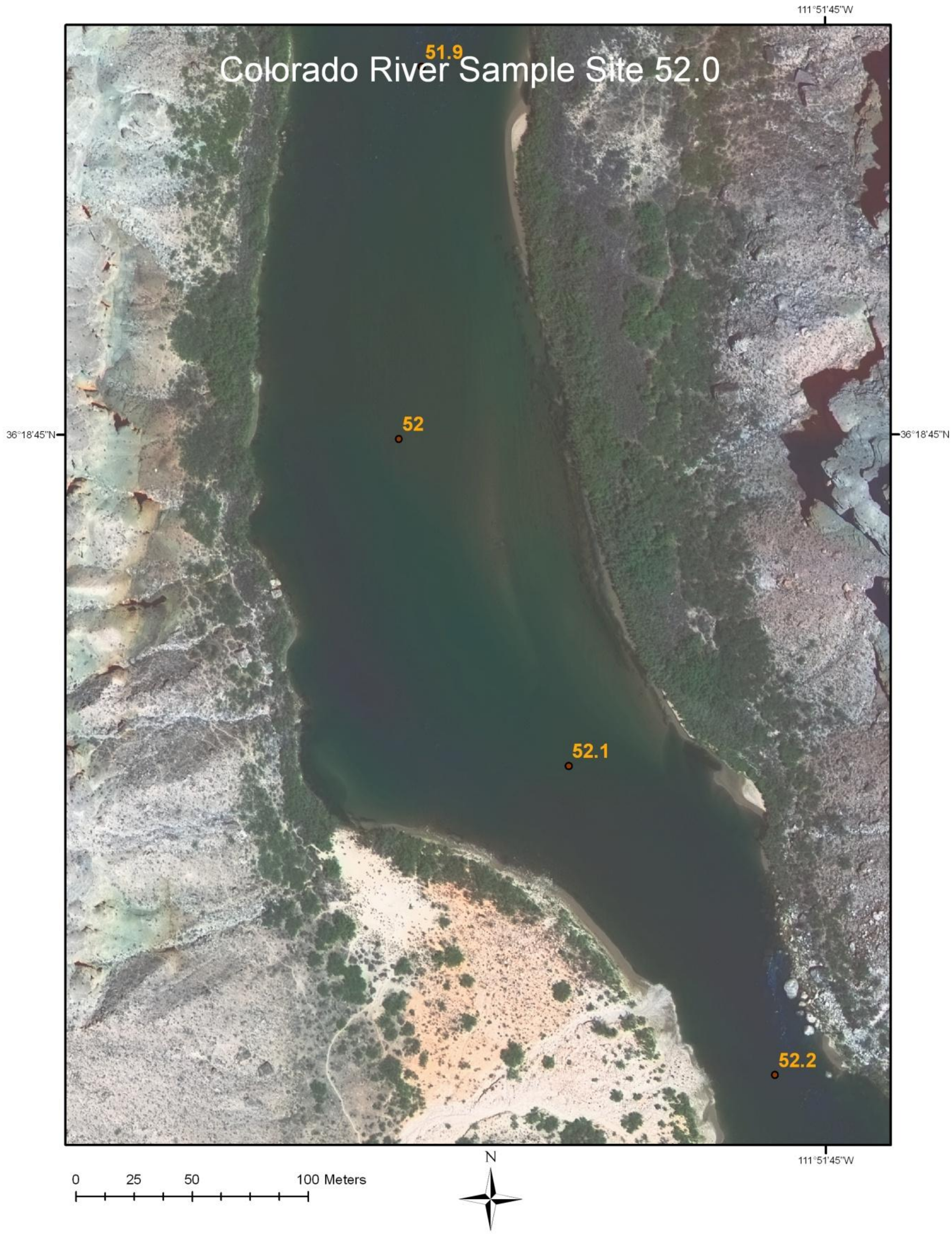
Appendix 2 cont. (Colorado River, River Right, River Mile 47.1)



Appendix 2 cont. (Colorado River, River Left, River Mile 50.4)

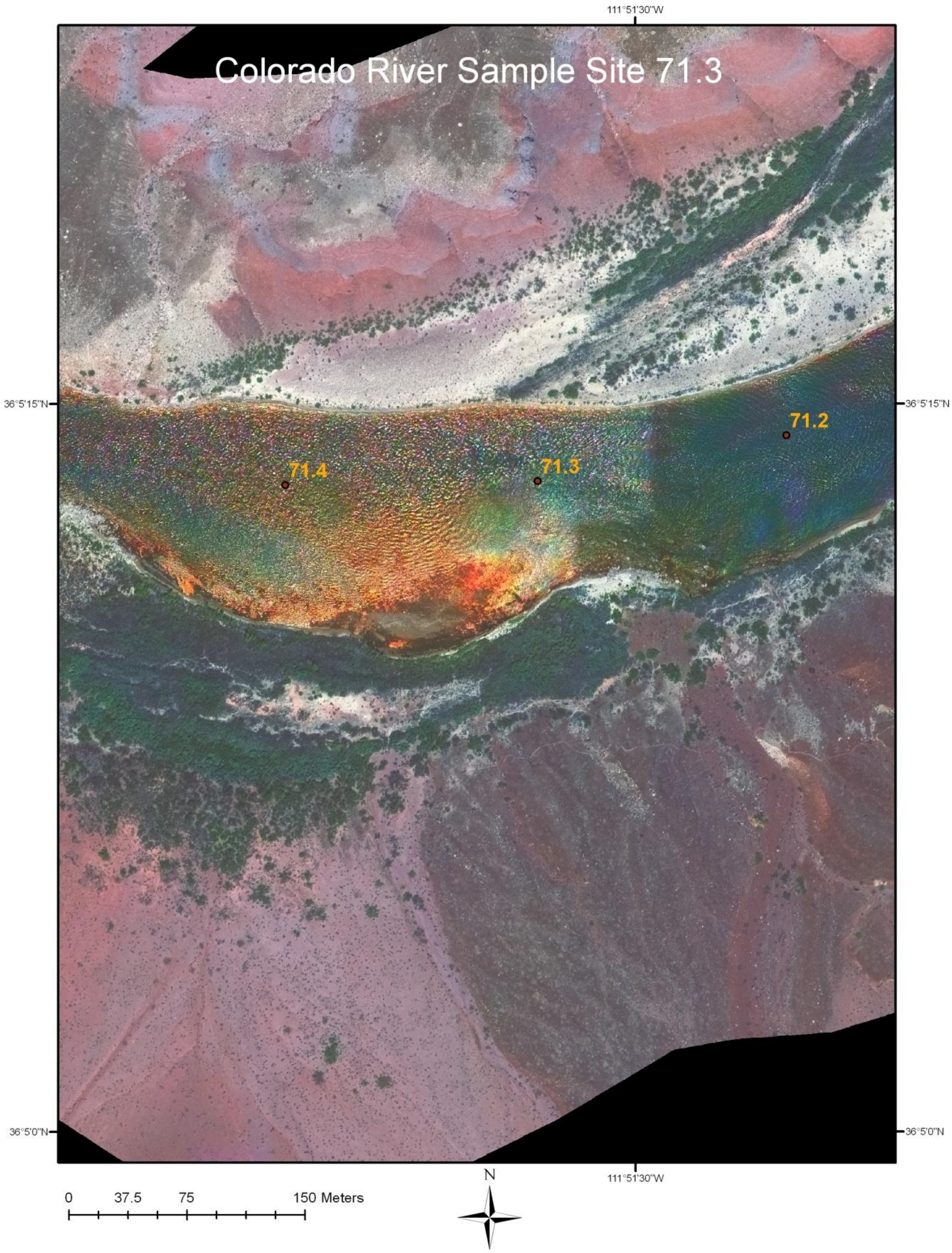


Appendix 2 cont. (Colorado River, River Right, River Mile 52.0)

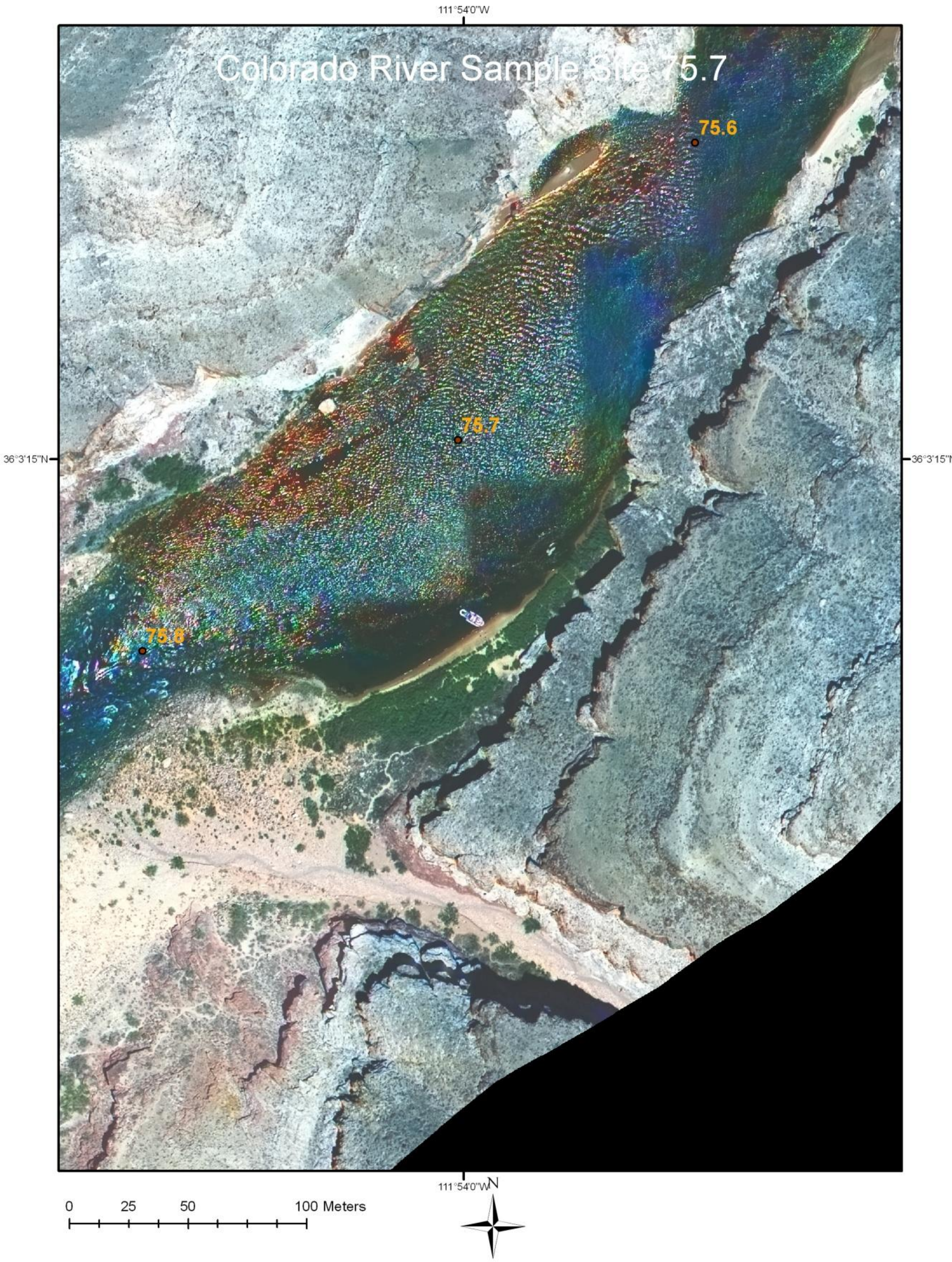


Appendix 2 cont. (Colorado River, River Right, River Mile 56.8)

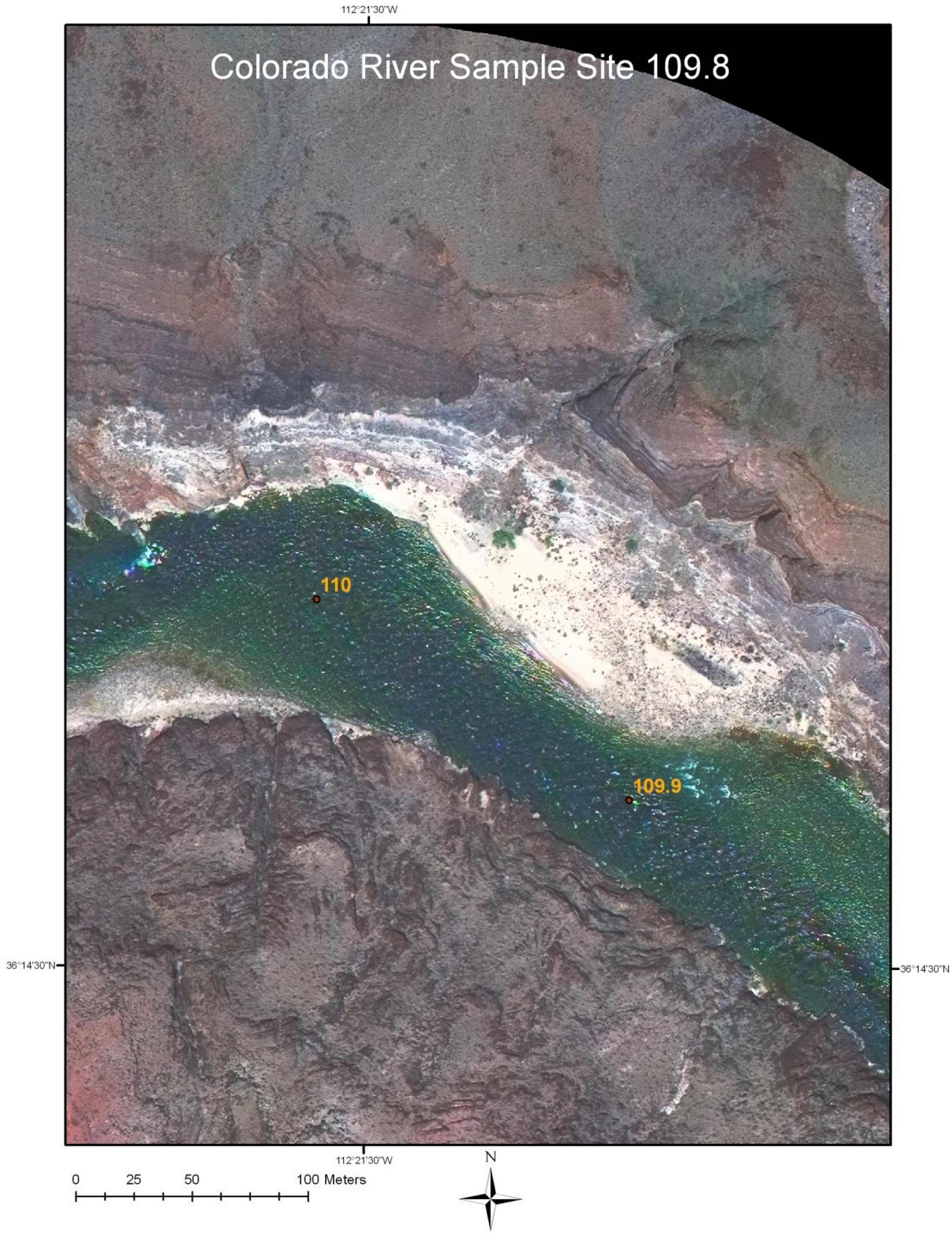
Appendix 2 cont. (Colorado River, River Left, River Mile 71.3)



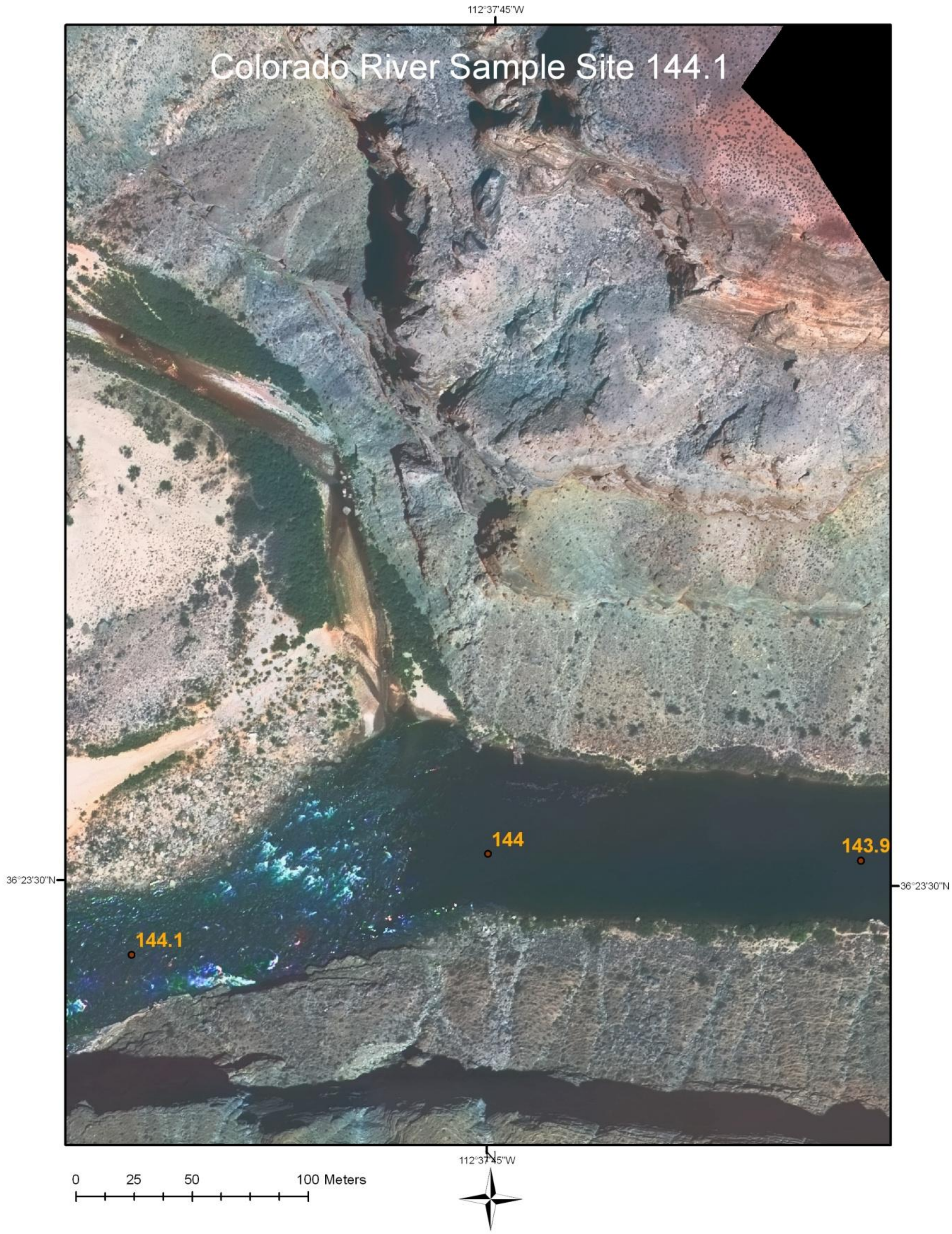
Appendix 2 cont. (Colorado River, River Left, River Mile 75.7)



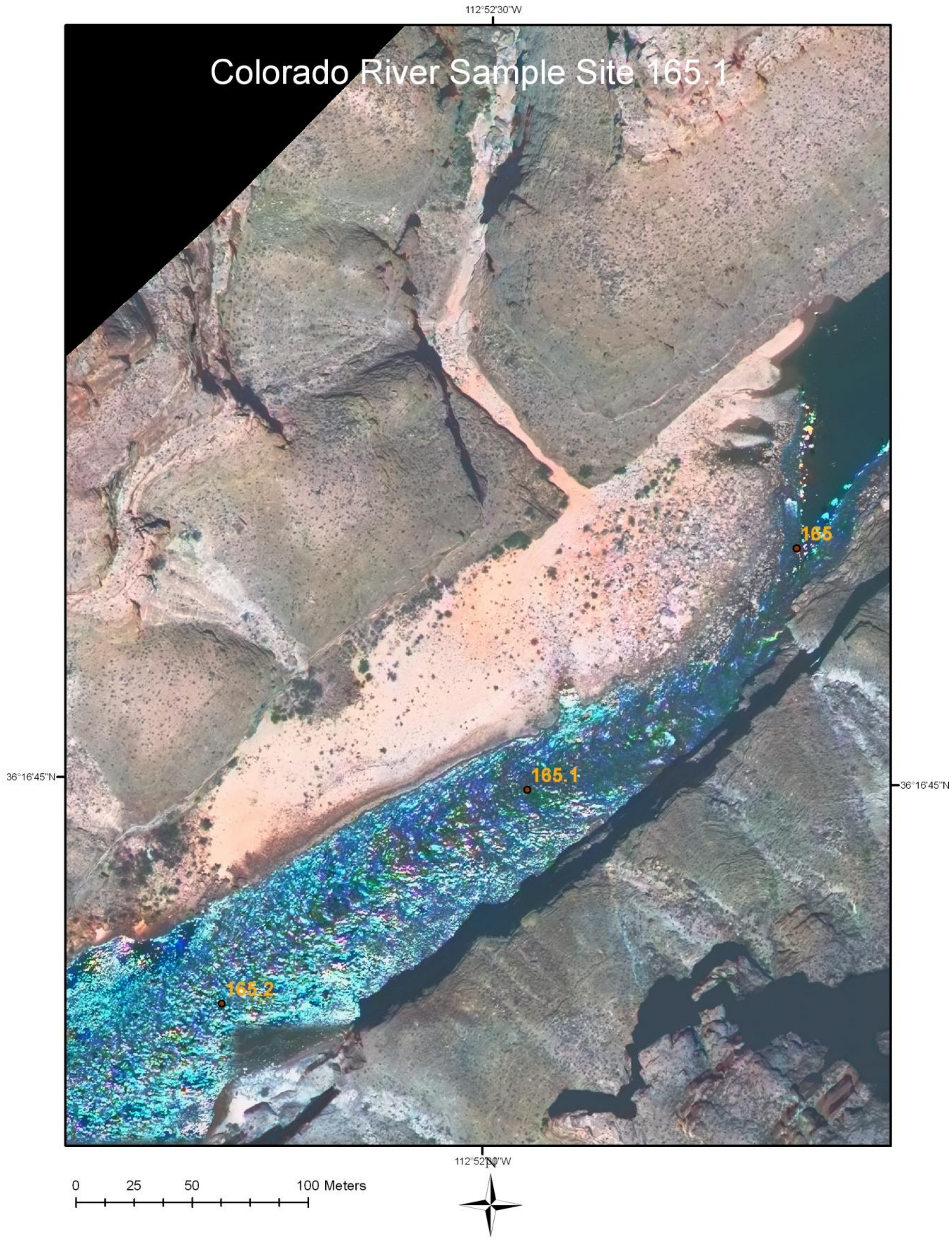
Appendix 2 cont. (Colorado River, River Right, River Mile 109.8)



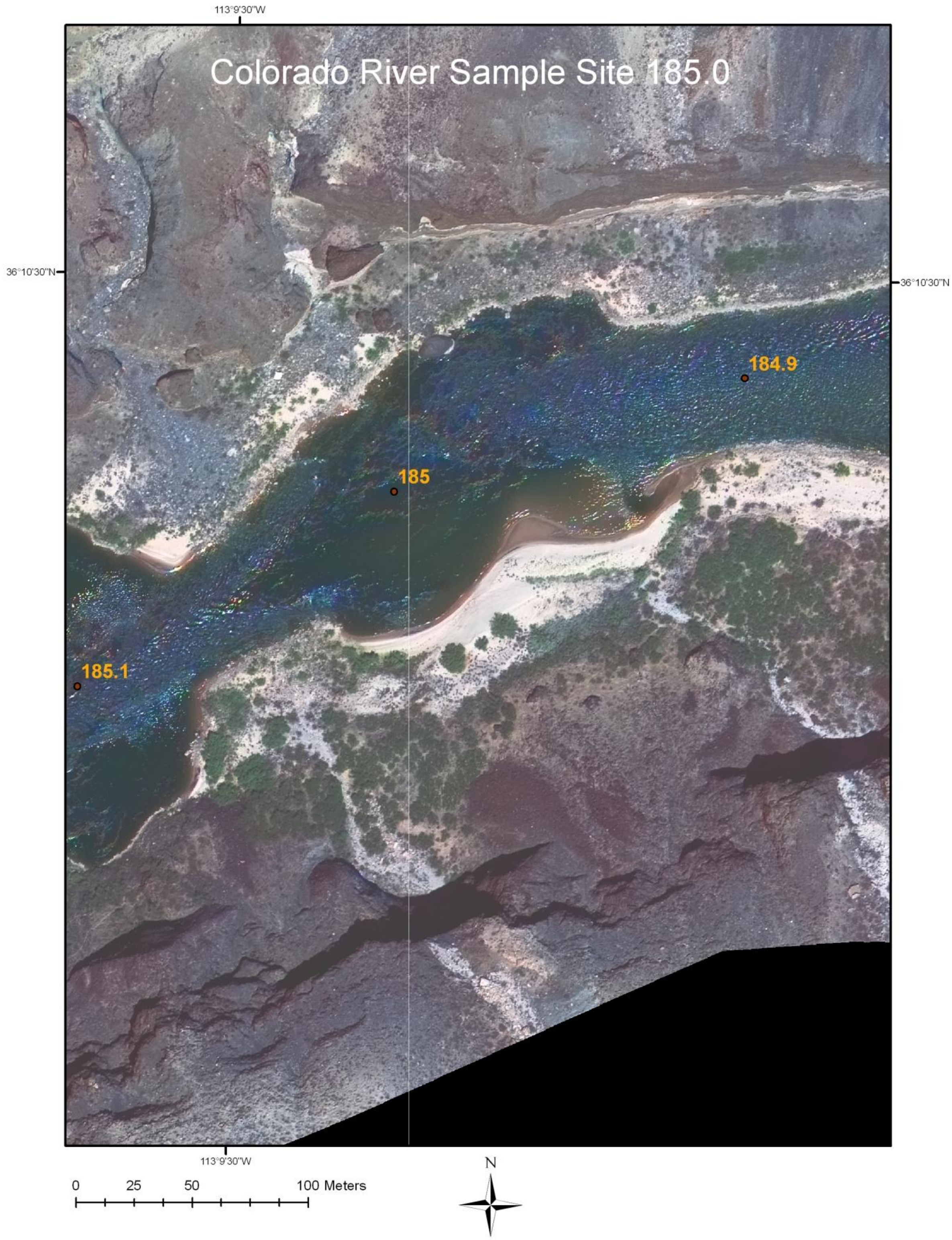
Appendix 2 cont. (Colorado River, River Left, River Mile 144.1)



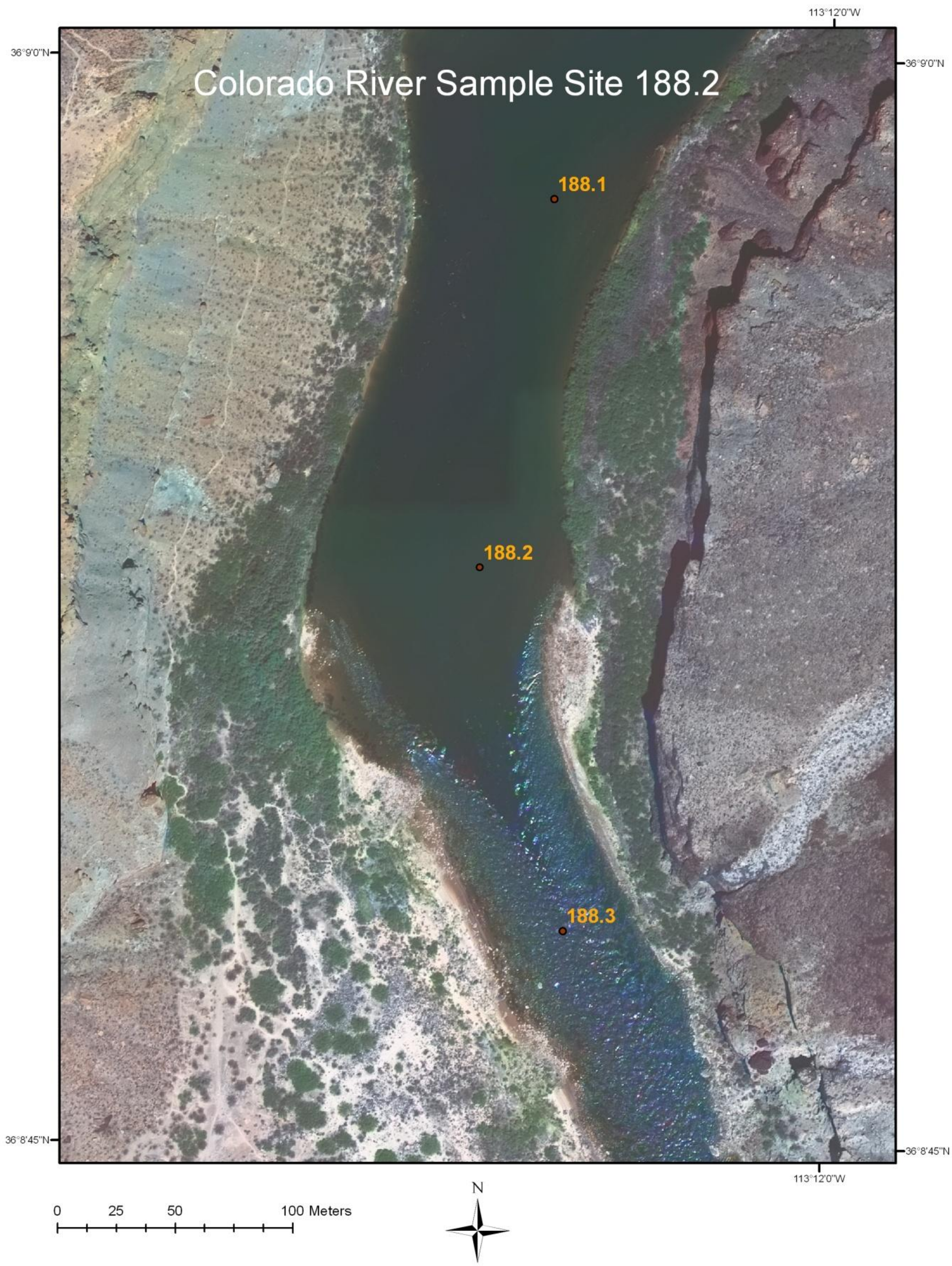
Appendix 2 cont. (Colorado River, River Right, River Mile 165.1)



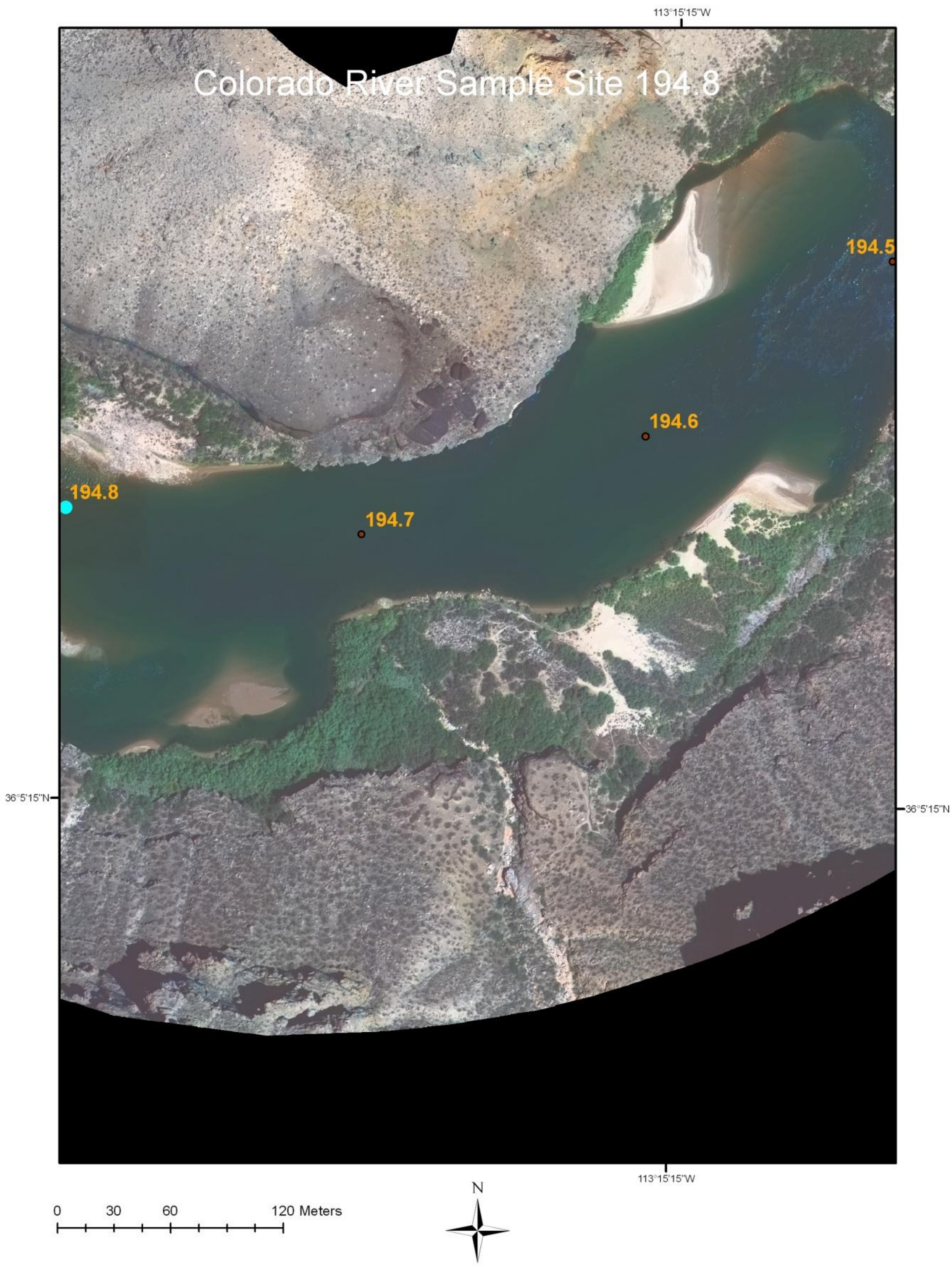
Appendix 2 cont. (Colorado River, River Left, River Mile 185.0)



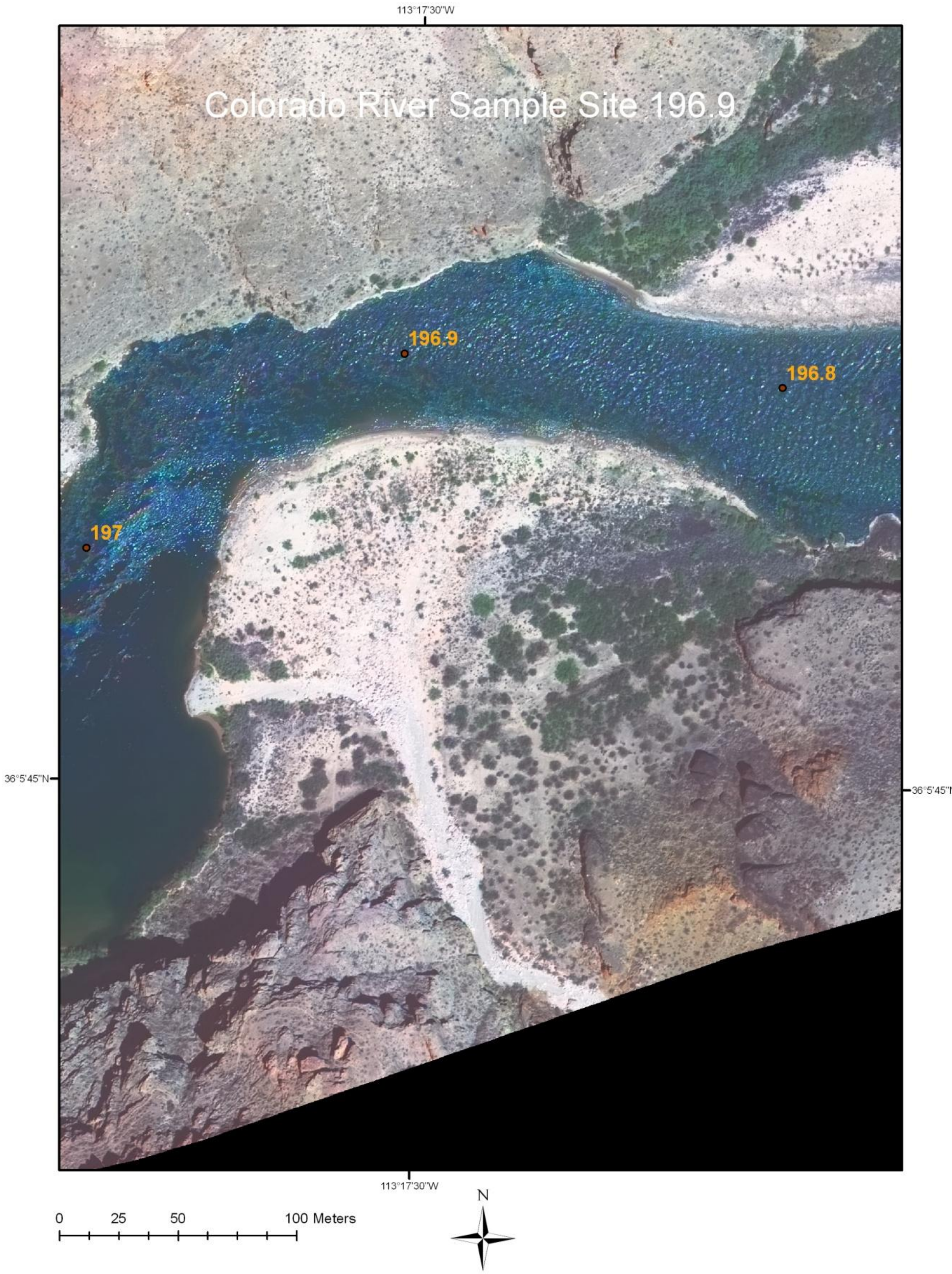
Appendix 2 cont. (Colorado River, River Right, River Mile 188.2)



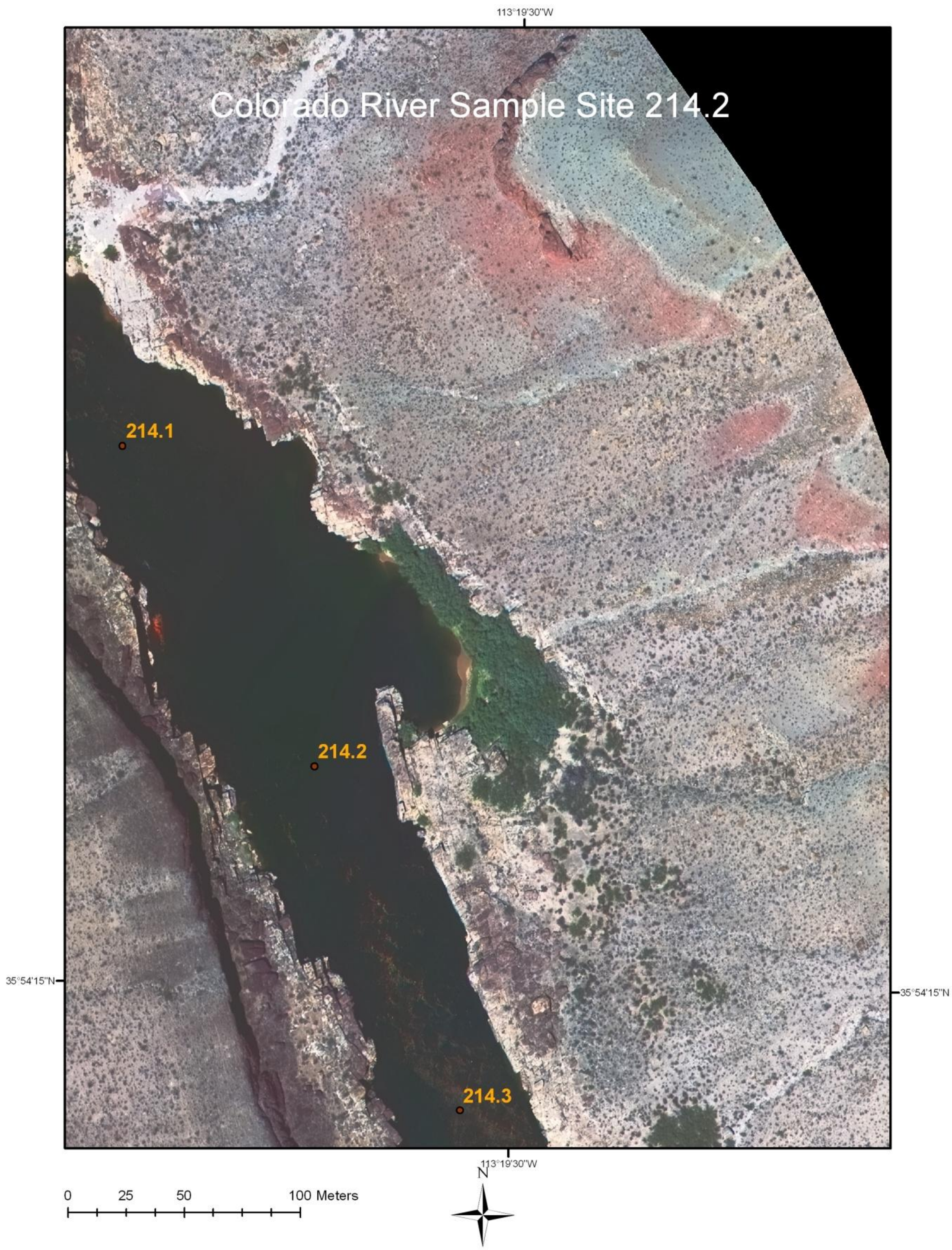
Appendix 2 cont. (Colorado River, River Left, River Mile 194.8)



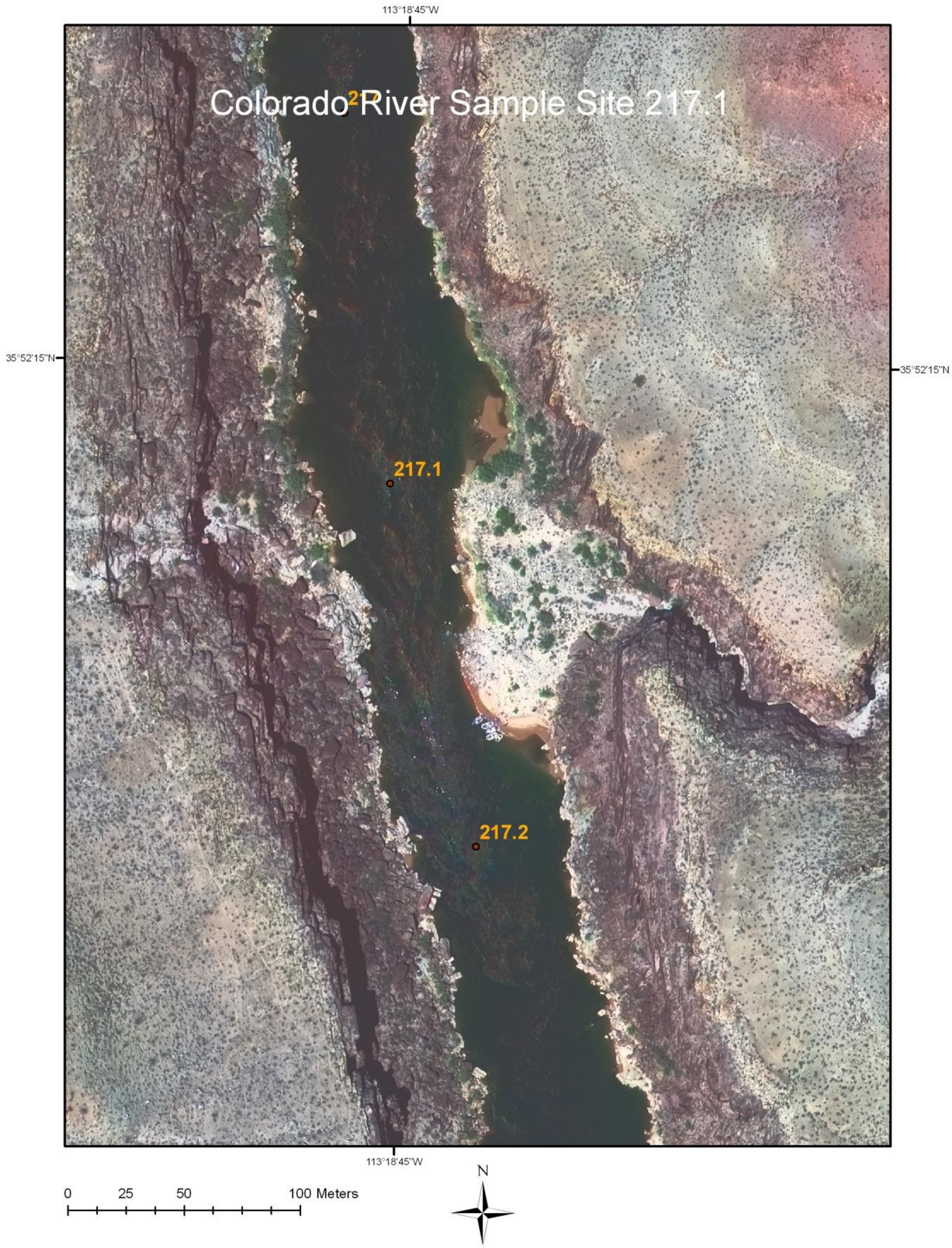
Appendix 2 cont. (Colorado River, River Left, River Mile 196.9)



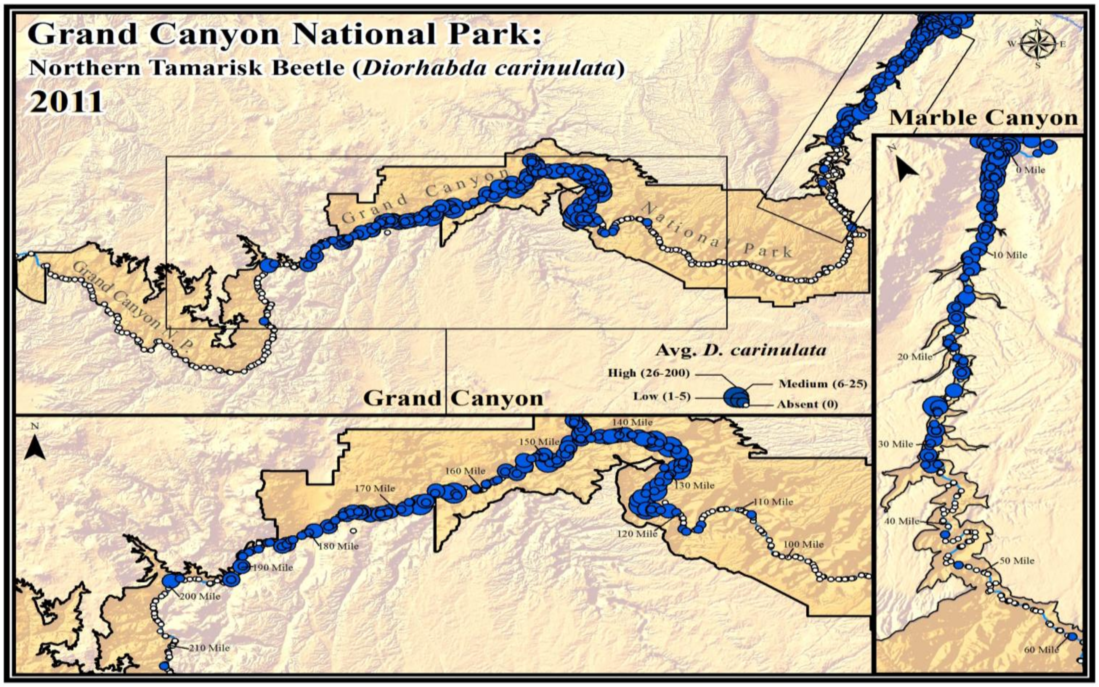
Appendix 2 cont. (Colorado River, River Right, River Mile 214.2)



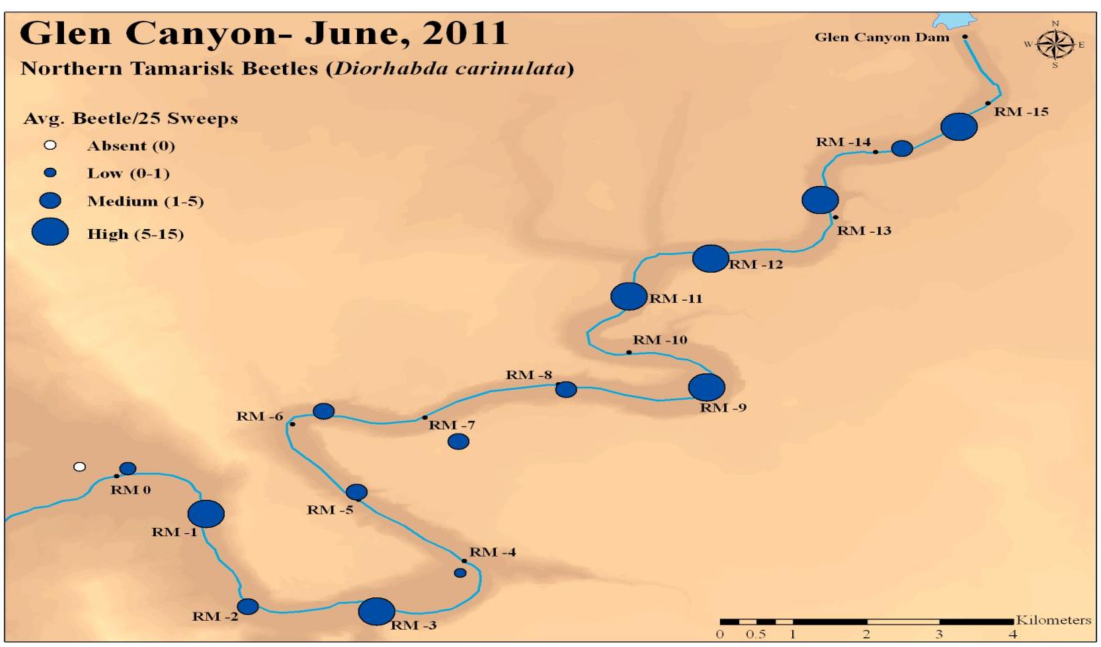
Appendix 2 cont. (Colorado River, River Right, River Mile 217.1)



Appendix 3. Maps of tamarisk leaf beetle (larvae and adults) detections, non-detection locations and defoliation rates per month during 2011 tamarisk leaf beetle surveys in Grand Canyon National Park and Glen Canyon National Monument.

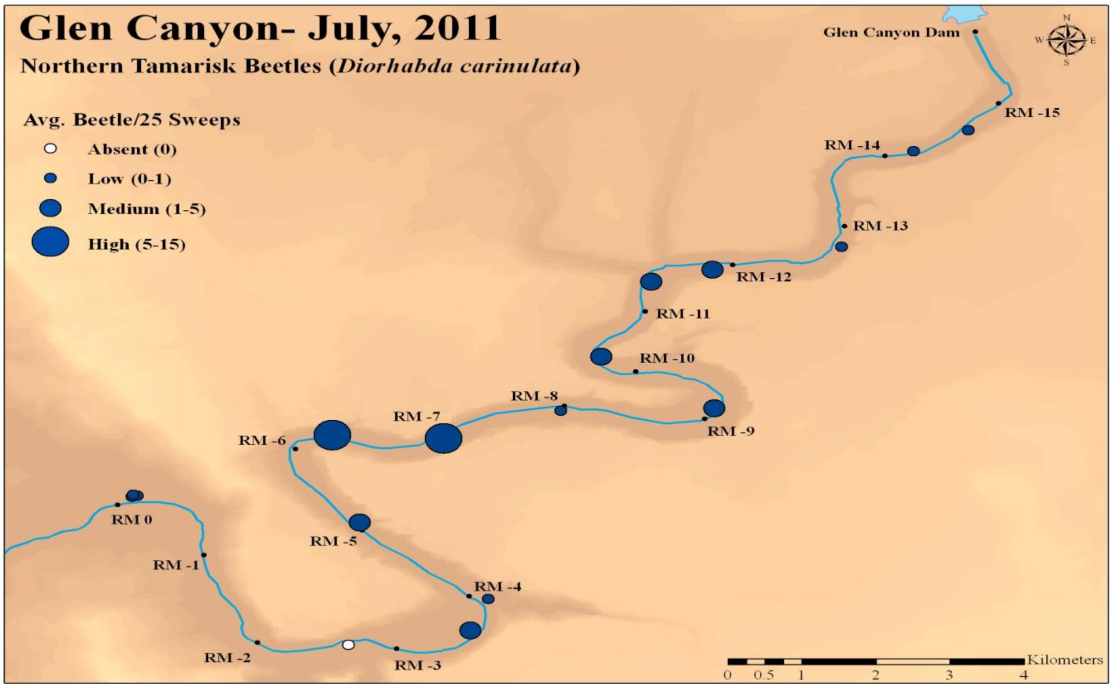


Map #1. Tamarisk Leaf Beetle (larvae and Adults) detection locations and non-detection locations during 2011 tamarisk leaf beetle surveys from Lee's Ferry to the boundary of Lake Mead.

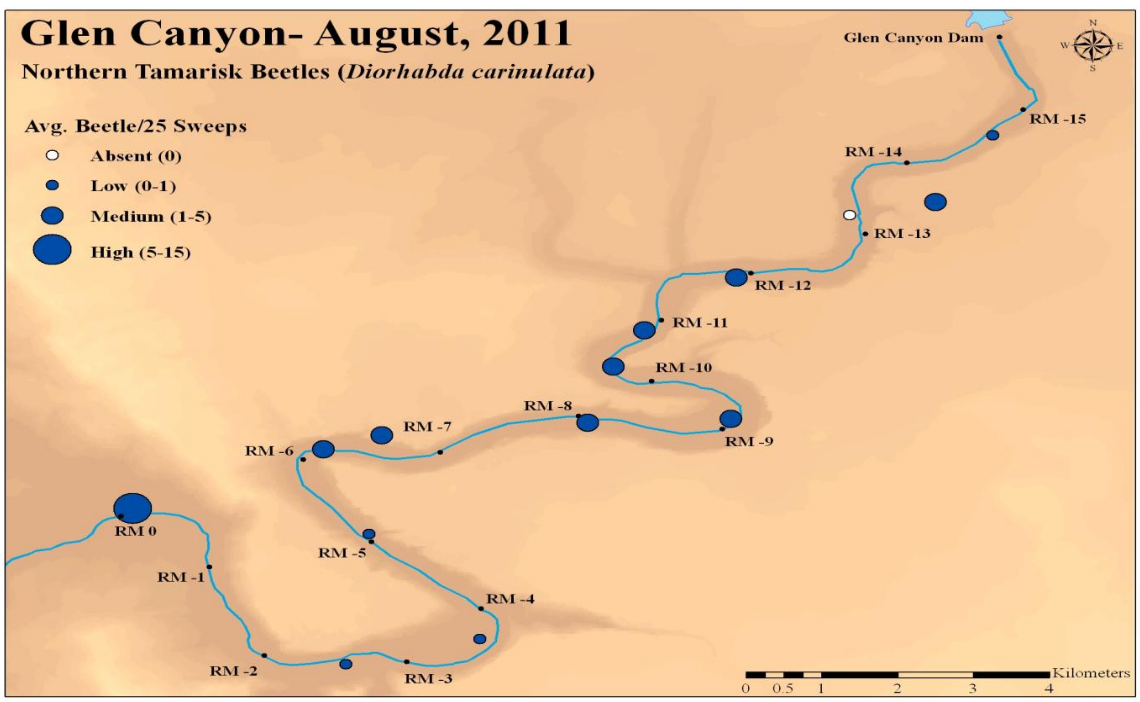


Map #2. Tamarisk Leaf Beetle (larvae and Adults) detection locations and non-detection locations during June 2011 tamarisk leaf beetle surveys from Lee's Ferry to Glen Canyon Dam.

Appendix 3 cont. (Tamarisk Leaf Beetle distribution in Grand Canyon NP and Glen Canyon NM)

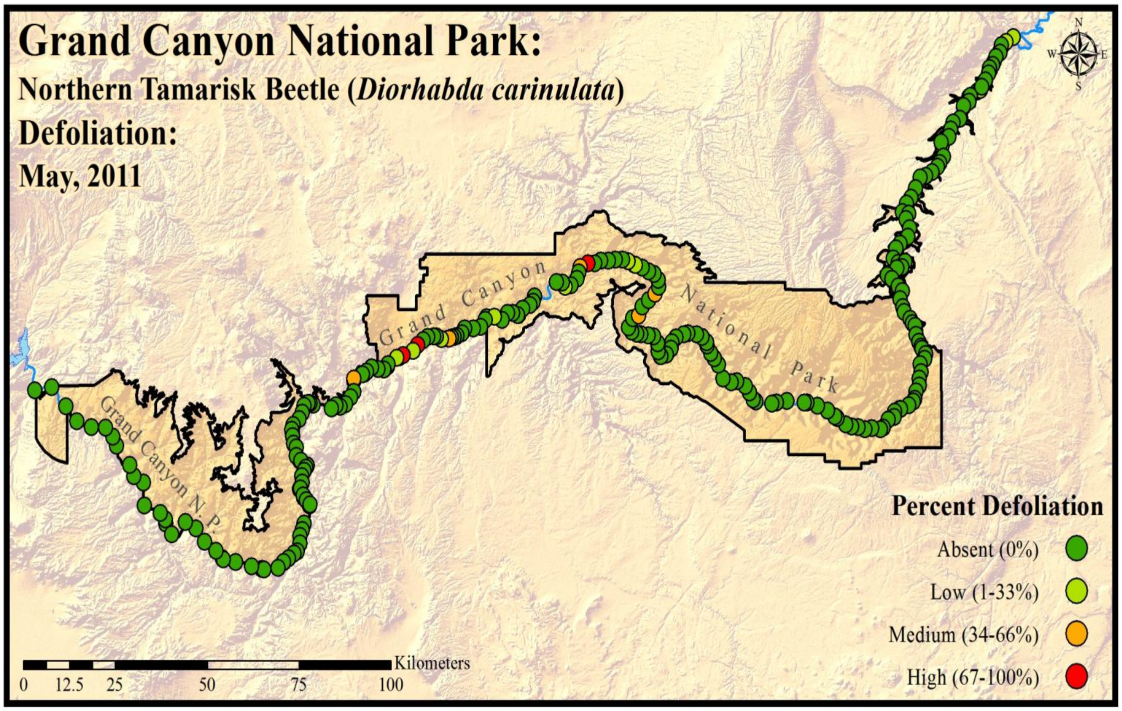


Map #3. Tamarisk Leaf Beetle (larvae and Adults) detection locations and non-detection locations during July 2011 tamarisk leaf beetle surveys from Lee's Ferry to Glen Canyon Dam.

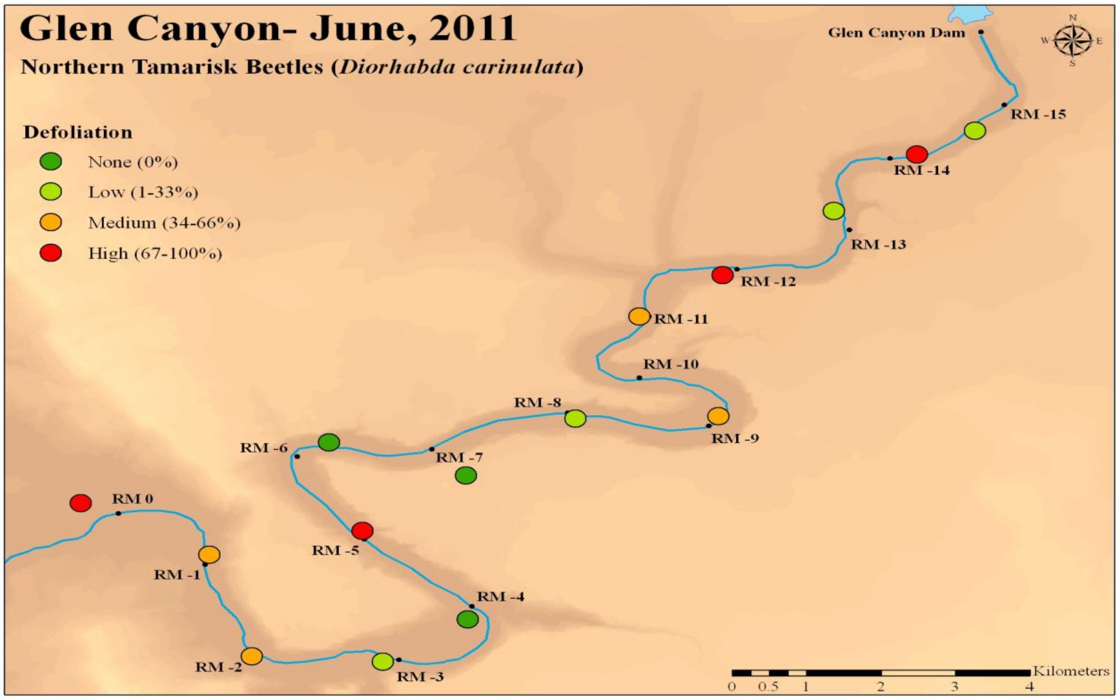


Map #4. Tamarisk Leaf Beetle (larvae and Adults) detection locations and non-detection locations during August 2011 tamarisk leaf beetle surveys from Lee's Ferry to Glen Canyon Dam.

Appendix 3 cont. (Tamarisk Leaf Beetle defoliation in Grand Canyon NP and Glen Canyon NM)

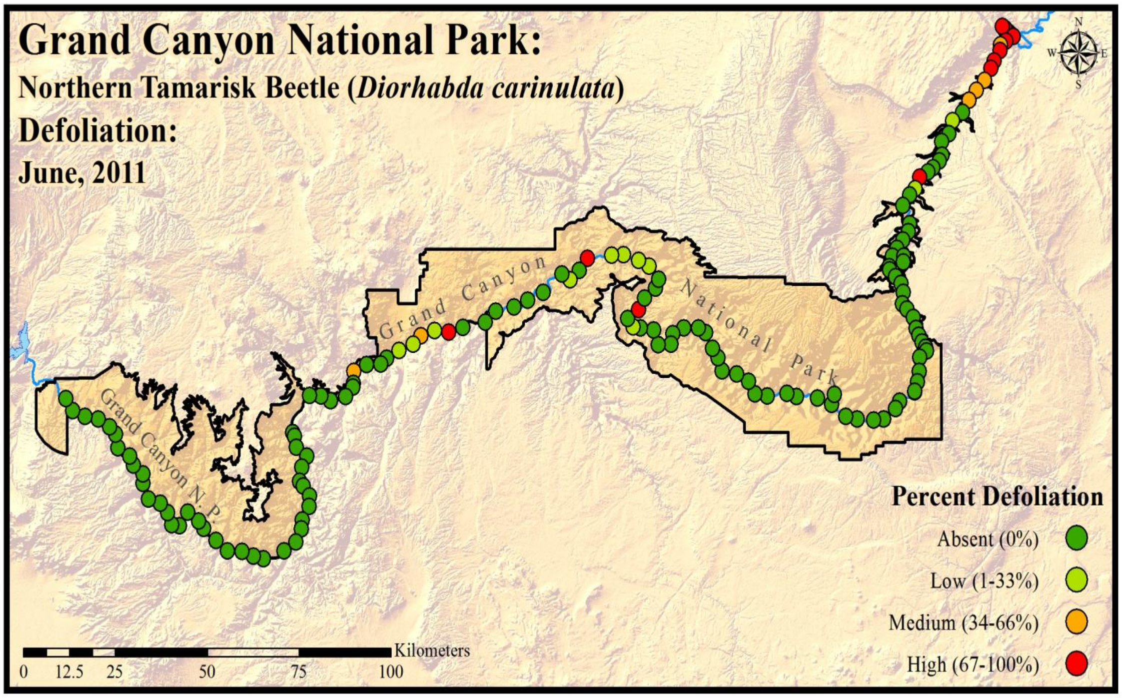


Map #5. Defoliation of tamarisk by tamarisk leaf beetle in Grand Canyon National Park during May of 2011.

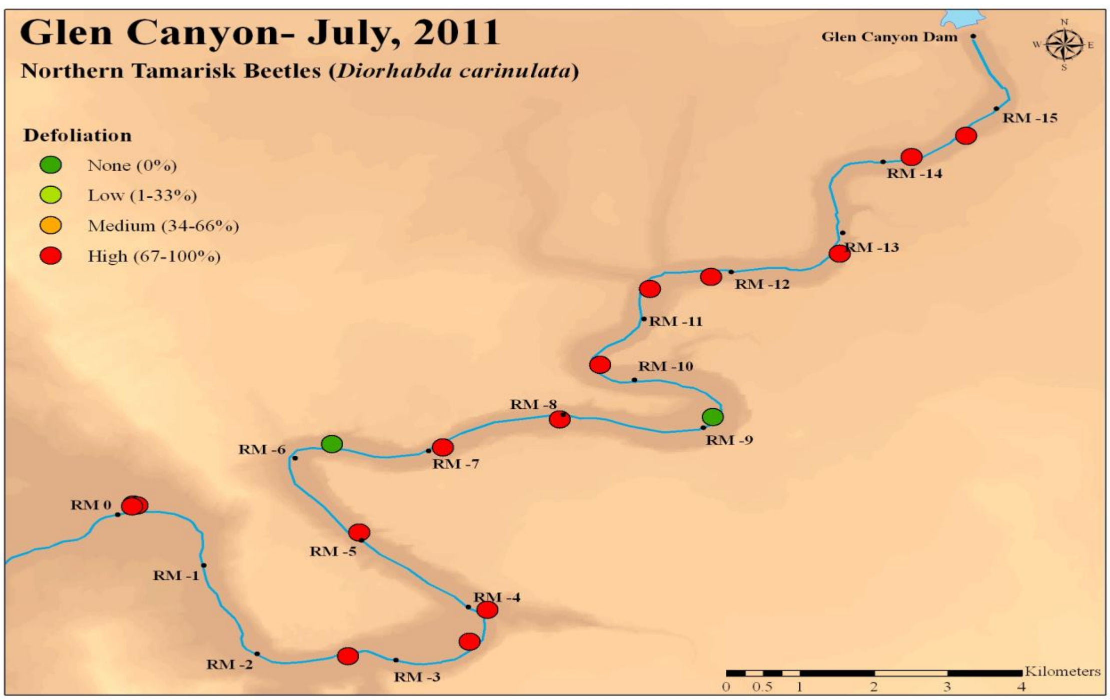


Map #6. Defoliation of tamarisk by tamarisk leaf beetle between Lee’s Ferry and Glen Canyon Dam during June of 2011.

Appendix 3 cont. (Tamarisk Leaf Beetle defoliation in Grand Canyon NP and Glen Canyon NM)

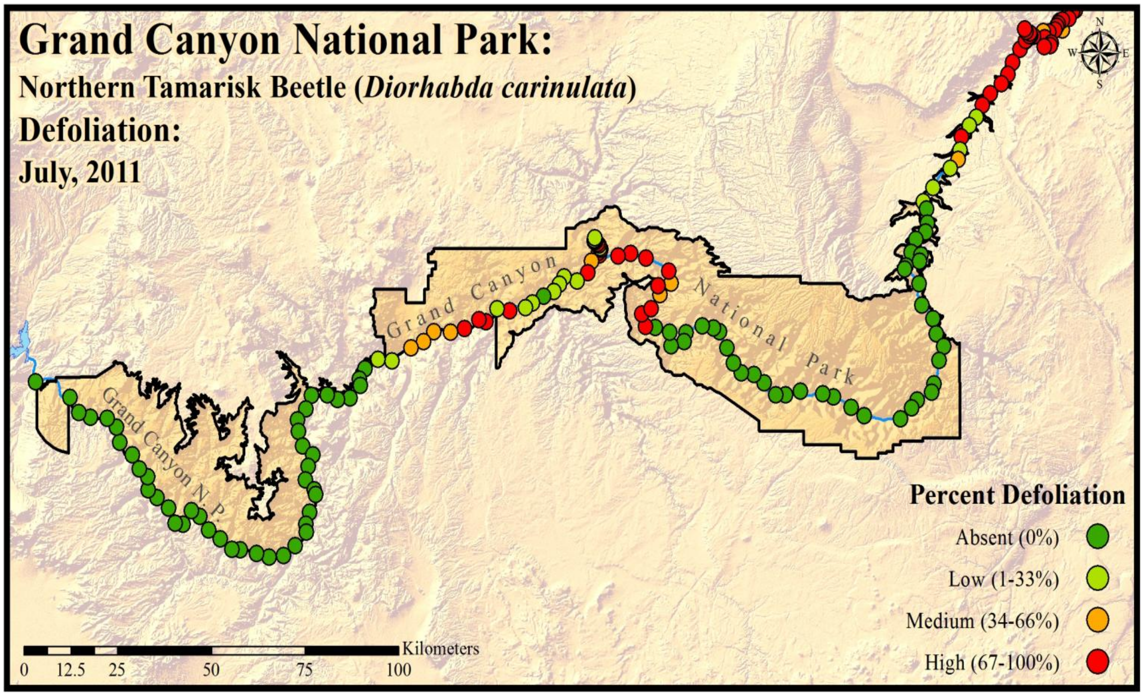


Map #7. Defoliation of tamarisk by tamarisk leaf beetle in Grand Canyon National Park during June of 2011.

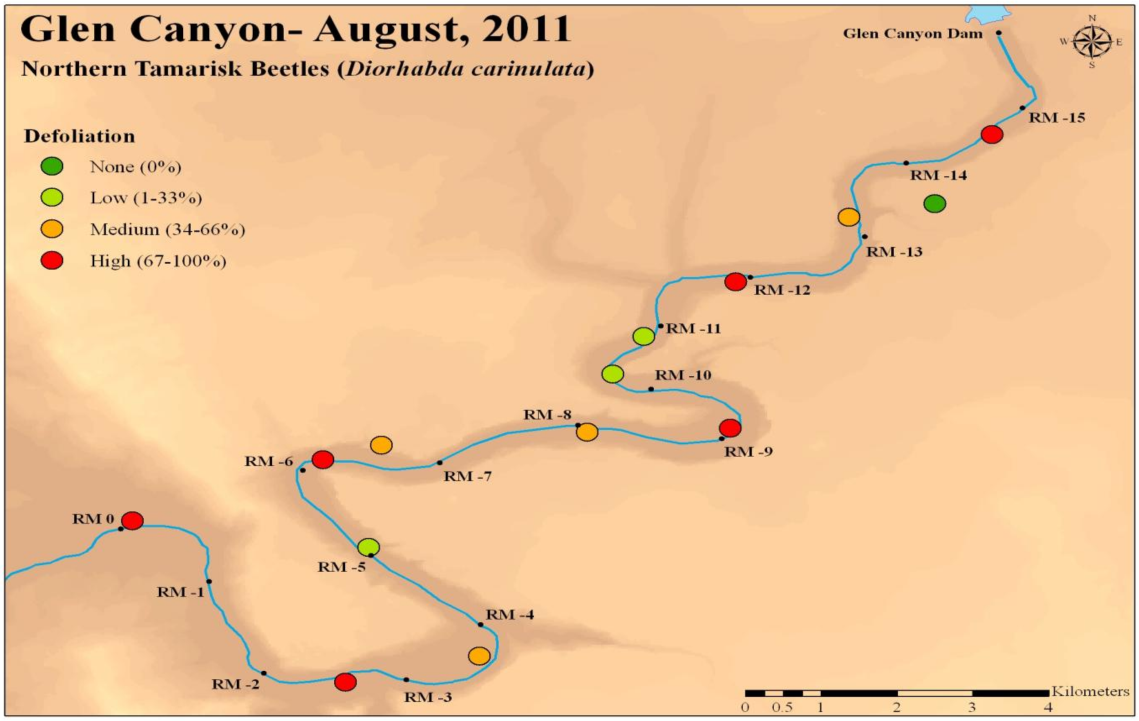


Map #8. Defoliation of tamarisk by tamarisk leaf beetle between Lee's Ferry and Glen Canyon Dam during July of 2011.

Appendix 3 cont. (Tamarisk Leaf Beetle defoliation in Grand Canyon NP and Glen Canyon NM)

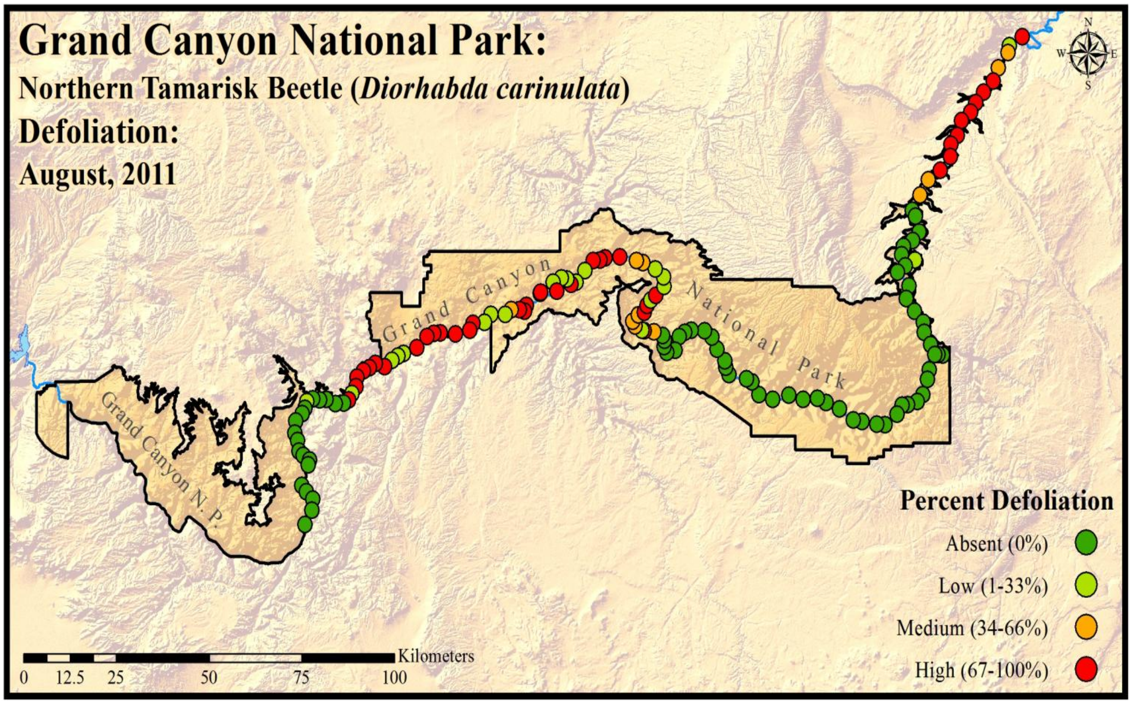


Map #9. Defoliation of tamarisk by tamarisk leaf beetle in Grand Canyon National Park during July of 2011.

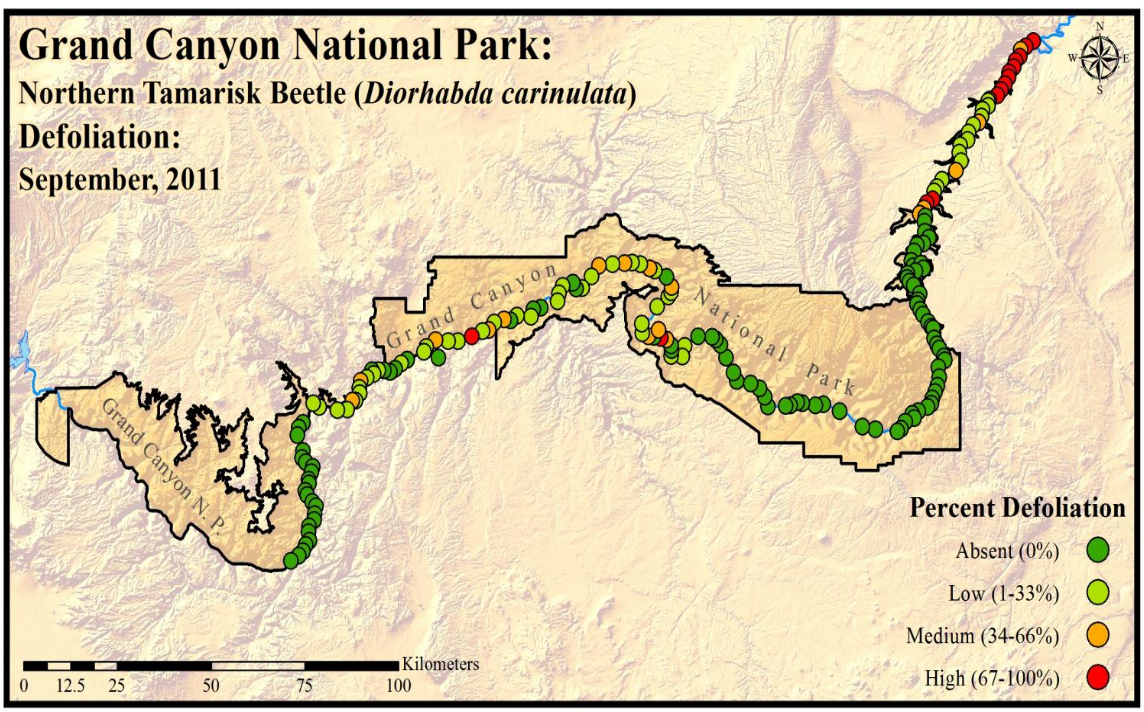


Map #10. Defoliation of tamarisk by tamarisk leaf beetle between Lee's Ferry and Glen Canyon Dam during August of 2011.

Appendix 3 cont. (Tamarisk Leaf Beetle defoliation in Grand Canyon NP and Glen Canyon NM)

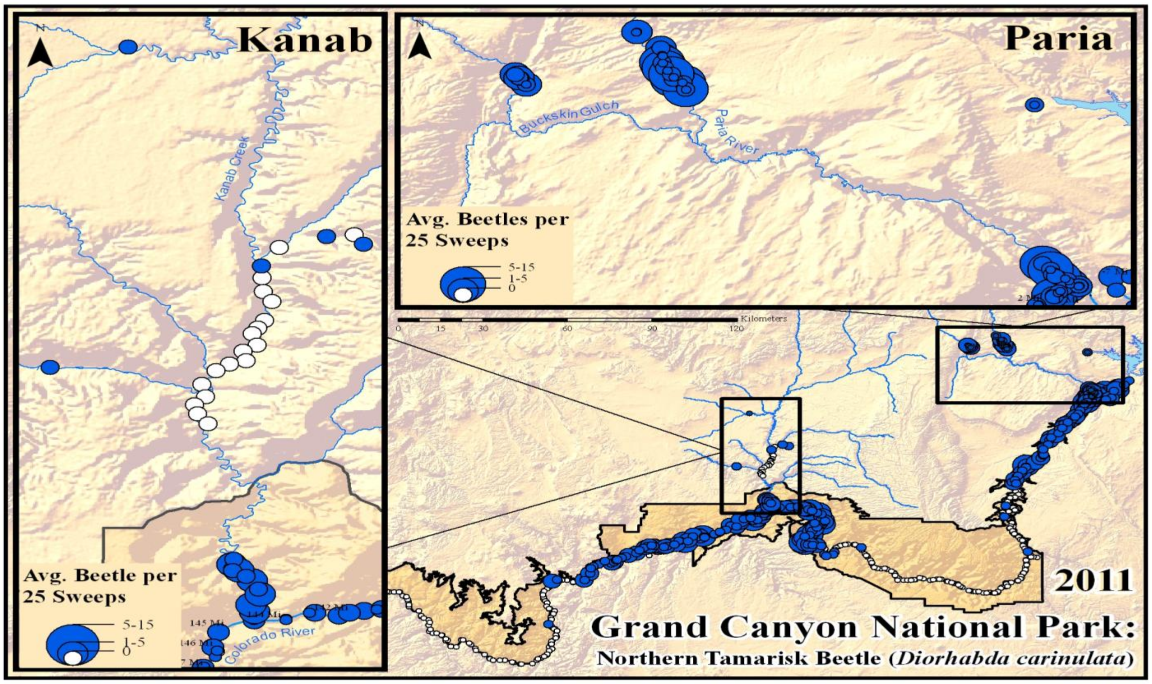


Map. #11. Defoliation of tamarisk by tamarisk leaf beetle in Grand Canyon National Park during August of 2011.

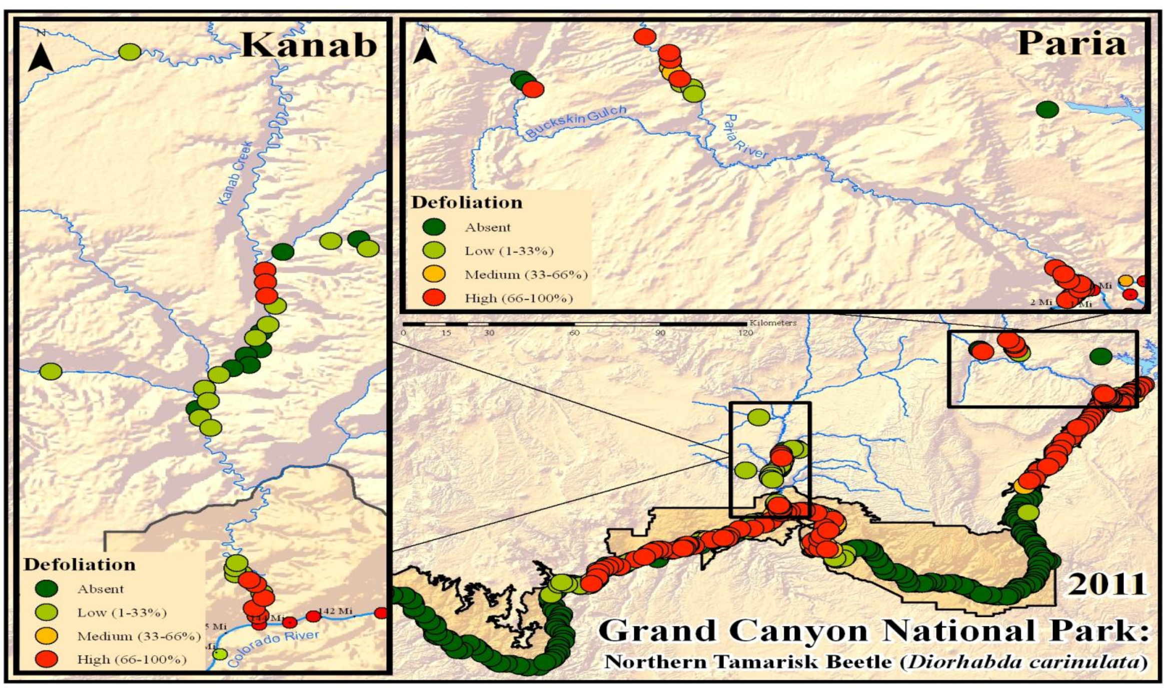


Map #12. Defoliation of tamarisk by tamarisk leaf beetle in Grand Canyon National Park during September of 2011.

Appendix 3 cont. (Tamarisk Leaf Beetle detection and defoliation in Grand Canyon NP and Glen Canyon NM Tributaries)



Map #13. Tamarisk Leaf Beetle (larvae and Adults) detection locations and non-detection locations during 2011 tamarisk leaf beetle surveys in Grand Canyon Tributaries; Paria Canyon, Buckskin Gulch, Kanab Creek, Old Spanish National Historic Trail and Pipeline Valley Wash, AZ.



Map #14. Tamarisk Leaf Beetle defoliation locations during 2011 tamarisk leaf beetle surveys in Grand Canyon Tributaries; Paria Canyon, Buckskin Gulch, Kanab Creek Old Spanish National Historic Trail and Pipeline Valley Wash, AZ.

Appendix 4. 2007-2011 CRMP bird monitoring sites displayed by the year that tamarisk leaf beetles were detected at the site, and riparian breeding bird species detected at each site.

CRMP SITE	YEAR	ATFL	BCFL	BCHU	BEVI	BEWR	BGGN	BLGR	BUOR	COYE	GTGR	HOFI	HOOR	INBU	LABU	LEGO	LUWA	MODO	NOMO	SOSP	SUTA	SWFL	YBCH	YEWA
6 Mile Camp	2010 2011	X		X		X	X		X	X		X		X		X	X	X		X			X	X
8.5 Mile Camp	2011					X	X			X		X					X							
Soap Creek Camp	2010 2011			X		X	X					X		X			X							X
13 Mile Camp-No site at 13 mile in TLB data												X					X							
18 Mile Wash Camp	2011	X		X						X		X			X		X							X
20 Mile Camp	2010 2011	X		X		X	X			X		X			X		X	X					X	X
Fence Fault Camp/30 Mile Camp		X										X			X		X							X
South Canyon Camp		X										X					X							
Little Redwall Camp	2011	X				X				X		X					X			X				X
Nautiloid Camp				X						X		X			X		X							X
Martha's Camp		X		X		X				X		X					X				X			X
Duck n Quack Camp	2011	X		X		X	X			X		X			X		X				X		X	X
Upper Saddle Camp	2011	X		X	X	X	X		X	X		X	X	X	X	X	X	X		X	X		X	X
Little Nankoweap Camp	2011	X		X		X	X			X		X				X	X				X			X
Main Nankoweap Camp		X			X	X	X			X		X	X			X	X				X		X	X
Kwagunt Camp		X		X		X	X	X		X		X					X	X			X			X
Malgosa Camp						X											X							
Opposite Malgosa	2011			X		X	X	X		X		X					X	X					X	X
60 Mile Camp		X		X		X	X			X		X			X	X	X						X	X
Basalt Camp		X		X			X			X		X				X	X						X	X
Cardenas Camp		X		X		X	X			X		X					X	X						X
Unkar Left Camp		X			X	X				X		X					X	X					X	X
Nevills Camp		X					X			X		X					X				X		X	X
Upper Nevills Camp		X		X			X	X		X		X					X	X			X		X	X
Hance Camp		X					X			X		X					X						X	X

Appendix 4 cont.

CRMP SITE	YEAR	ATFL	BCFL	BCHU	BEVI	BEWR	BGGN	BLGR	BUOR	COYE	GTGR	HOFI	HOOR	INBU	LABU	LEGO	LUWA	MOD	NOM	SOSP	SUTA	SWFL	YBCH	YEWA
Salt Creek Camp				X								X												
Granite Camp		X		X		X	X					X					X	X						X
Boucher Camp										X		X					X							
Upper Boucher Camp				X													X							X
Palisades Camp		X				X	X			X		X					X							X
Lower Tuna Camp					X												X							
103 Mile Camp		X				X						X					X							X
Hot Na Na Camp				X						X		X					X							X
Ross Wheeler Camp	2011					X											X							X
110 Mile Camp	2011						X										X							
120 Mile Camp	2011	X								X		X					X	X						X
122 Mile Canyon Camp /122.3 Mile Camp /Below Forester Right Camp/Forester/Above Fossil Camp	2010 2011	X		X	X	X				X		X			X	X	X	X						X
Fossil Camp	2011	X		X		X	X			X		X				X	X	X	X					X
Below Bedrock Camp	2011	X		X						X						X	X	X						X
Junebug Camp	2011	X										X				X	X							
Across Deer Creek Camp	2011	X		X		X						X				X	X							X
Above Olo Camp	2011	X		X			X										X							X
Football Field Camp/ Back Eddy Camp	2010 2011	X		X								X			X	X	X	X						X
Above Kanab Camp /Fishtail Camp	2011	X			X	X				X		X		X			X							X
Patch Camp	2011			X						X		X					X						X	X
158.7 Mile Camp/161.3 Mile Camp/Second Chance	2011			X		X				X		X					X	X						X
Tuckup Camp	2010 2011	X		X			X			X		X			X		X							
Upper National Camp	2011						X										X						X	X
Below National Camp/167.7 Mile Camp	2011	X		X	X	X	X			X	X	X	X				X			X			X	X
Mohawk Camp	2011	X		X	X	X	X					X	X				X							X
Below Lower Lava Camp		X		X	X	X	X				X	X				X	X				X			X

Appendix 4 cont.

CRMP SITE	YEAR	ATFL	BCFL	BCH	BEVI	BEW	BGG	BLGR	BUO	COY	GTG	HOFI	HOO	INBU	LAB	LEG	LUW	MOD	NO	SOSP	SUT	SWF	YBC	YEW
Lower Chevron Camp		X		X	X	X	X			X		X				X	X	X	X				X	X
Upper 185 Mile Camp/Lower 185 Mile Camp	2010 2011	X		X	X		X			X		X				X	X							X
Lower Whitmore Camp/Whitmore Helipad Camp	2011	X			X		X					X					X	X	X					X
Fat City Camp	2011	X	X	X	X	X	X	X		X		X	X			X	X	X		X			X	X
Froggy Fault Camp		X	X	X	X	X	X			X		X	X			X	X	X		X	X		X	X
Indian Canyon Camp	2011	X			X		X			X		X					X							X
214 Mile Camp		X		X	X		X					X					X	X						
Opposite 3 Springs Camp				X	X		X					X					X				X		X	X
217 Mile Rapid Camp					X		X			X	X	X					X					X	X	