Lake Havasu 2012 Aquatic Plant Monitoring Report

A Final Report Submitted to RNT Consulting and the Central Arizona Project

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Geosystems Research Institute Report 4009

April 2013

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Executive Summary

Findings

- Thirteen aquatic plant species were found during the 2012 survey. The maximum depth of plant colonization observed was 34.3 ft for macroalgae and 28 ft for rooted plants. The observed littoral zone extends to 34 feet with the maximum potential depth for colonization at 39 ft for rooted plants. In 2011, the littoral zone extended only to 30 feet, consequently the 4 ft increased the littoral zone by over 300 survey points. In 2012, 31% of the littoral zone was vegetated constituting 19% of the entire lake.
- Lakewide there was a decrease in the number of vegetated points from 2011, but the decrease was not significant. Spiny naiad (*Najas* marina) was the most common plant being present at 54.5% of the vegetated points. Chara (*Chara* sp.) was second most common at 39.9%. Spiny naiad and sago pondweed (*Stuckenia pectinata*) both were found at 12.8% of the vegetated points.
- The invasive species curlyleaf pondweed (*Potamogeton crispus*) and Eurasian watermilfoil (*Myriophyllum spicatum*) *were* found at 0.6% and 3.0%, respectively, of vegetated points. Eurasian watermilfoil was also detected for the first time at Bill Williams NWR.
- Spiny naiad biovolume tended to occupy the entire water column from 6 to 16 ft. The greatest biovolume observed in 2012 was at 16 ft depth. The embayments off of the channel leading into Bill Williams have very high biovolumes and could be contributing to the nuisance mat problems. In 2011, the biovolume was greater in deep water (16 to 25 ft) than in 2012.
- Wind direction is a significant driver of direction of plant mat drift. Drones drifted an average of 353m/hr. While some plant mats are likely from Bill Williams, more northern embayments are the likely source for predominately spiny naiad mats and are being driven by the wind downstream. Plant mats may drift as much as 8.5 km (5.3 mi) in a 24 hours period.
- Anecdotal evidence suggested that an algal bloom early in the 2012 growing season may have limited plan abundance. One year of reduced plant growth does not infer that nuisance growth and mat formation will no longer occur.
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Recommendations

- Install weather stations near the Wilmer pump and additional locations along the shoreline to the north to detect wind direction, if tracking of potential mat float direction is desired.
- Continue mat removal in and near Bill Williams NWR, but also include the river channel and shallow embayments to the north.
- Additional research on the phenology of plants in the reservoir will assist in predicting the time and magnitude of mat formation.

- Whole lake plant surveys should be performed each year, or at least every other year, to track potential problems from invasive plant species and monitor for expansion of plant habitat.
- Submersed plant abundance is driven by light availability; monitoring of early to mid-season transparency will assist in predicting years for potential problems.

Please cite this report as:

Fernandez, A. L. and J. D. Madsen. 2012. Lake Havasu 2012 Aquatic Plant Monitoring Report. Geosystems Research Institute Report 4009, Geosystems Research Institute, Mississippi State University, Mississippi State, MS. April 2013.

Introduction

Lake Havasu is a 20,400 acre reservoir located on the border of California and Arizona (Figure 1). It was created in 1938 by the construction of Parker Dam on the Colorado River and is the southernmost reservoir in a chain of four reservoirs located on this river (Bureau of Reclamation webpage, www.usbr.gov). In 1973, construction of the Central Arizona Project (CAP) Aqueduct began at Lake Havasu and ended in 1993, south of Tuscon, AZ (Central Arizona Project webpage, www. cap-az.com). The 336 mile aqueduct provides 49.8 billion gallons of water per year to municipal, agricultural, and Native American communities throughout Arizona. Lake Havasu also supplies 1 billion gallons per day of water to Southern California via the Colorado River Aqueduct (Bureau of Reclamation webpage, www.usbr.gov).

Lake Havasu is a popular tourist destination and is visited by 2.5 million people annually (Lake Havasu City webpage, www.lhcaz.gov). Surrounded by the foothills of the rugged Mohave Mountains, the lake provides recreational activities such as speed boating, jet skiing, water skiing, sailing, and fishing. The most common fish species caught are crappie (*Pomoxis nigromaculatus*), striped bass (*Morone saxatilis*), sunfish (*Lepomis* spp.), channel catfish (*Ictalurus punctatus*), and largemouth bass (*Micropterus salmoides*). Lake Havasu is also inhabited by three endangered fish: the razorback sucker (*Xyrauchen texanus*), flannelmouth sucker *(Catostomus latipinnis)*, and bonytail chub (*Gila elegans;* Lake Havasu webpage, http://www.golakehavasu.com).

In 2007, quagga mussels (*Dreissena rostriformis bugensis*) were discovered in Lake Mead, one of the reservoirs north of Lake Havasu and have since been discovered in Lake Havasu (Figure 2; Central Arizona Project webpage, cap-az.com). In the years following the introduction and establishment of quagga mussels, there has been an increase in the amount of floating dead plant material (Figure 3). These floating mats clog the Mark Wilmer intake pump for CAP. The nuisance vegetation is likely the result of quagga mussels improving water transparency allowing for more light to reach the reservoir floor and promoting plant growth (Madsen et al. 2012). In 2011, a study of the aquatic plant community began to address the nuisance mat problems. In 2012, to further assess the distribution and abundance of the plant community and predict the movement of the plant mats, the point-intercept lake survey and drift study were continued. The results of these studies are presented in this report.

Methods

Point Intercept Survey

Aquatic plant distribution was evaluated using the point-intercept survey method during late August 2012 (Madsen 1999). The same 200m grid used during the 2011 survey was used for the 2012 survey; however, twenty-nine points were unnavigable due to lower water levels or overgrowth by plants (Figure 4). Points were navigated to using a Trimble Yuma™ (Sunnyvale, CA) tablet computer with an internal Global Positioning System (GPS) that has an accuracy of 1 to 3 meters depending on satellite signal reception. Spatial data was recorded onto the Yuma™

using FarmWorks Site Mate® software (Hamilton, IN) which records geographic and attribute data. Database templates with a picklist of commonly occurring plants in Lake Havasu were used for recording presence or absence of aquatic plant species. At each point, water depth was also recorded using a Lowrance LCX-28C depth finder.

A total of 1594 points were sampled for the 2012 survey. After navigating to a point, a weighted rake was deployed to depths of less than or equal to 35 feet. This depth was chosen based on plants being found in water depths up to 30 feet during the 2011 survey. The presence or absence of aquatic plants species collected by the rake was recorded. Percent frequency of occurrence was calculated for each species by dividing the total number of points with a species present by the total number of sampled points. Estimated acreage was calculated by multiplying the number of points a species was found at by 9.9 (the acreage represented by one point).

Changes in the occurrence of plant species between points sampled in 2011 and 2012 were compared with a Cochran-Mantel-Haenszel test (Stokes et al. 2000). The test evaluates dependent variables, in this case sampling the same points both years, for differences in the correlated proportion within a given dataset. Only points sampled (n=1594) in both years were included in the analysis. Total species richness was calculated by averaging the number of species per point. A t-test was used to determine if differences in average species richness between years existed. The analytical software SAS® (Cary, NC) conducted all the analyses at a p=0.05 level of significance.

Biovolume Assessment

During the point survey, plant heights of predominantly spiny naiad populations were measured at 82 points in order to calculate biovolume. Biovolume represents the percent of the water column occupied by vegetation (Sabol et al. 2009). It is useful for evaluating vegetation control cases and assessing fish habitat. In Lake Havasu, biovolume allows quantification of spiny naiad populations in different areas of the lake to potentially help identify the source of plant mats. Plant canopy height was measured from the hydroacoustic signatures observed with the depth finder. Percent biovolume was calculating by dividing the canopy height by water depth and multiplying by 100.

Drift Study

During October 1-4, 8, and 9 2012, two custom built GPS tracking devices, called drones, were deployed in different areas of Lake Havasu to predict mat drift (Figure 5). On October 1, drift was monitored near the Colorado River inflow. The following five days were focused on the Bill Williams area since it is near the Mark Wilmer pump intake and in the narrow river-like southern section of the reservoir that leads into Bill Williams. During the course of the study, the pumps were not operating to unforeseeable circumstances.

Two drones were released from randomly chosen locations in the study area between the hours of 7am and 6pm. Within a minute of being turned on, the drones record the longitude and latitude, time and date to a USB drive located inside of the drone. Their position is then recorded every fifteen minutes until they are manually turned off. The drones release position and time was also recorded on the Yuma®. The drones drifted for 1 hour before being collected. During that hour, wind direction was monitored and any major wind shifts were documented in a field notebook. Wind direction was determined based on our own estimations and designated as: north, northwest, northeast, south, southwest, southeast, east or west. At the end of each hour, the drones were turned off, the collection location and time for each drone was recorded on the Yuma®, and wind speed was recorded from an on board weather station (Figure 6). The drones were released multiple times throughout the day which allowed for detection of daily wind patterns.

Since wind was an apparent driver of drift direction, wind data from the nearby weather station KAZLAKEH32 attained via the website WeatherUndergound.com was compared to the wind data collected by our on board weather system. This website allows easy retrieval of weather information with many weather stations to choose from and access to past years of meteorological data. The Pearson's product-moment correlation coefficient, which measures the linear relationship between two variables, was used to determine if there was a relationship between off-site wind data and on-site wind data (Rodgers and Nicewander 1988).

At the completion of the study, the data collected by the drones was exported into excel spreadsheets and then displayed in ArcGIS® software by ESRI. The mountainous area seems to have distorted the GPS signal making the drone information undecipherable. Consequently, the release and collection positions recorded in the Yuma® were used for all drone analyses. Linear regressions, which model the relationship between an explanatory variable and dependent variable, were used to analyze the drone drift distance with wind speed and drone drift direction with wind direction (Raftery et al. 1997). All of the analyses were conducted at the p=0.05 significance level by the software SigmaPlot (Systat, San Jose, CA).

Results and Discussion

Lake Havasu is a deep reservoir with over half of the surveyed points at greater than 30ft with a mean depth of approximately 32 feet (Figure 7). Although deep, light is able to reach much of the reservoir floor. A plot of species richness to depth shows that the maximum observed depth of colonization was 34.3 feet, with greater species richness at shallower depths (Figure 8).

However, based on the average secchi depth of 13.1 ft, the maximum depth of rooted plant colonization could occur in depths up to 39.5 feet (Figure 9). This is an increase from 2011, when the average secchi depth was 10.7 ft and maximum depth of plant colonization was 32 ft. Based on the observed depth of colonization by aquatic plants, the "littoral zone" or range to which rooted plants will survive is between 0 to 34.3 feet (Figure 7). Consequently, the number of survey points considered part of the littoral zone increased by a third for the 2012 survey (Table 1).

Point- Intercept Survey

Table 2 lists the scientific and common name for each species. Hereafter, the plants will be referred to by common name. Lakewide, there were fewer points with plants in 2012 than in

2011, but the decrease was not significant (Table 2). Furthermore, the frequency of occurrence for many of the plants was less in 2012 than in 2011, but the decrease was only significant for narrowleaf pondweed ($p<0.001$) and nitella ($p<0.001$). The overall decrease may be a result of the severe drought experience by much of the Colorado River watershed. Although Lake Havasu's water levels remained fairly constant throughout the year, the reservoirs north of Lake Havasu were at much lower levels and the flow of water into the lake may have altered the water environment resulting in the decreased observance of plants (Wersal et al. 2006, 2009). Anecdotally, transparency was lower during the early part of the growing season, due to an algal bloom. This may have suppressed plant growth.

A total of 13 plants species were observed during this survey. The most common plants were spiny naiad, chara, southern naiad, and sago pondweed. Based on field observations of drifting mats in 2012 and from 2011 mat samples, aside from chara, these are also the plants that most often form the mats (Madsen et al. 2012). The two invasive species Eurasian watermilfoil and curlyleaf pondweed were also still found in Lake Havasu during the 2012 study.

Although percent frequency of occurrence decreased slightly for spiny naiad between 2011 and 2012, it was still the most frequently occurring plant and is found throughout the entire reservoir (Figure 10). Spiny naiad presence represents 54.3% of the vegetated points surveyed during 2012 and covers approximately 1630 acres (Table 3, Figure 11). The maximum depth for spiny naiad growth increased to 28 feet in 2012 compared to 27 feet in 2011 (Figure 12).

Chara, a macroalgae, was the only plant to significantly increase in percent frequency of occurrence between 2011 and 2012 (Table 1, Figure 13). The increase in presence from 5.2% of all the surveyed point in 2011 to 7.6% in 2012 makes chara the second most commonly occurring plant in 2012 (Figure 14). In 2011, it was the fourth most common plant with less percent frequency than southern naiad and sago pondweed. Chara coverage increased by an estimated 300 acres from 2011 (Table 3). It was also the deepest growing plant at 34.3 ft with an average depth of 16.3ft (Figure 15). In 2011, the maximum depth of growth was 30 ft. Chara would likely be the plant to be found growing at the estimated maximum depth of plant colonization of 39 ft. Chara responds more quickly to open habitat than other aquatic plant species.

Southern naiad was found at 2.5% of the surveyed points during 2012 compared to 3.3% during the 2011 survey (Figure 16). The decrease in presence is most notable near the Colorado River inflow where the plant was only found at one point in 2012 (Figure 17). However, it was still found frequently in the Bill Williams area and the shallow embayments throughout the reservoir (Figure 17). The average depth for southern naiad growth was 11.4ft (Figure 18).
In 2011, sago pondweed was the second most common plant occurring at 3.5% of the surveyed points; however, during the 2012 survey the plant was present at 2.5% of surveyed points (Figure 19). Sago pondweed was most common along the embayments off the main channel that flows into Bill Williams (Figure 20). Sago was found growing at an average depth of 8.3ft (Figure 21).

The distribution of widgeongrass is mentioned because it was found nearly 9km farther downstream during 2012 than in 2011 (Figure 22, Figure 23). It was the only plant distribution to be noticeably different while out conducting the survey. The percent frequency of occurrence increased slightly in 2012 from 2.13% to 2.20%. The increase is due to the addition of the new populations downstream in the shallow embayments.

Nonnative Species Assessment

There was no significant change in the frequency of occurrence for the two invasive, nonnative species curlyleaf pondweed or Eurasian watermilfoil between 2011 and 2012. During the 2012 point intercept survey, both species were only observed in the northern part of the reservoir (Figure 24). However, during the October visit to Lake Havasu, a small population of Eurasian watermilfoil was found near the boat launch in Bill Williams. The population was probably introduced by a boat using the boat launch. Eurasian watermilfoil has been associated with decreases in native species richness and diversity so control of this plant is crucial while the population is still small (Madsen et al. 2008). Mechanical removal of the small population may be feasible since it was detected early; however, since Eurasian watermilfoil mainly spreads via vegetative fragments, care needs to be taken to limit the spread of these fragments during the removal process (Madsen and Smith 1997). A full discussion of in-lake management options for invasive plants, such as curlyleaf pondweed and Eurasian watermilfoil, is available in a best management practices manual (Getty et al. 2009).

Biovolume

Of the 82 points surveyed for biovolume, 77% of the points had spiny naiad biovolumes ranging between 1-25 ft deep. The average height of the plant canopy was 2.9ft, with a maximum canopy height of 16 ft which resulted in 100% biovolume. Biovolume was at its maximum at 16 ft deep (Figure 25). The downstream area of Lake Havasu has the greatest depths, so much of the area is uninhabitable; however, the embayments off of the river channel are shallow enough for plant growth. Fifty percent of the points that had vegetation growth to the surface (100% biovolume) occurred in these bay areas. In Bill Williams, the average biovolume at a point was 25%. In the area near the Colorado River inlet, the average bivolume was 22.1%.

Drone Drift Study

The wind direction and speed from the weather station KAZLAKEH32 were not correlated with the wind direction and speed collected from the on-board weather station at the study sites (Figure 26, 27). This is likely due to many factors such as the height of the measuring device and topographical differences of the terrain (Bechrakis and Sparis 2004). As a result, the on board wind data was used to analyze drone drift.

No significant relationship was detected between the distance the drones traveled and the wind speed. However, a significant relationship was found between the wind direction and drone drift direction (Figure 28). Since the drones were not correctly recording GPS location data, we could only use the release and collection locations for generating drone drift distance and direction. Consequently, the smaller but frequent shifts in wind direction were not recorded in our drift data which may be the reason a relationship between wind speed and travel distance was not detected. Shifts in wind direction affect the surface current almost instantaneously, so the drones could have moved backwards for many meters before continuing to drift in the direction of the predominant wind. As illustrated in the drone drift maps, the drones move with the wind (Figures 29-45). On average, the drones also moved farther in the afternoon than in the morning (Table 4).

Based on the daily average, the drones could drift approximately 8.5km over a 24hr period. In a day, given the correct wind direction (west to northwest), a plant mat nearly 4km past the Whitsett intake pumping plant could travel to the Wilmer intake pump. Plant mats originating from Bill Williams would need an east wind to be blown out of Bill Williams. Based on daily wind observations from December 2009 to December 2011 collected by Lake Havasu/Site Six weather station (Lat 34.45, Long -114.37), dominant wind direction in Lake Havasu is out of the east from May to August (Windfinder webpag, Windfinder.com). Therefore, mat movement out of Bill Williams would be very possible.

During our study in the Bill Williams area, similar drift patterns were observed every morning and afternoon (Figures 32-34, 38-40, 43-45). At the first release of the day, typically around 7:30am, the wind would be from the east, southeast or northeast. This would generate a westward drift path. By 9:30, the winds would shift and originate from the west or northwest. Subsequently, drone drift path would shift accordingly. In September and October, the predominant wind direction is from the west which our field observations support (Windfinder webpage, Windfinder.com).

While plant mats originating from Bill Williams seems the most likely source given the proximity to the pumping station, results from the mat composition study in 2011, show a high proportion of spiny naiad when spiny naiad biomass is quite low in Bill Williams (Madsen et al 2012). Results from the 2012 drift study indicate that the embayments upstream from Bill Williams could be the source of the plant mats (Figures 33, 35-37, 39, 41-43). The embayments have high biovolumes of spiny naiad, and given the potential distance a mat could cover in one day, these areas could easily contribute to the mat problem. Since wind direction plays an important role in drift directions, Bill Williams may be contributing more of the mats from July to August when wind is mainly from the east. Then in September and October, the source may be from areas upstream when wind is mainly from the west. This is assuming that the southern area of Lake Havasu experiences the same wind pattern that is collected from a station located near north of the lake. Since we could not correlate the station wind data with our own on board wind data, it may be helpful to install a weather station near these areas to detect possible microclimates.

Acknowledgements

This research was supported by the Central Arizona Project by a subcontract through RNT Consulting. We received special assistance from Doug Adams, Bill Bryan, and other staff of the Bureau of Land Management Lake Havasu Field Office. Scott Bryan of Central Arizona Project provided information regarding project operations. Thanks to Renata Claudi for inviting us to work on this interesting project.

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Conclusions and Recommendations

Findings

- Thirteen aquatic plant species were found during the 2012 survey. The maximum depth of plant colonization observed was 34.3 ft for macroalgae and 28 ft for rooted plants. The observed littoral zone extends to 34 feet with the maximum potential depth for colonization at 39 ft for rooted plants. In 2011, the littoral zone extended only to 30 feet, consequently the 4 ft increased the littoral zone by over 300 survey points. In 2012, 31% of the littoral zone was vegetated constituting 19% of the entire lake.
- Lakewide there was a decrease in the number of vegetated points from 2011, but the decrease was not significant. Spiny naiad (*Najas* marina) was the most common plant being present at 54.5% of the vegetated points. Chara (*Chara* sp.) was second most common at 39.9%. Spiny naiad and sago pondweed (*Stuckenia pectinata*) both were found at 12.8% of the vegetated points.
- The invasive species curlyleaf pondweed (*Potamogeton crispus*) and Eurasian watermilfoil (*Myriophyllum spicatum*) *were* found at 0.6% and 3.0%, respectively, of vegetated points. Eurasian watermilfoil was also detected for the first time at Bill Williams NWR.
- Spiny naiad biovolume tended to occupy the entire water column from 6 to 16 ft. The greatest biovolume observed in 2012 was at 16 ft depth. The embayments off of the channel leading into Bill Williams have very high biovolumes and could be contributing to the nuisance mat problems. In 2011, the biovolume was greater in deep water (16 to 25 ft) than in 2012.
- Wind direction is a significant driver of direction of plant mat drift. Drones drifted an average of 353m/hr. While some plant mats are likely from Bill Williams, more northern embayments are the likely source for predominately spiny naiad mats and are being driven by the wind downstream. Plant mats may drift as much as 8.5 km (5.3 mi) in a 24 hours period.
- Anecdotal evidence suggested that an algal bloom early in the 2012 growing season may have limited plan abundance. One year of reduced plant growth does not infer that nuisance growth and mat formation will no longer occur.

Recommendations

- Install weather stations near the Wilmer pump and additional locations along the shoreline to the north to detect wind direction, if tracking of potential mat float direction is desired.
- Continue mat removal in and near Bill Williams NWR, but also include the river channel and shallow embayments to the north.
- Additional research on the phenology of plants in the reservoir will assist in predicting the time and magnitude of mat formation.
- Whole lake plant surveys should be performed each year, or at least every other year, to track potential problems from invasive plant species and monitor for expansion of plant habitat.
- Submersed plant abundance is driven by light availability; monitoring of early to mid-season transparency will assist in predicting years for potential problems.

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Table 1. Comparison of Lake Havasu littoral zone plant survey parameters between 2011 and 2012.

Parameter	2011	2012
Points considered littoral zone	650	964
Maximum depth of littoral zone (ft)	30	34
Avg. depth (ft)	10.0	11.5
Mean no. of vegetated points	0.49	0.31
Avg. species richness per point	0.77	0.45

Table 2. List of species found in Lake Havasu during the point-intercept survey between 2011 and 2012 by scientific name and authority, common name, native, exotic or invasive status, and lakewide percent frequency of occurrence.

Species Name	**Common Name**	**Native (N) or Invasive (I)**	**2011 % Frequency (n=1594)**	**2012 % Frequency (n=1594)**
Arundo donax L.	Giant reed	I	.06	0.00
Chara sp.	Chara	N	5.21	7.59[a]
Myriophyllum spicatum L.	Eurasian watermilfoil	I	1.19	0.56
Najas guadalupensis (Spreng.) Magnus	Southern naiad	N	3.32	2.45
Najas marina L.	Spiny naiad	N	10.92	10.35
Nitella sp.	Nitella	N	1.88	0.00[a]
Potamogeton crispus L.	Curlyleaf pondweed	I	0.31	0.13
Potamogeton foliosus Raf.	Narrowleaf pondweed	N	0.44	0.06[a]
Potamogeton nodosus Poir.	American pondweed	N	0.31	0.06
Ruppia maritima L.	Widgeongrass	N	2.13	2.20
Schoenoplectus californicus (C.A. Mey) Palla	California bulrush	N	0.63	0.82
Schoenoplectus tabernaemontani (C.C. Gmel.) Palla	Softstem bulrush	N	0.50	0.31
Stuckenia filiformis (Pers.) Borner	Fineleaf pondweed	N	0.50	0.00
Stuckenia pectinata (L.) Borner	Sago pondweed	N	3.45	2.45
Typha angustifolia L.	Narrowleaf cattail	N	0.56	0.19
Typha latifolia L.	Broadleaf cattail	N	0.19	0.25

	2011	**2012**
Mean number of vegetated points	0.20	0.19
Average species richness per point	0.32	0.27[a]
Average depth (ft)	33.0	32.3

Note: An “a” indicates a statistically significant change in frequency of occurrence from the previous year for the given plant species.

Table 3. Estimated acreage for aquatic plants observed in the littoral zone during the Lake Havasu Survey from 2011 to 2012.

Common Name	**2011 Estimated Acres**	**2012 Estimated Acres**
Chara	822	1200
Eurasian watermilfoil	188	89.1
Southern naiad	525	386
Spiny naiad	1720	1630
Curlyleaf pondweed	49.5	19.8
Narrowleaf pondweed	69.3	9.9
American pondweed	49.5	9.9
Widgeongrass	337	347
California bulrush	99.0	129
Softstem bulrush	79.2	49.5
Sago pondweed	545	386
Narrowleaf cattail	89.1	29.7
Broadleaf cattail	29.7	39.6
Total	3170	3000

Table 4. Average distances the drones drifted each day of the drift study in October 2012.

Date	Daily Avg.	AM Avg.	PM Avg.
	Meters/Hr		
1-Oct	388	501	319
2-Oct	263	198	316
3-Oct	365	185	544
4-Oct	311	173	422
8-Oct	448	507	410
9-Oct	343	248	419
Avg. for all days	353	302	405

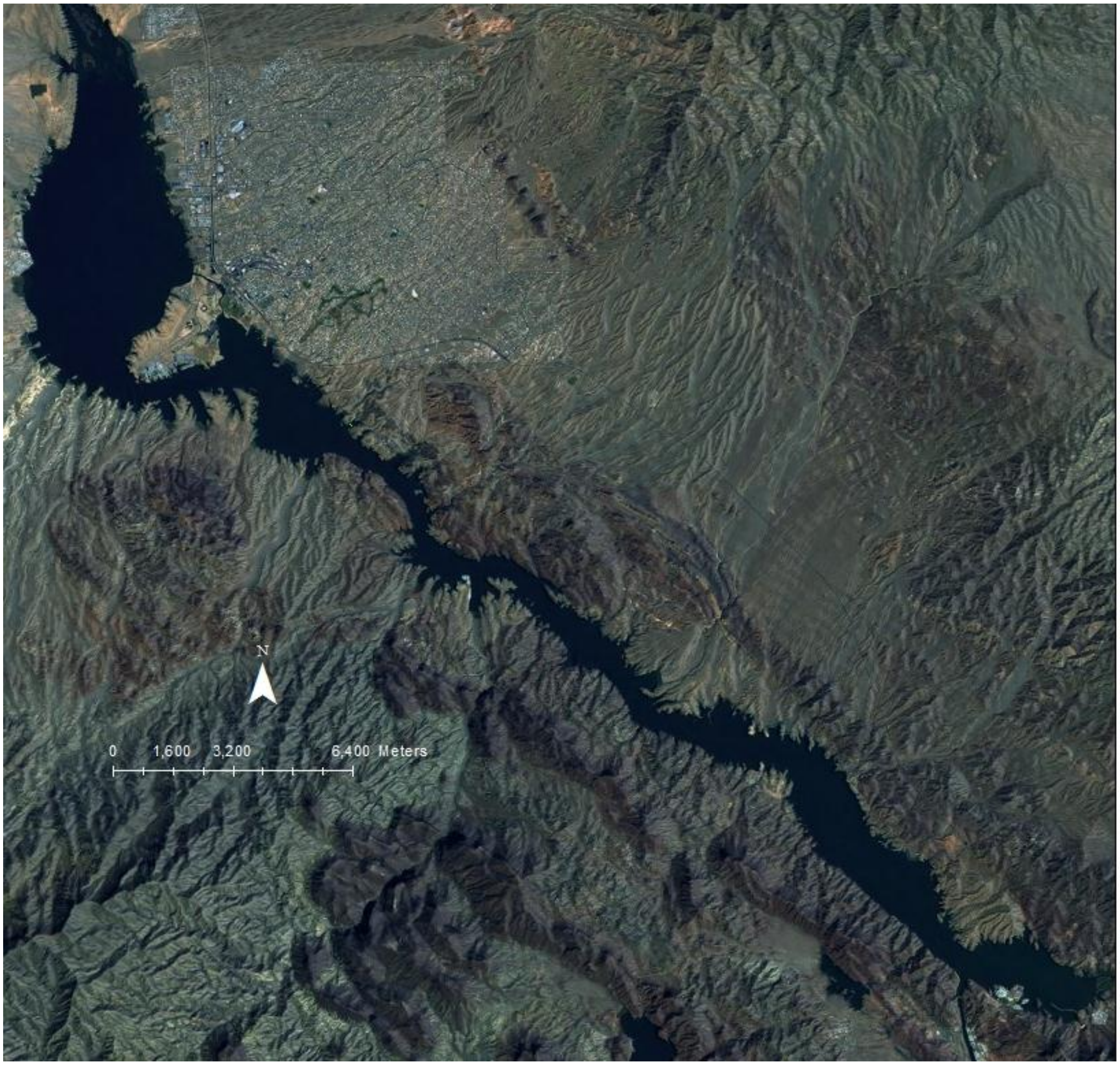

Figure 1. Map of Lake Havasu. The Colorado River inlet is at the northwestern end of the reservoir, and the outlet is near Parker Dam on the southeastern end. Bill Williams NWR enters the southeastern embayment.

Figure 2. Quagga mussels (*Dreissena rostriformis bugensis)* collected from Lake Havasu in September 2012. Photo by John D. Madsen

Figure 3. Drifting plant mat in Lake Havasu during August 2012. Photo by John D. Madsen

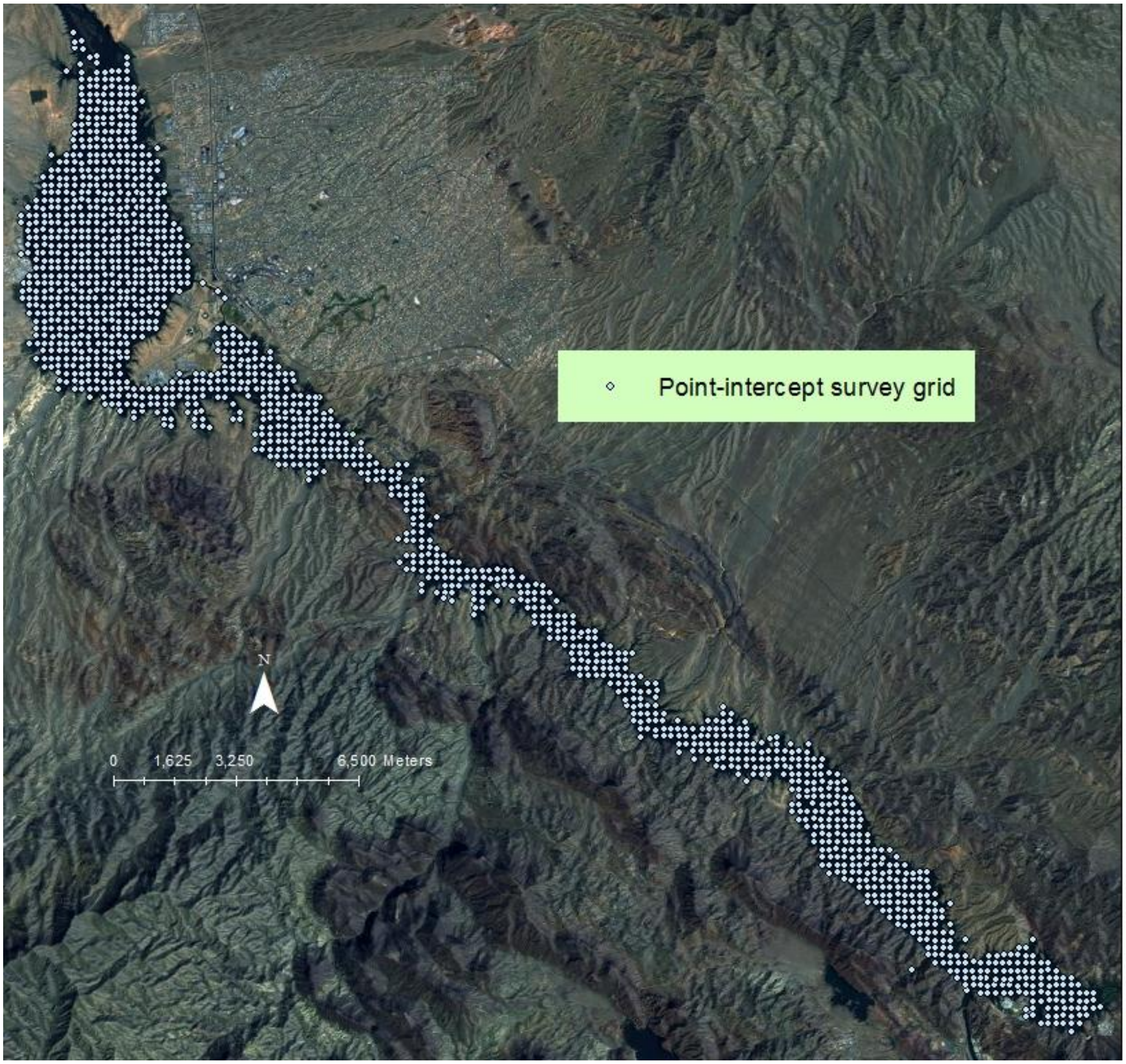

Figure 4. Two hundred meter grid points used for the August 2012 point-intercept survey.

Figure 5. GPS drone drifting in Bill Williams NWR during October 2012. Photo by John D. Madsen.

Figure 6. On board weather station that recorded average wind speed. Photo by John D. Madsen.

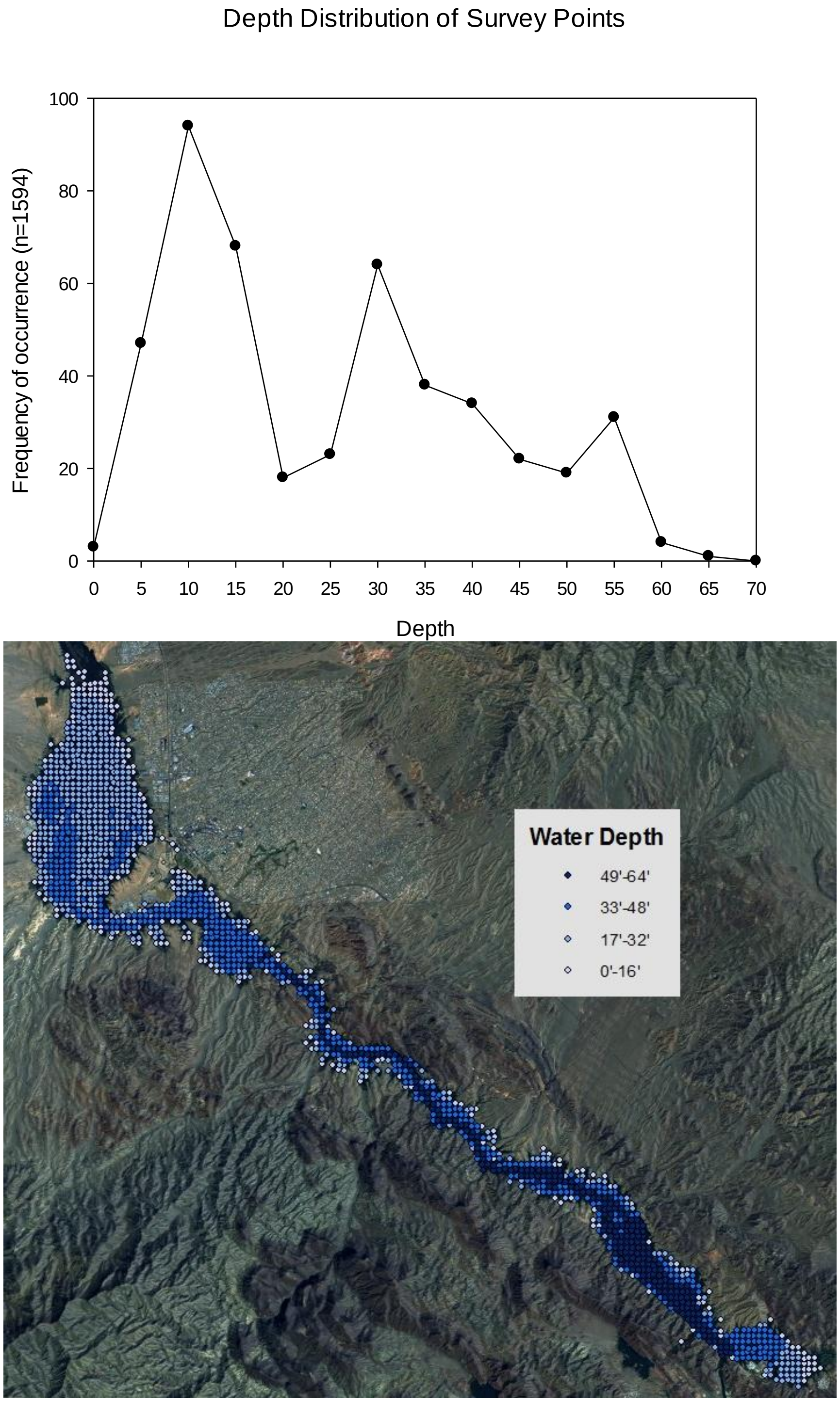

Figure 7. Depth characteristics of Lake Havasu, August 2012. Top) Frequency of occurrence of individual 1 ft depth intervals out of 1594 pts; Bottom) Map of the water depth distribution.

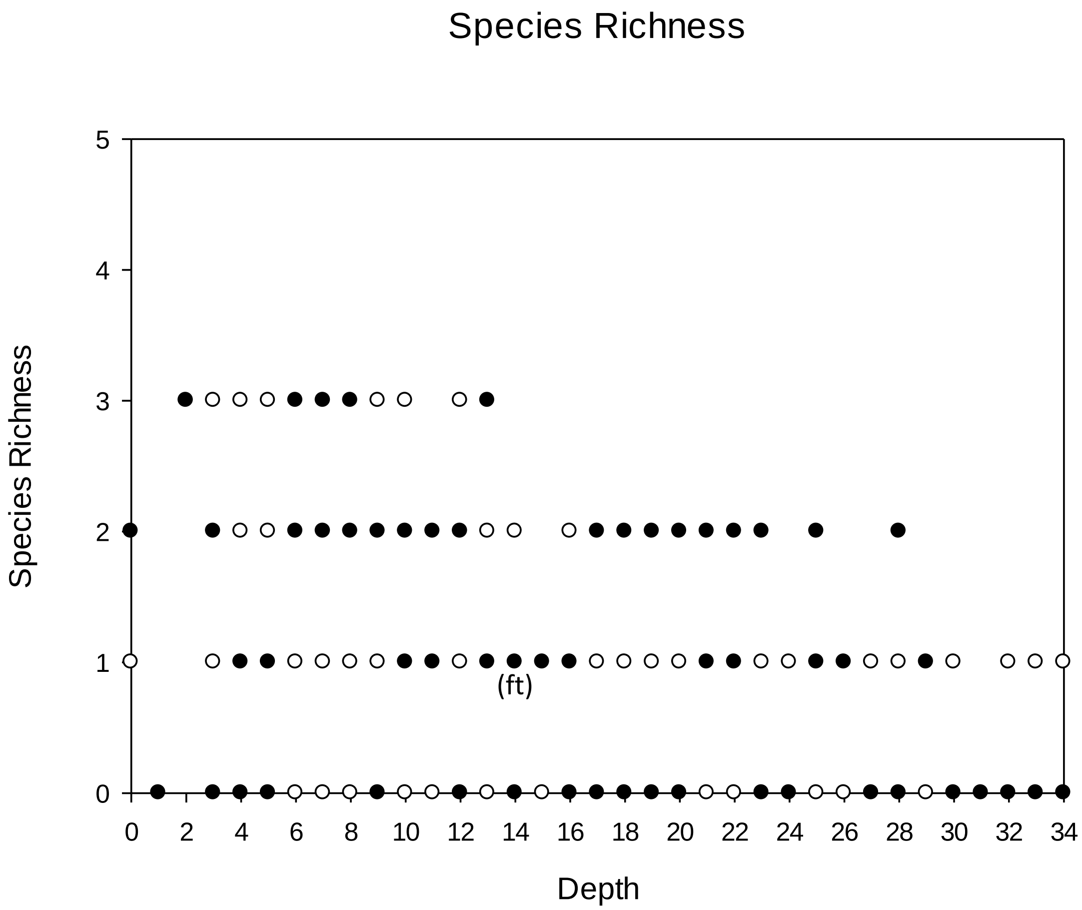

Figure 8. Species richness per point plotted against depth (ft) for vegetated points collected during the August 2012 point-intercept survey.

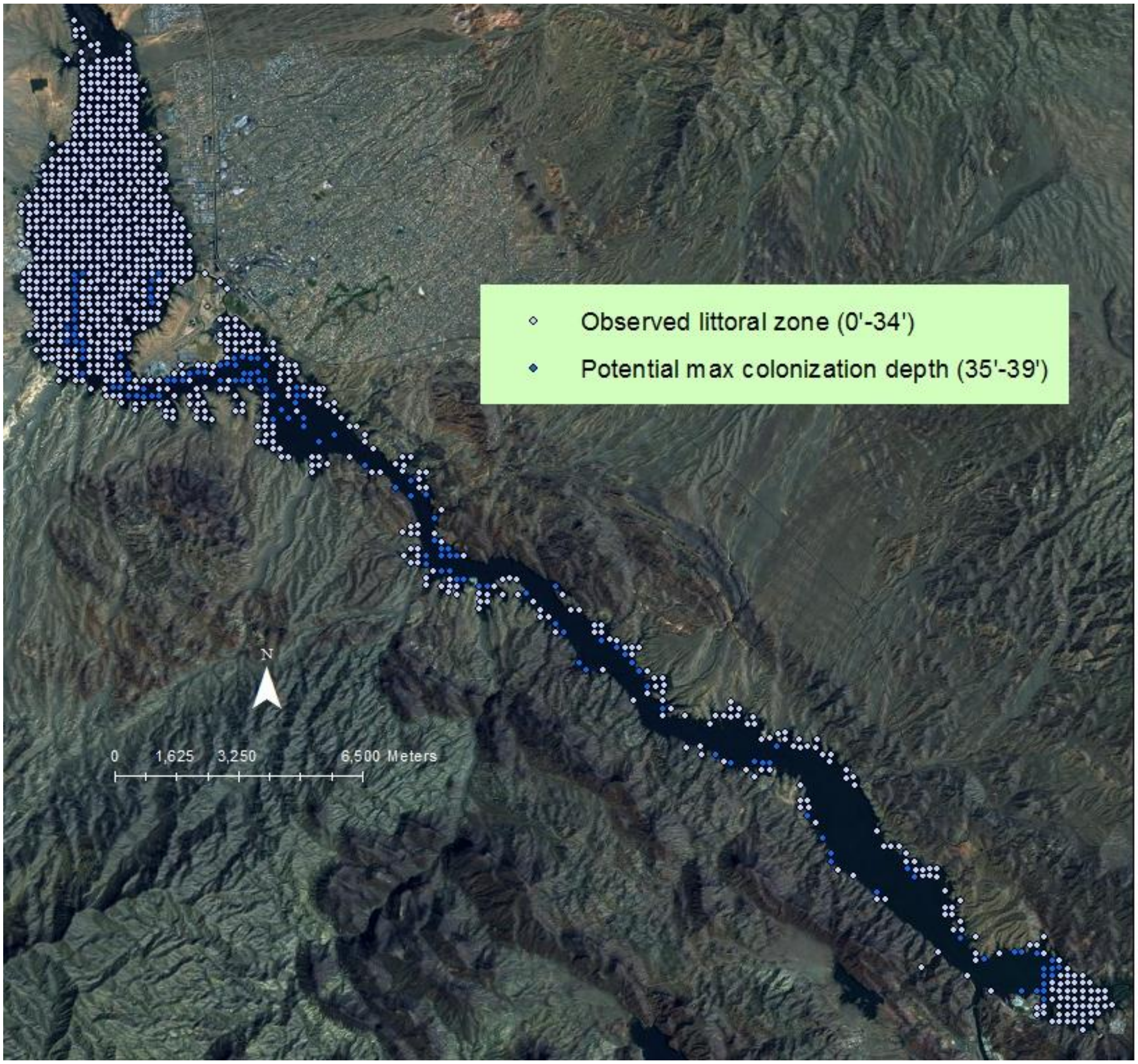

Figure 9. Distribution of the littoral zone points and the points determined to be the maximum potential colonization depth for rooted plants from the secchi disk readings. Areas without points exceed 39ft in depth.

Figure 10. Spiny naiad collected during the August 2012 point-intercept survey of Lake Havasu. Photo by John D. Madsen.

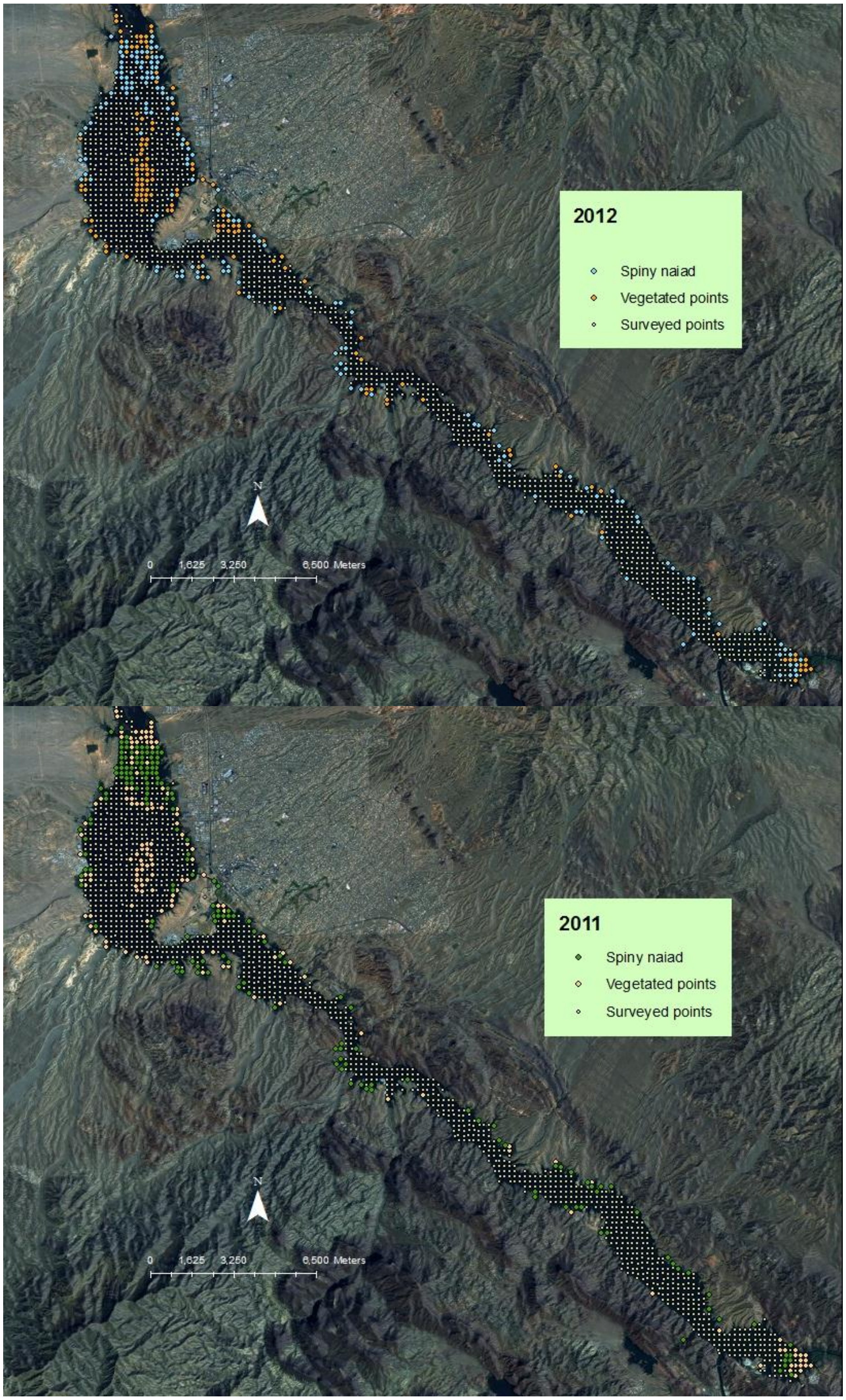

Figure 11. Distribution of spiny naiad collected during the point-intercept survey during Top) August 2012; Bottom) September 2011.

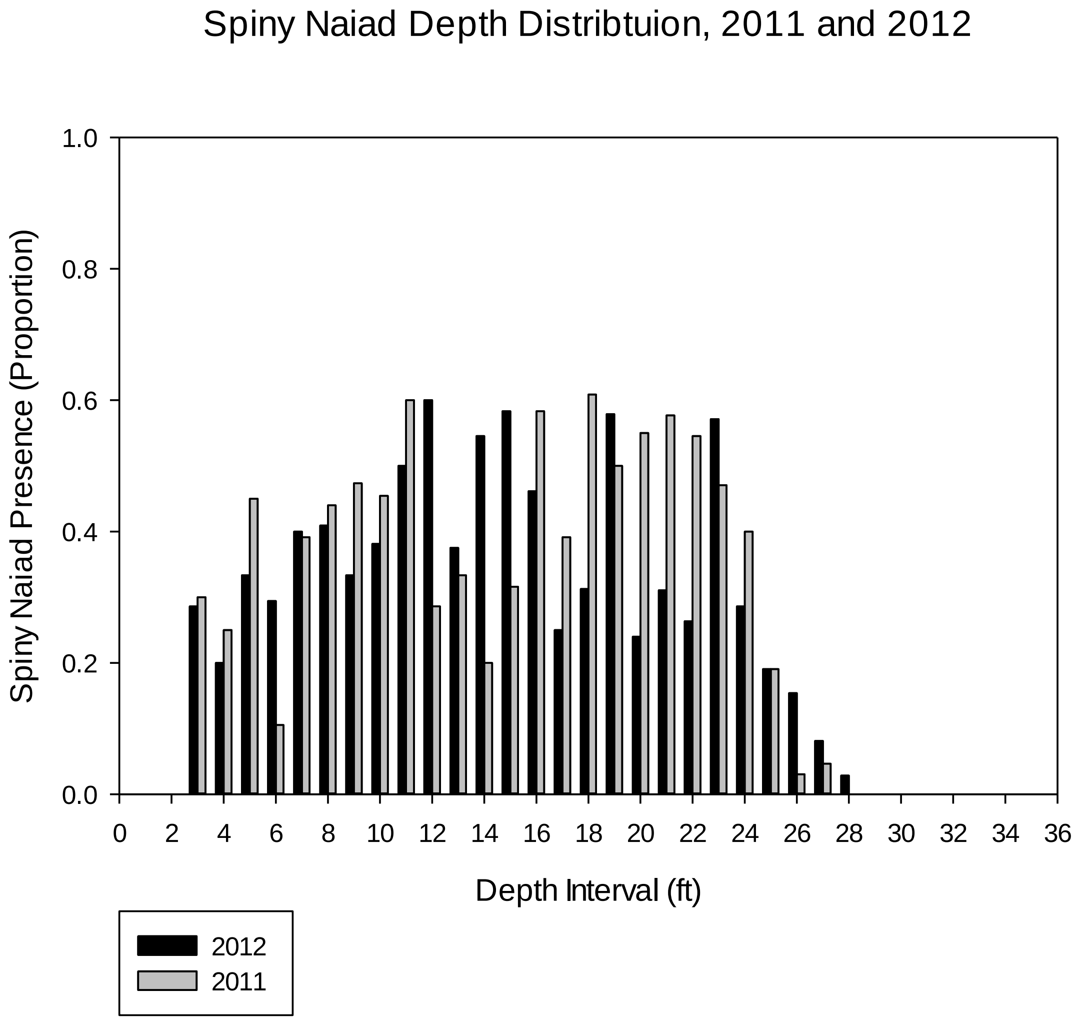

Figure 12. Comparison of depth distribution for spiny naiad collected in 2011 and 2012. In 2012 the average depth for spiny naiad growth was 14.83ft compared to 15.21ft in 2011. The maximum depth of growth was 28ft in 2012 and 27ft in 2011.

Figure 13. Chara collected during the August 2012 point-intercept survey of Lake Havasu. Photo by John D. Madsen.

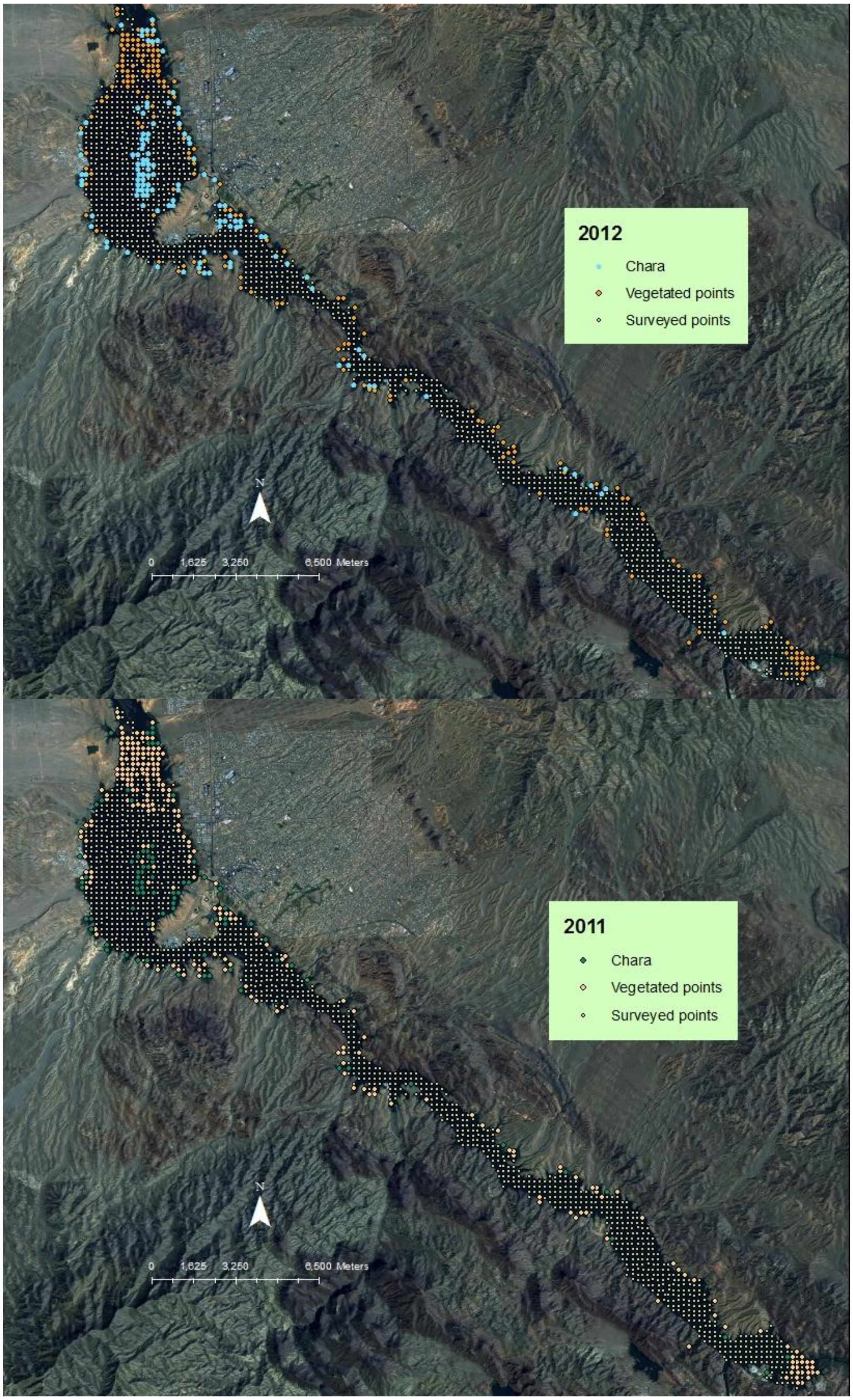

Figure 14. Distribution of chara collected during the point-intercept survey during Top) August 2012, Bottom) September 2011.

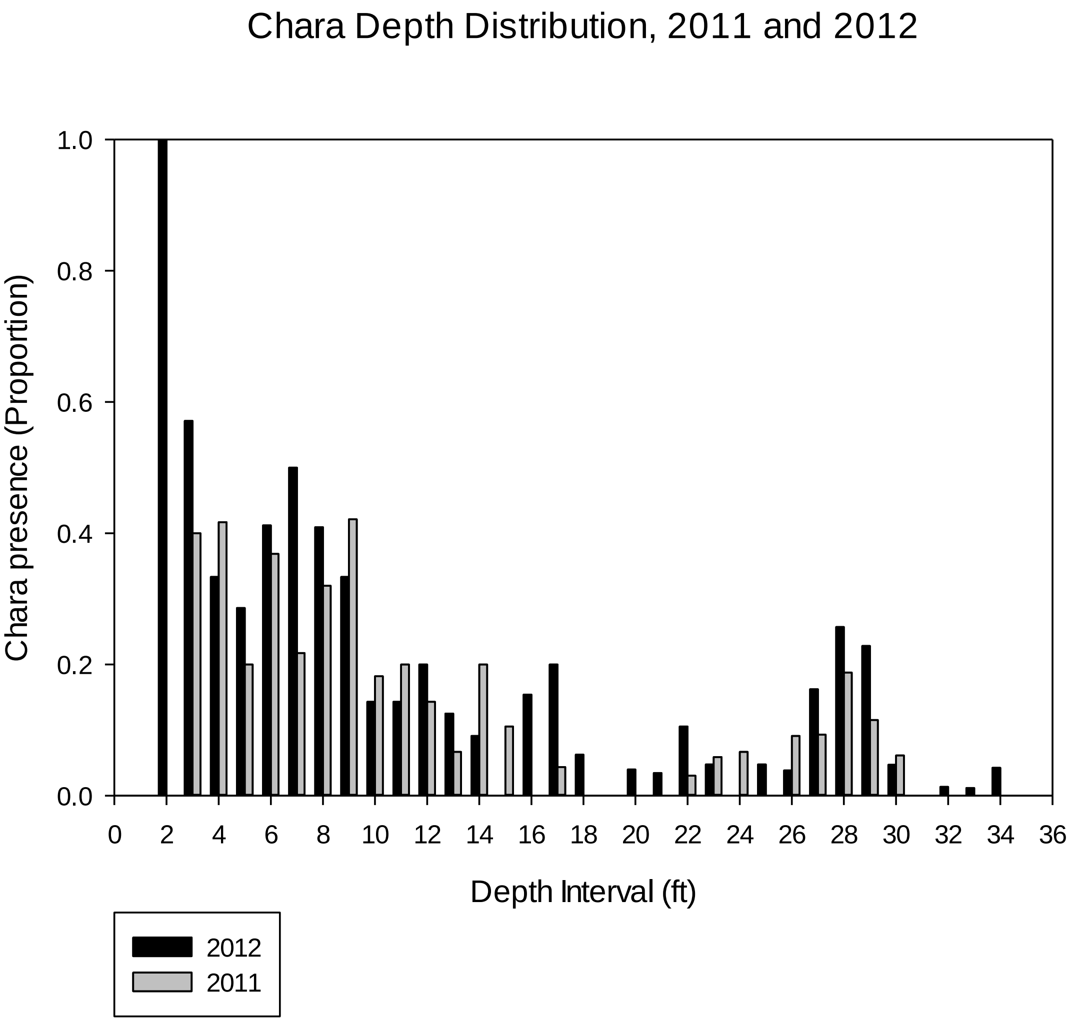

Figure 15. Comparison of depth distribution for spiny naiad collected in 2011 and 2012. In 2012 the average depth for chara growth was 16.20ft compared to 15.22ft in 2011. The maximum depth of growth was 34.3ft in 2012 and 30ft in 2011.

Figure 16. Southern naiad collected from Lake Havasu, August 2012. Photo by John D. Madsen.

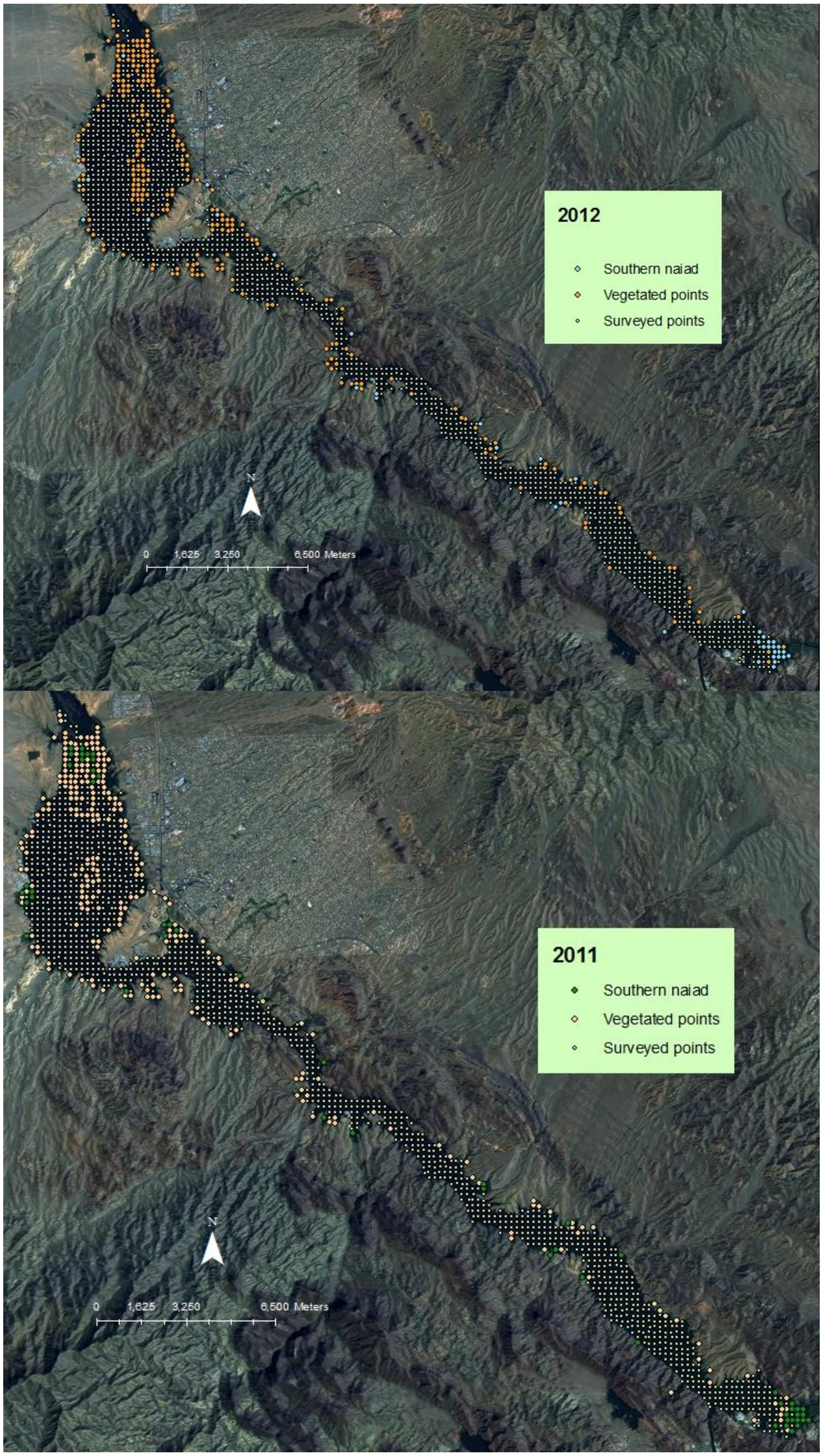

Figure 17. Distribution of southern naiad collected during the point-intercept survey during Top) August 2012, Bottom) September 2011.

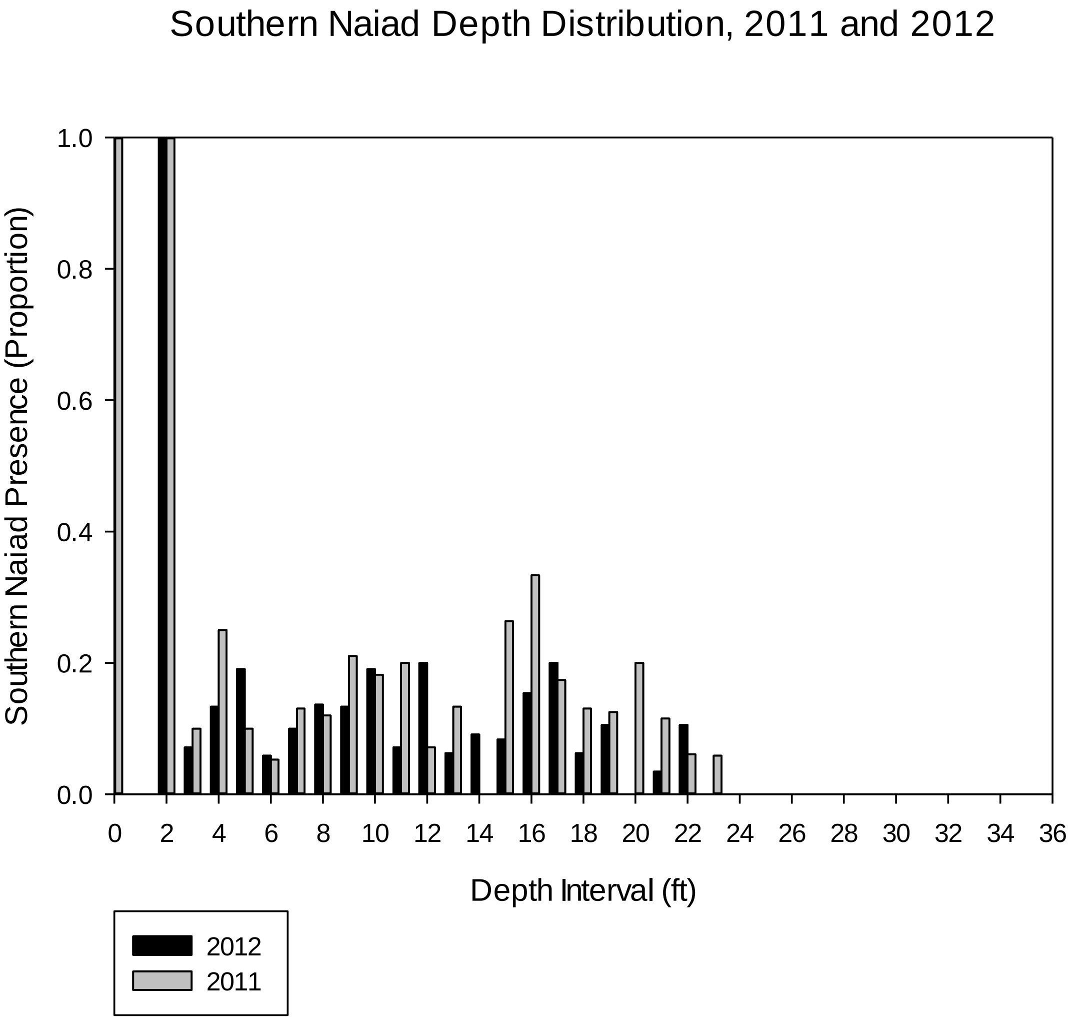

Figure 18. Comparison of depth distribution for spiny naiad collected in 2011 and 2012. In 2012 the average depth for southern naiad growth was 11.37ft compared to 13.05ft in 2011.

Figure 19. Sago pondweed collected in Lake Havasu, August 2012. Photo by John D. Madsen

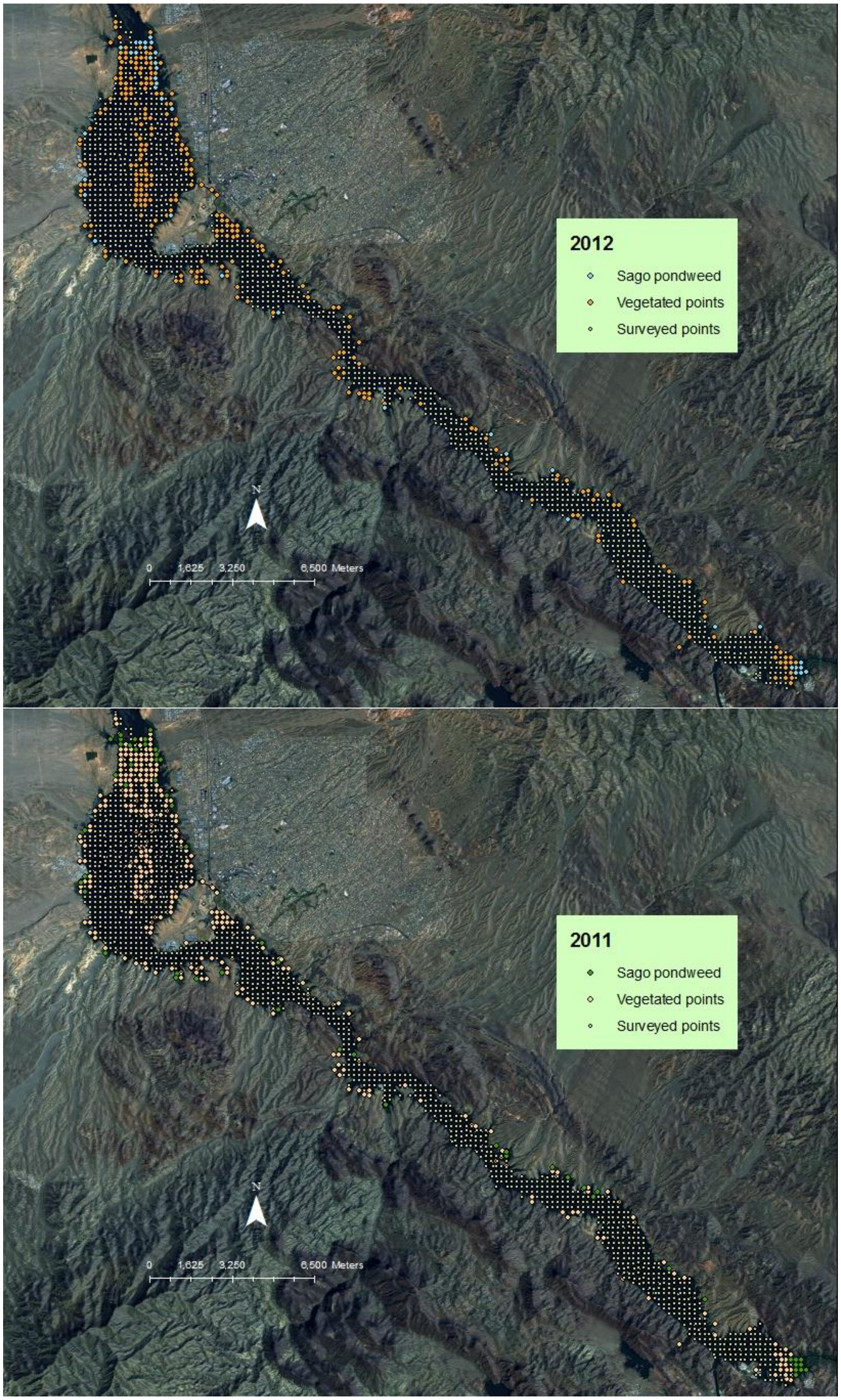

Figure 20. Distribution of sago pondweed collected during the point-intercept survey during: top) August 2012; B) September 2011.

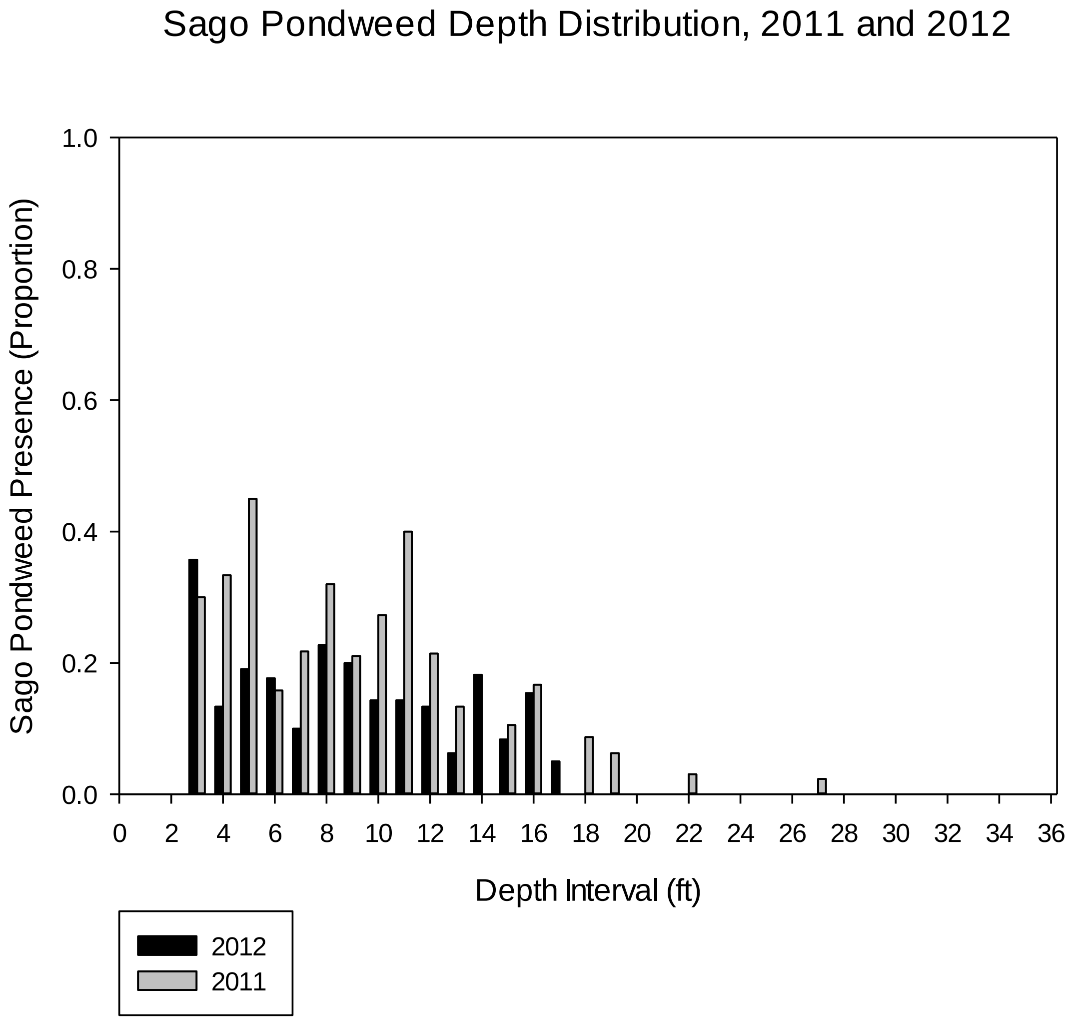

Figure 21. Comparison of depth distribution for spiny naiad collected in 2011 and 2012. In 2012 the average depth for sago pondweed growth was 8.28ft compared to 9.15ft in 2011.

Figure 22. Widgeongrass collected in Lake Havasu, August 2012. Photo by John D. Madsen

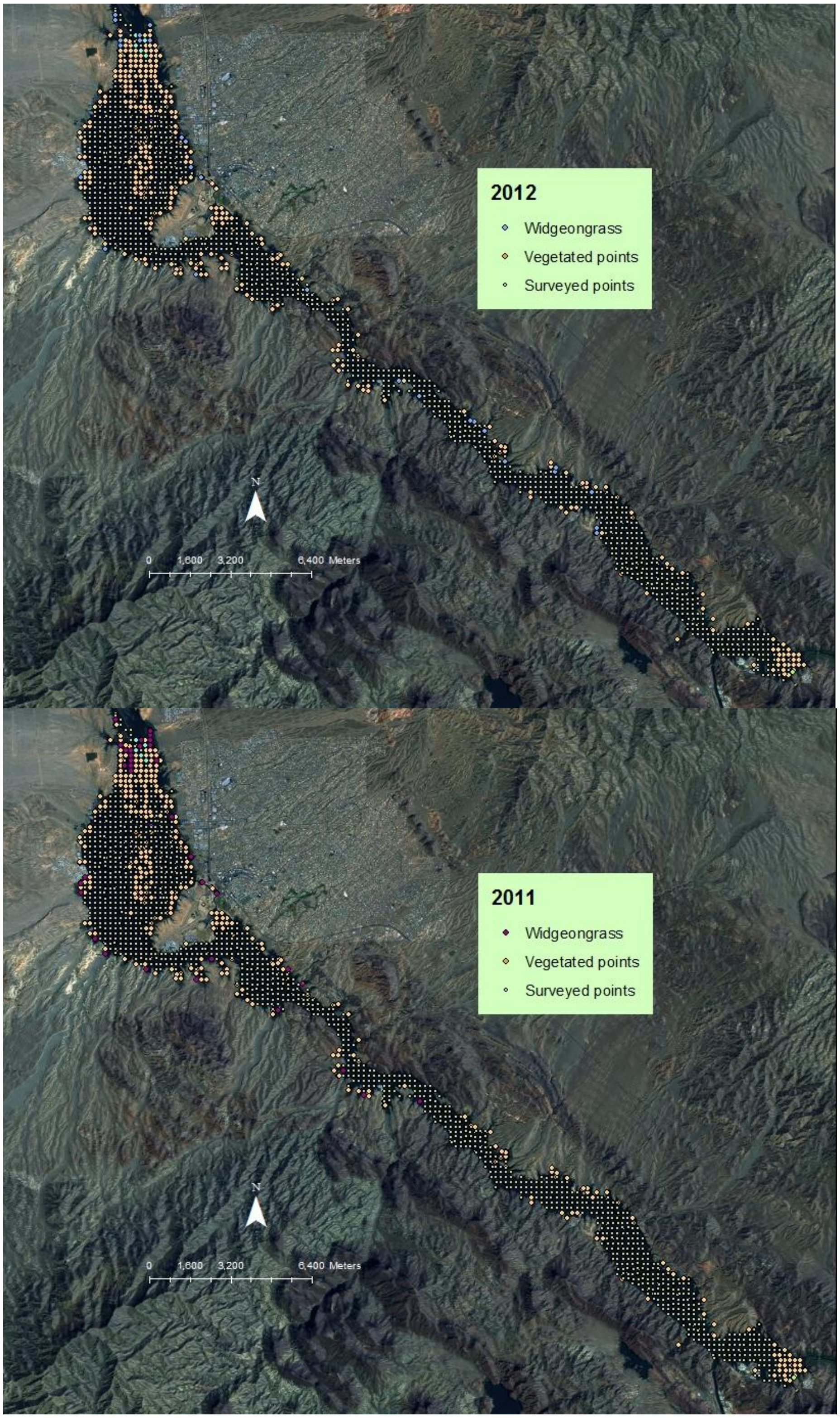

Figure 23. Distribution of widgeongrass during the point-intercept survey: top) August 2012; bottom) September 2011.

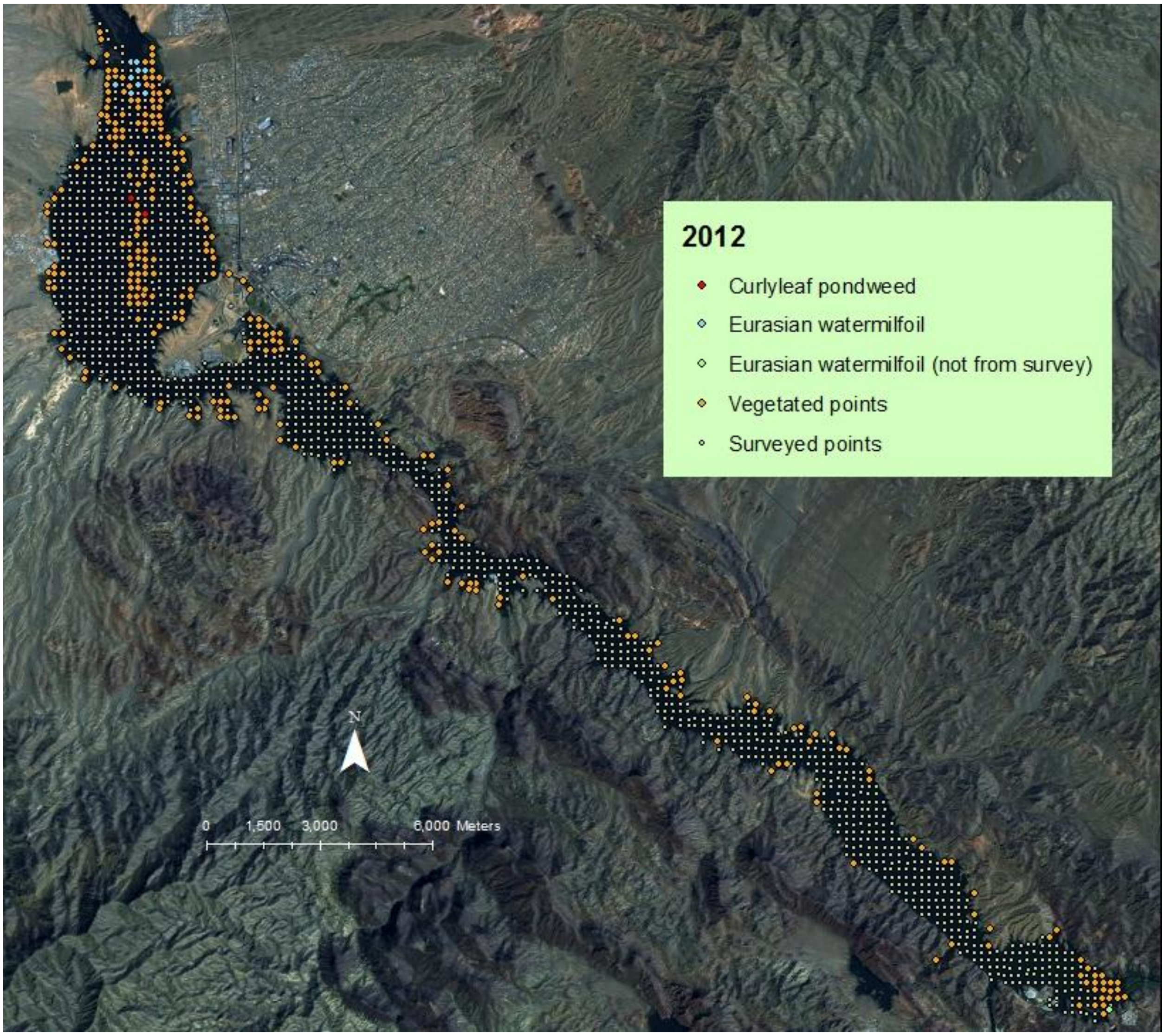

Figure 24. Distribution of invasive species found in Lake Havasu. The Eurasian watermilfoil depicted by the red point was found during the October 2012 drone drift study.

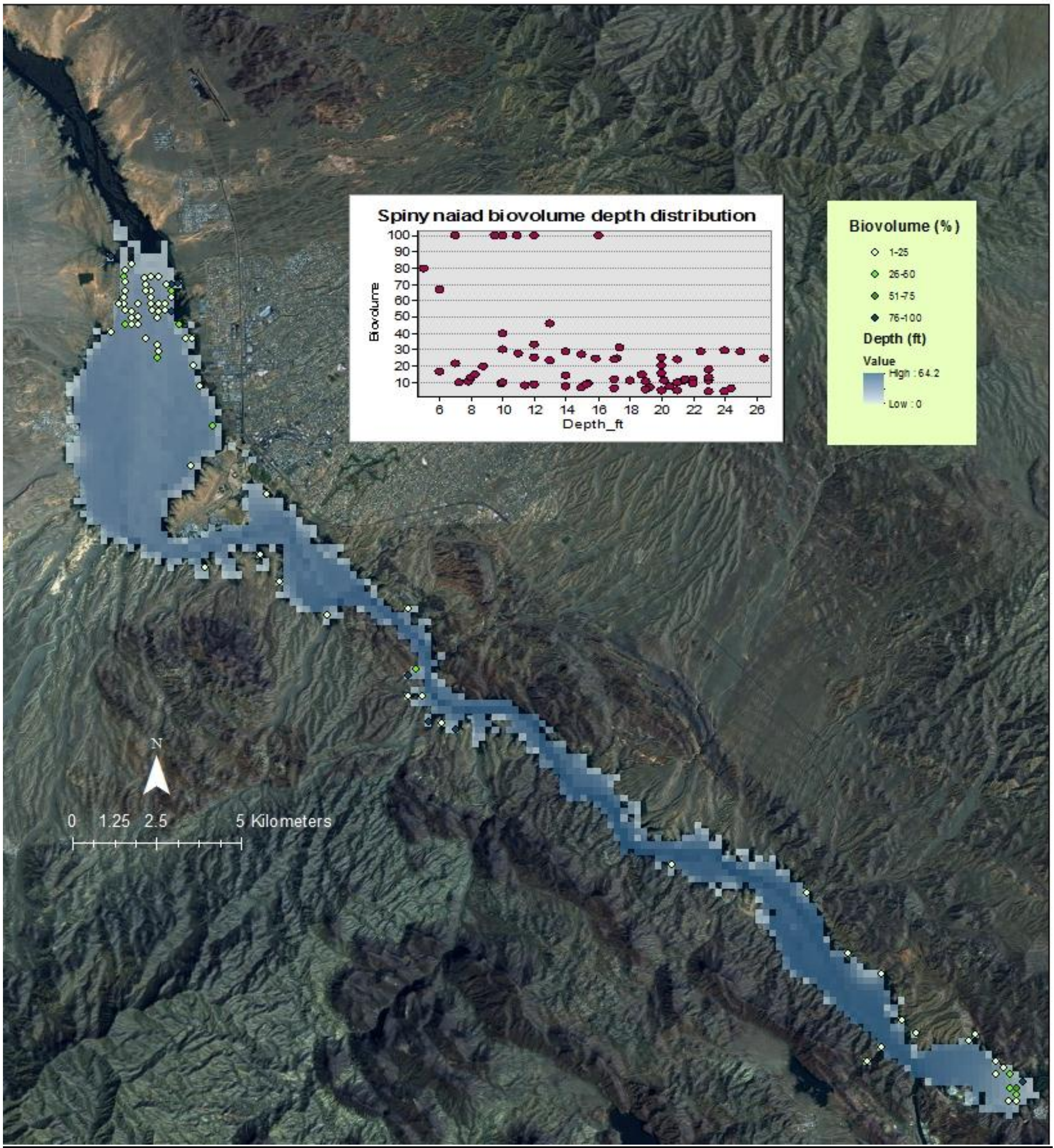

Figure 25. Percent biovolume of spiny naiad located throughout Lake Havasu. Percent biovolume decrease with increasing depth.

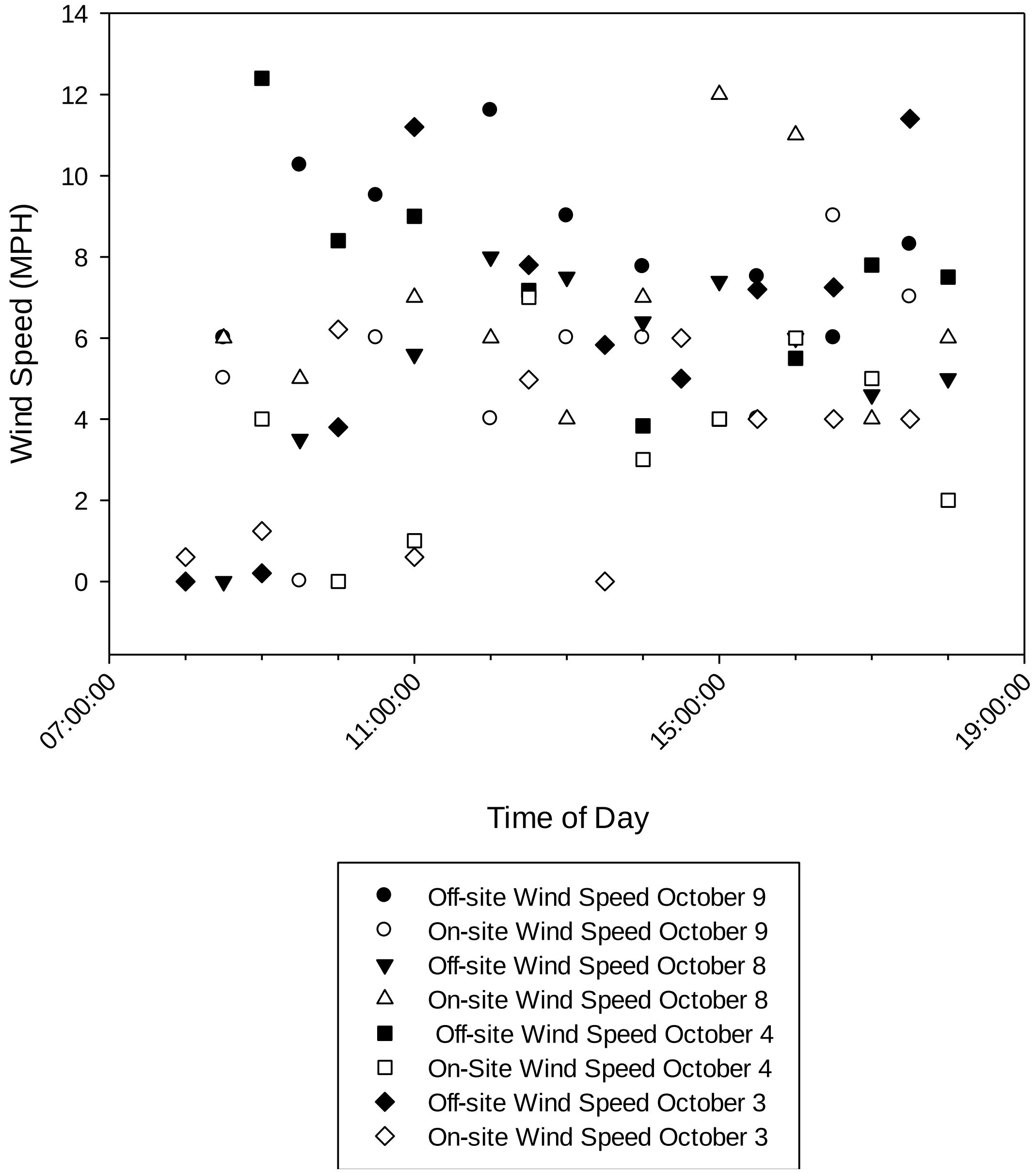

Figure 26. Scatter plot showing no correlation between the wind speed collected by the weather station KAZLAKEH32 and the on board weather station for each day of the drone drift study in October 2012.

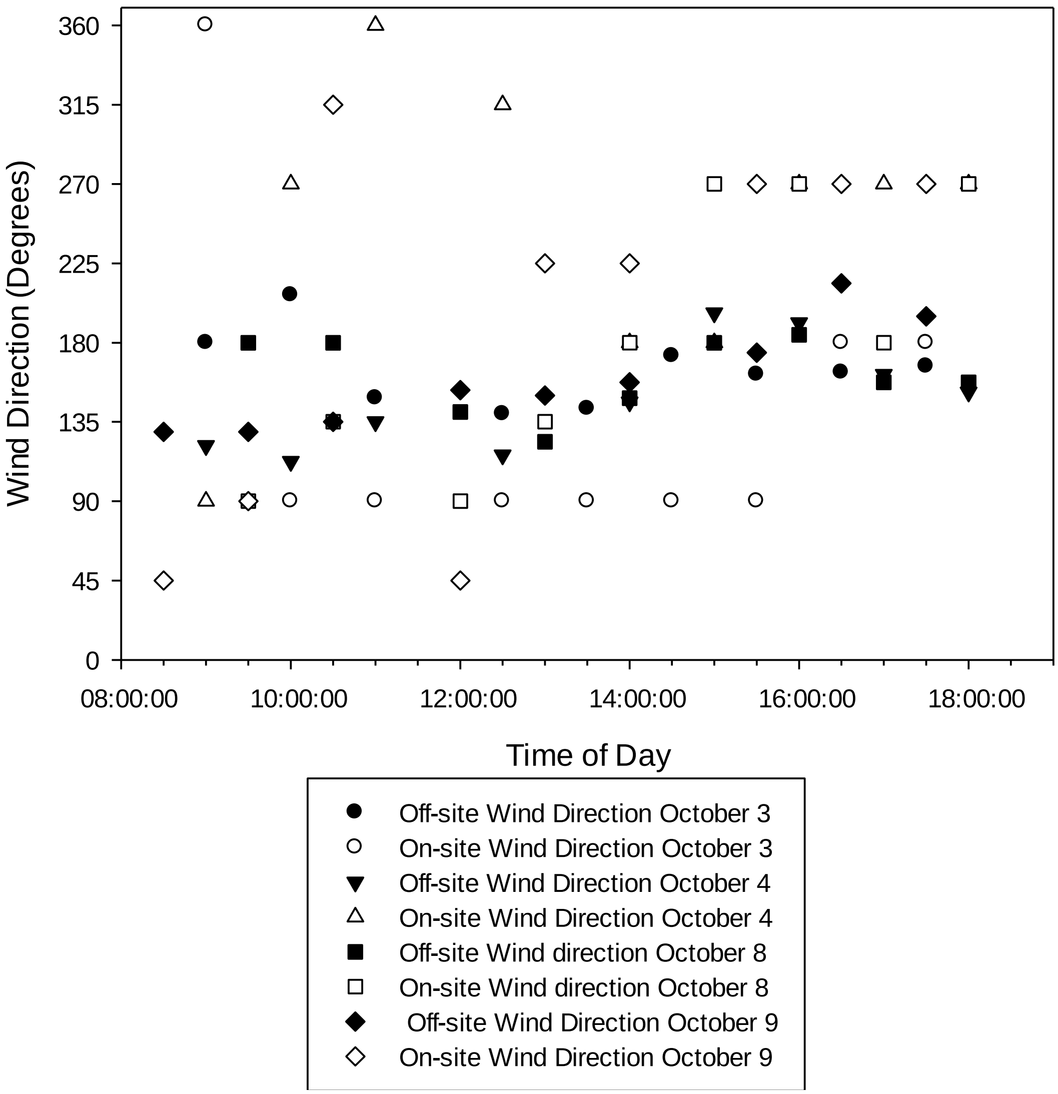

Figure 27. Scatter plot illustrating the observed wind direction from the on board weather system versus wind direction from the weather station KAZLAKEH32 for each day of the drone drift study during October 2012. There was no correlation between the data.

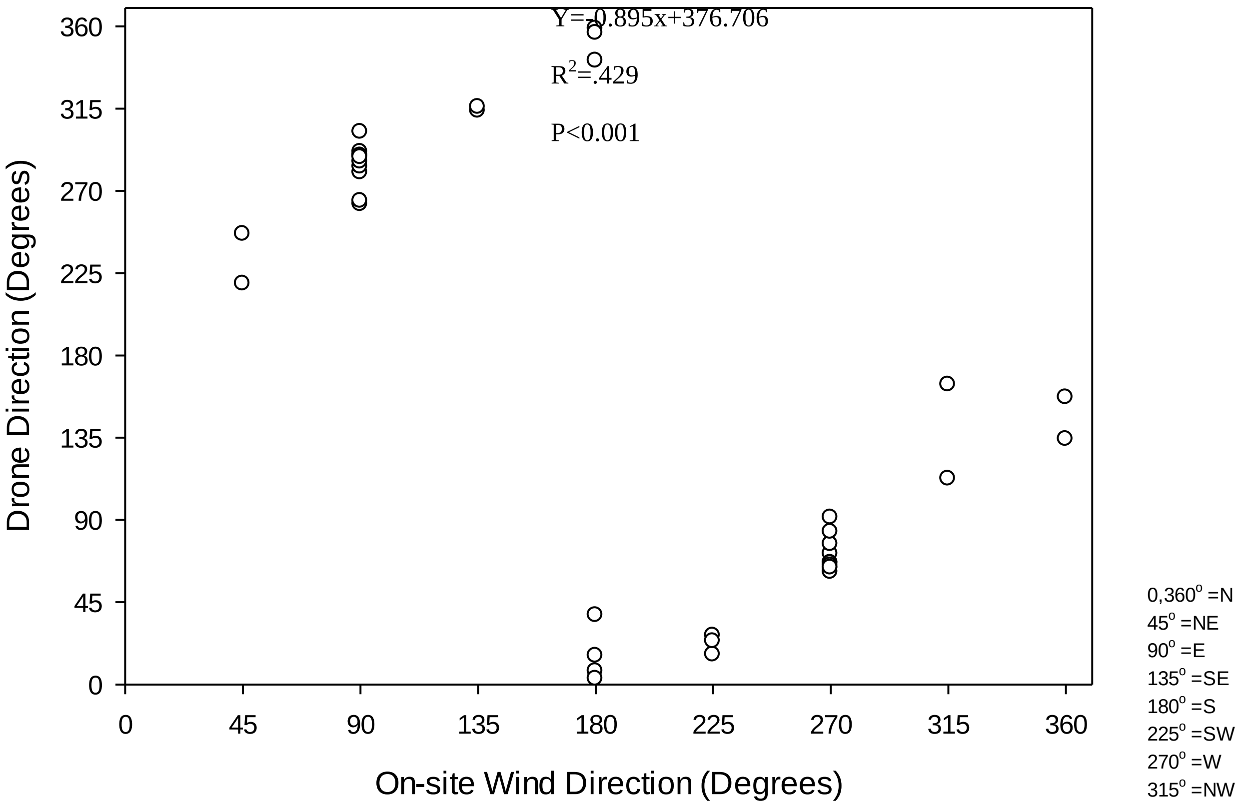

Figure 28. Scatter plot showing the significant negative linear relationship between the wind direction and drone drift direction.

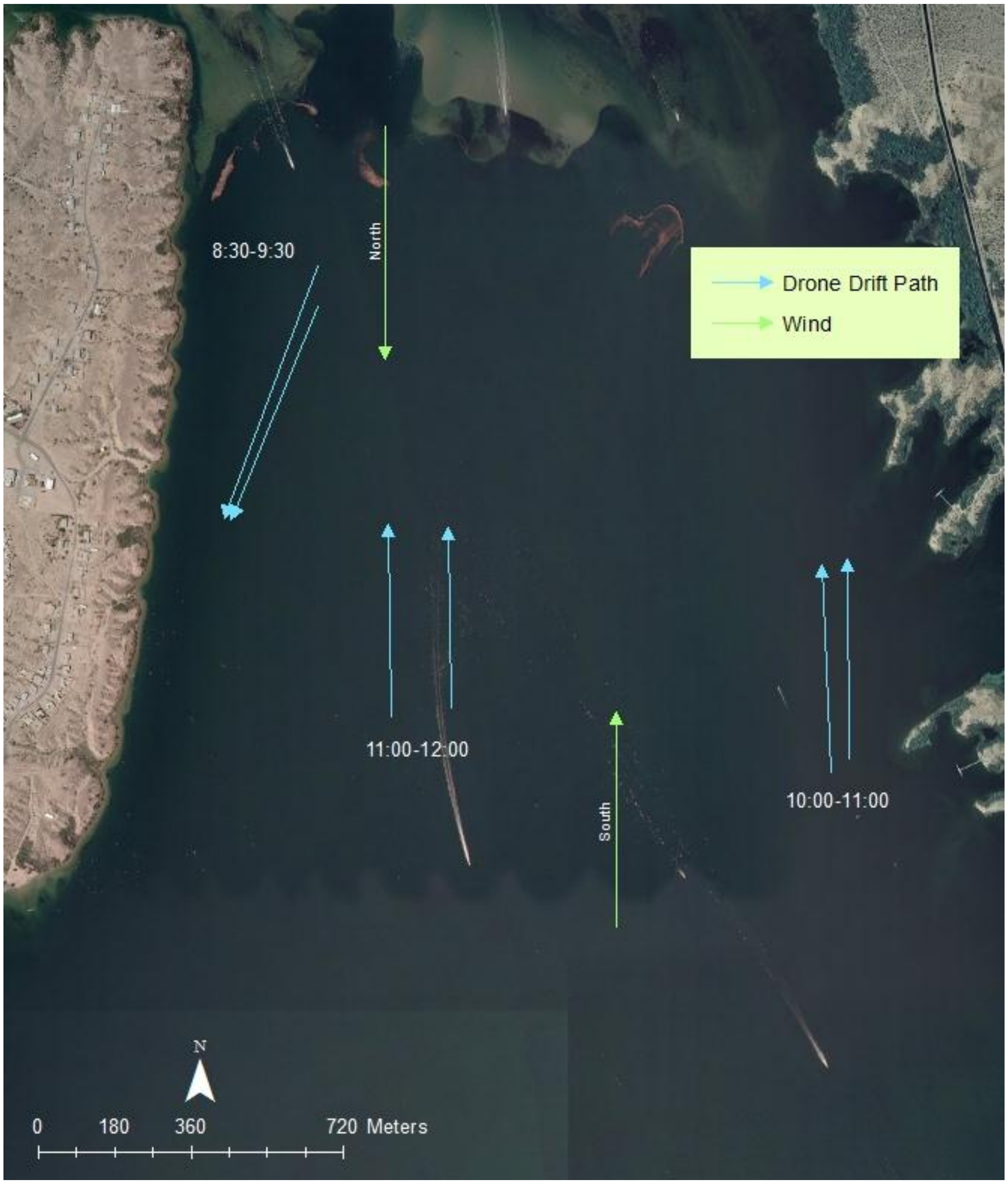

Figure 29. Morning drone drift paths and predominant wind direction observed near the Colorado River inflow in Lake Havasu on October 1, 2012. The length of the arrow tail is the scaled distance the drones traveled.

Figure 30. Afternoon drone drift paths and predominant wind direction observed in the widest section of Lake Havasu on October 1, 2012. The length of the arrow tail is the scaled distance the drones traveled.

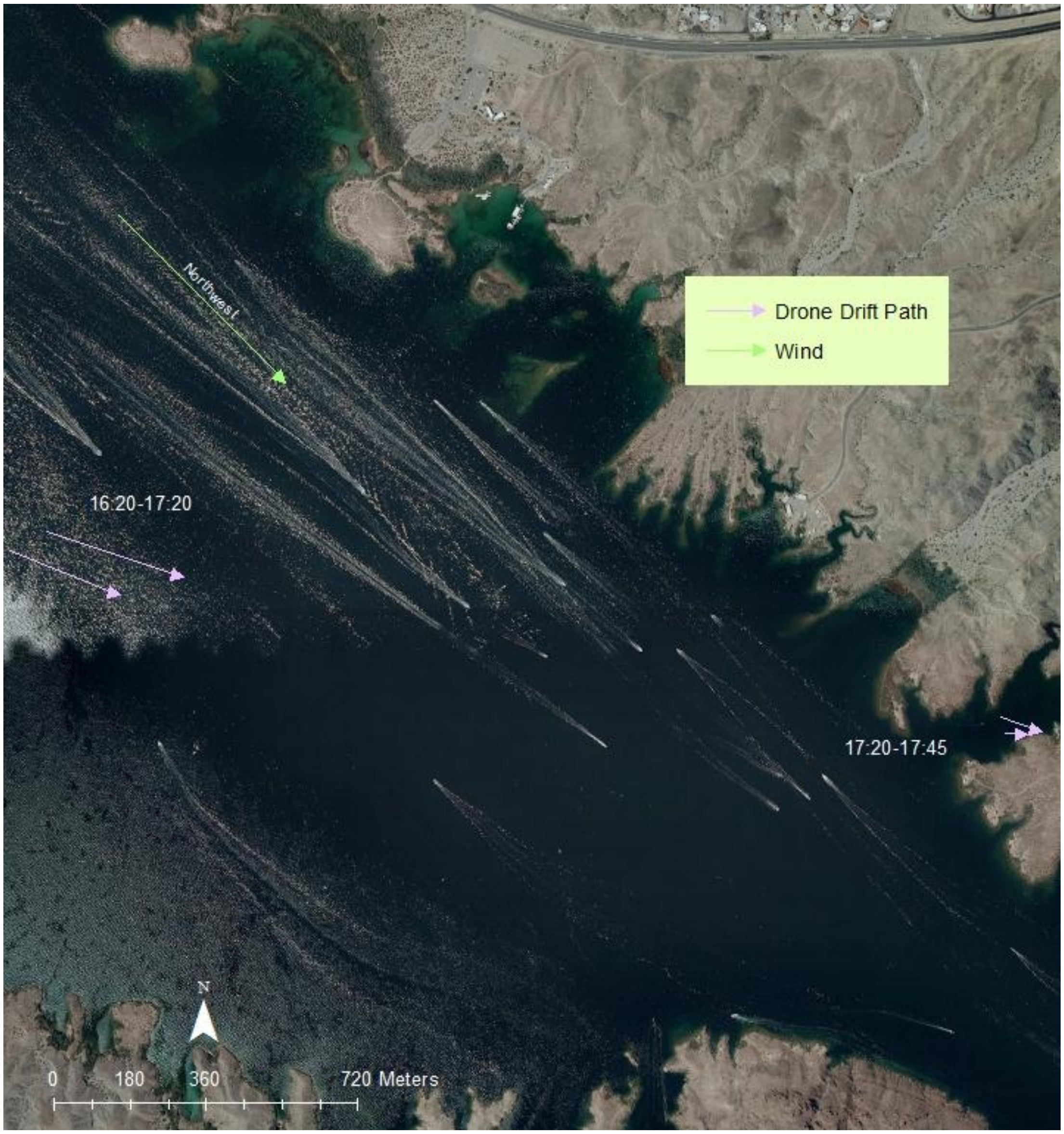

Figure 31. Afternoon drone drift paths and predominant wind direction observed near the entrance of the river-like area of Lake Havasu that flows into Bill Williams on October 1, 2012. The length of the arrow tail is the scaled distance the drones traveled.

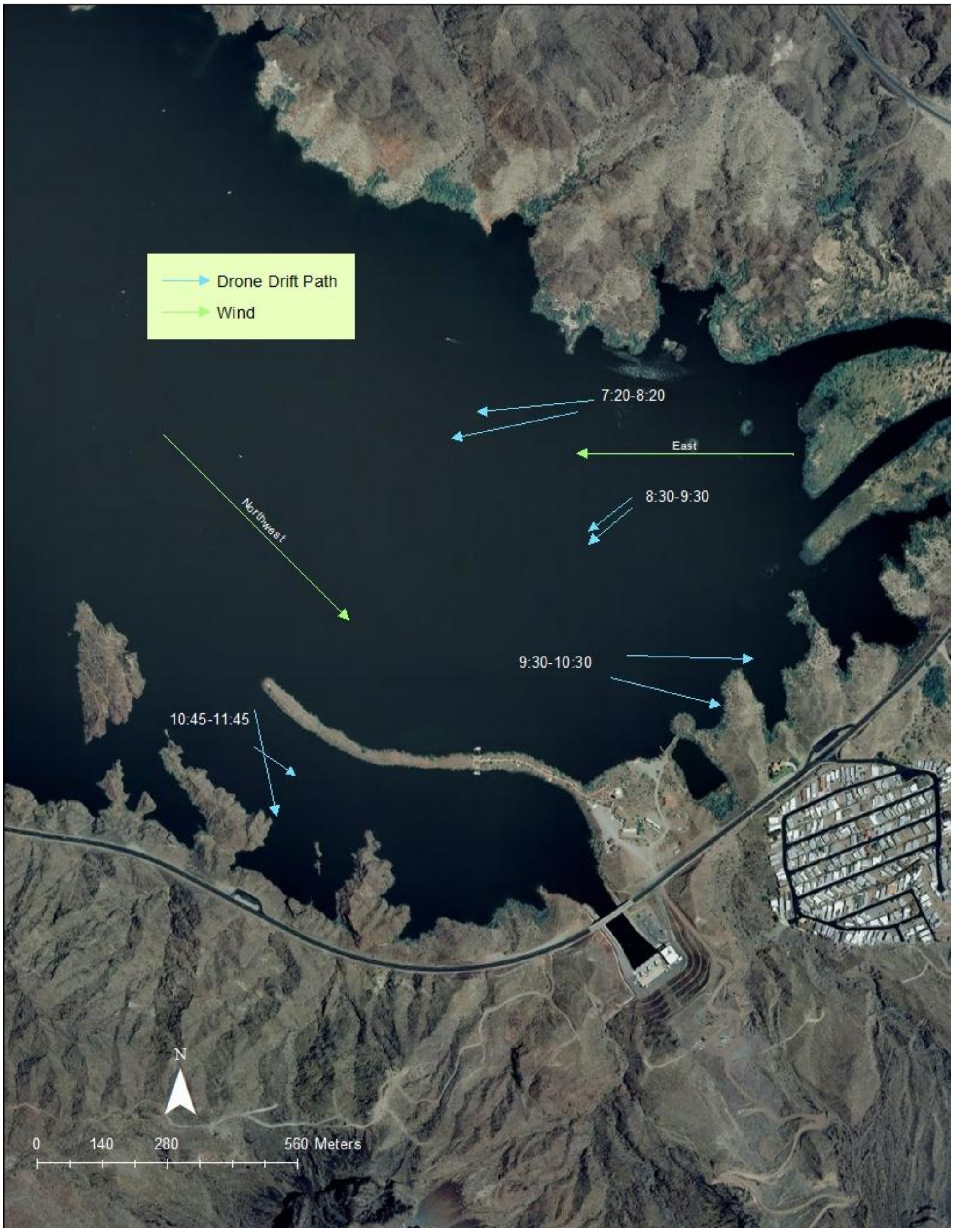

Figure 32. Morning drone drift paths and predominant wind direction observed in Bill Williams NWR on October 2, 2012. The length of the arrow tail is the scaled distance the drones traveled.

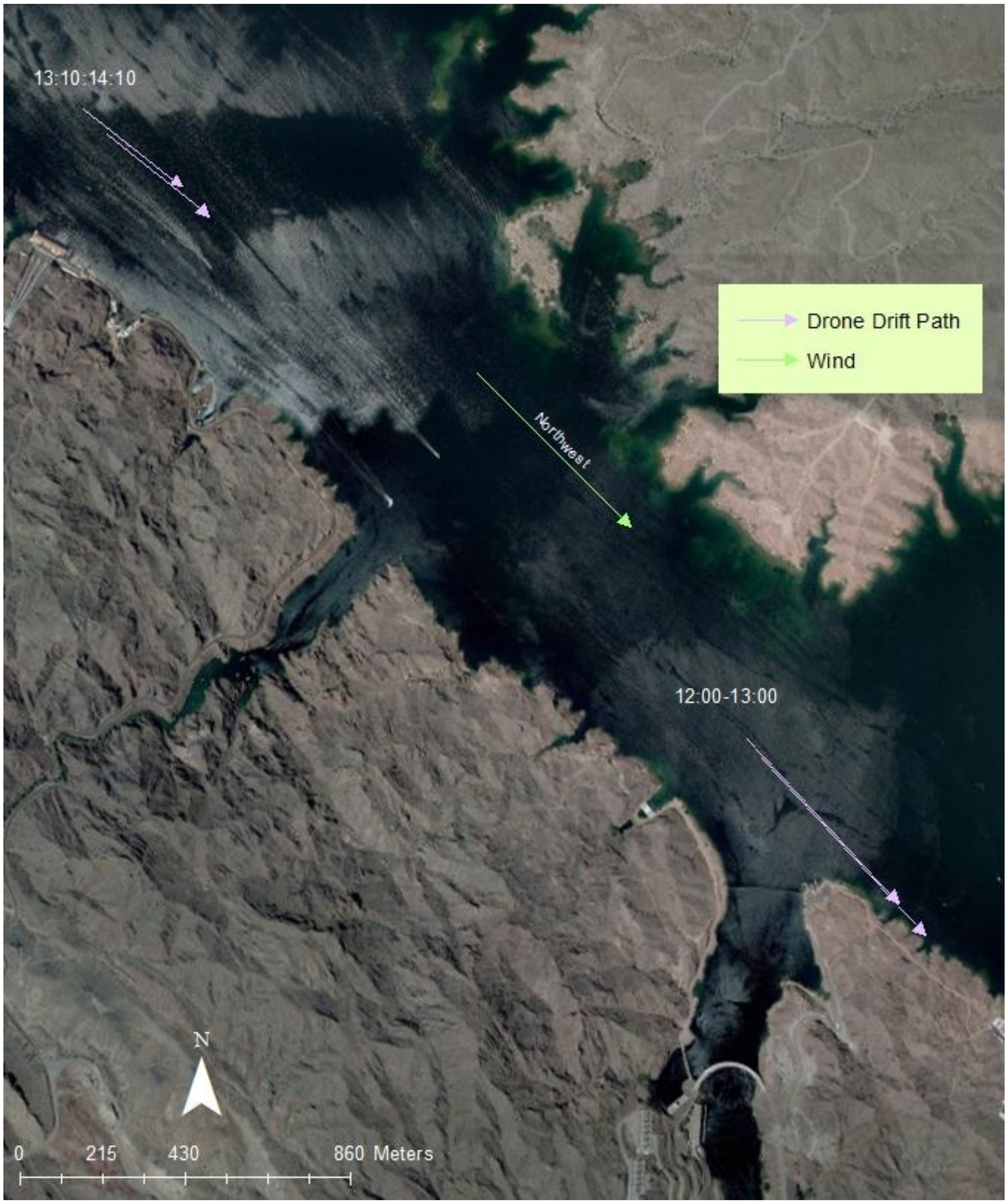

Figure 33. Afternoon drone drift paths and predominant wind direction observed near the Colorado River Aqueduct intake pump on October 2, 2012. The length of the arrow tail is the scaled distance the drones traveled.

Figure 34. Afternoon drone drift paths and predominant wind direction observed in Bill Williams NWR on October 2, 2012. The length of the arrow tail is the scaled distance the drones traveled.

Figure 35. Morning drone drift paths and predominant wind direction observed in river-like area of Lake Havasu that flows into Bill Williams NWR on October 3, 2012. The length of the arrow tail is the scaled distance the drones traveled.

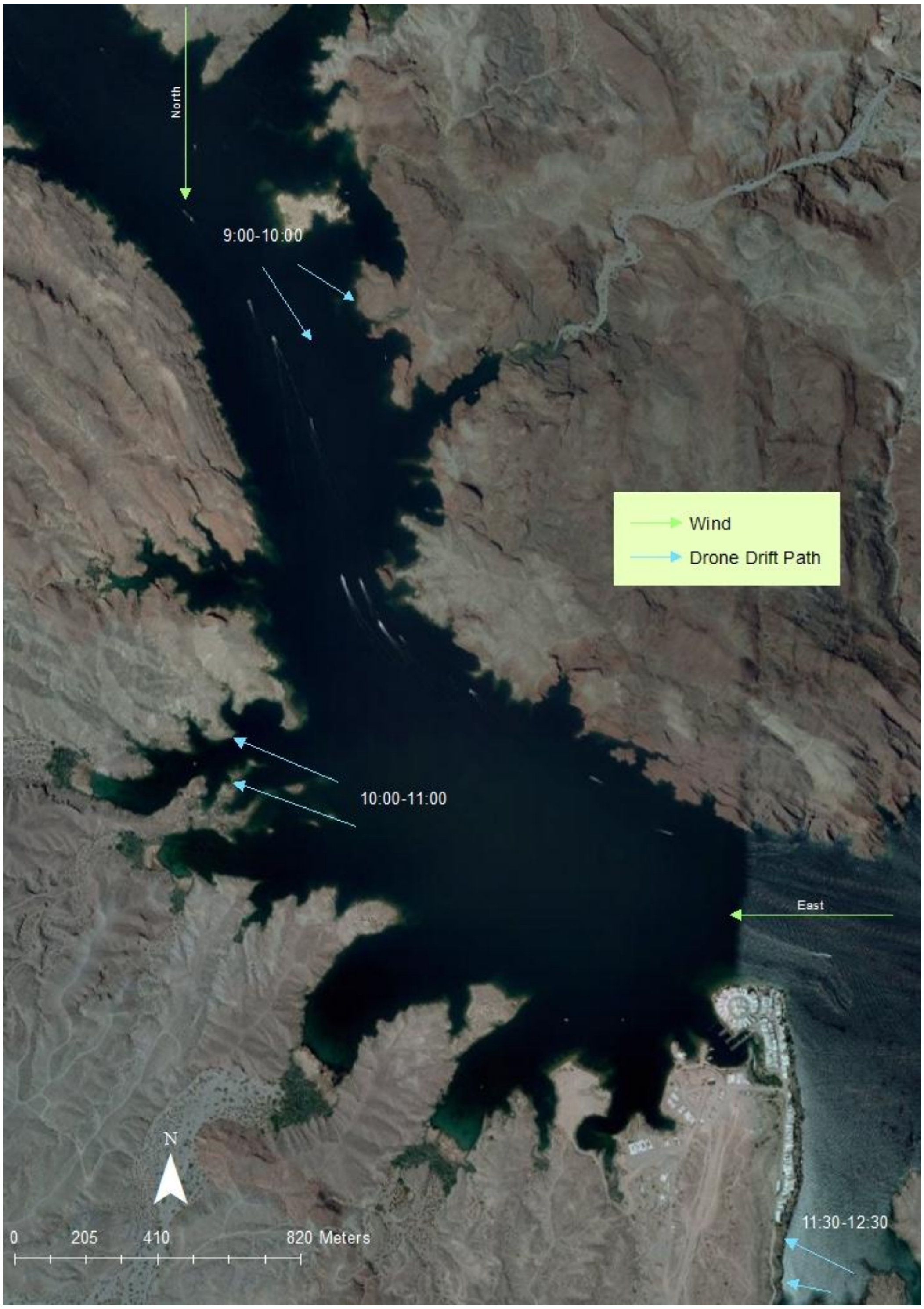

Figure 36. Morning drone drift paths and predominant wind direction observed in river-like area of Lake Havasu that flows into Bill Williams NWR on October 3, 2012. The length of the arrow tail is the scaled distance the drones traveled.

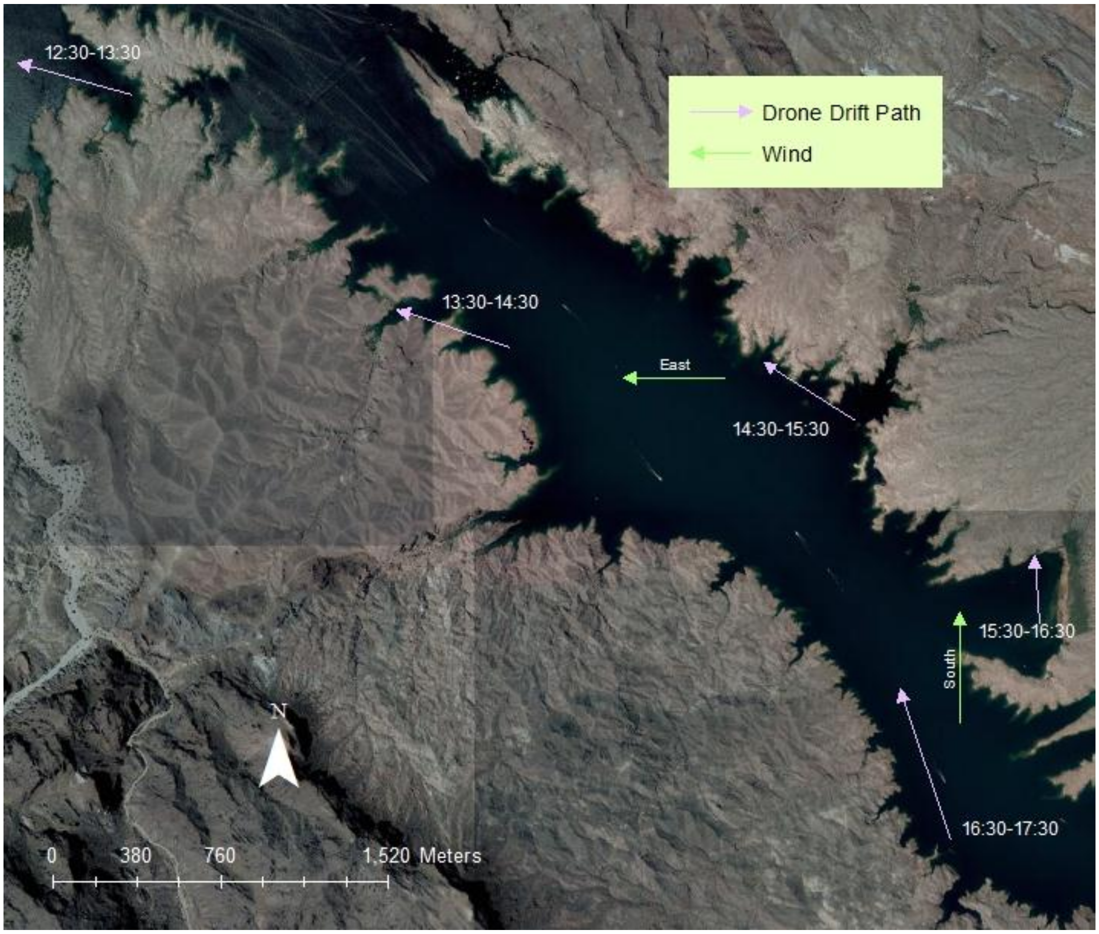

Figure 37. Afternoon drone drift paths and predominant wind direction observed in river-like area of Lake Havasu that flows into Bill Williams NWR on October 3, 2012. The length of the arrow tail is the scaled distance the drones traveled.

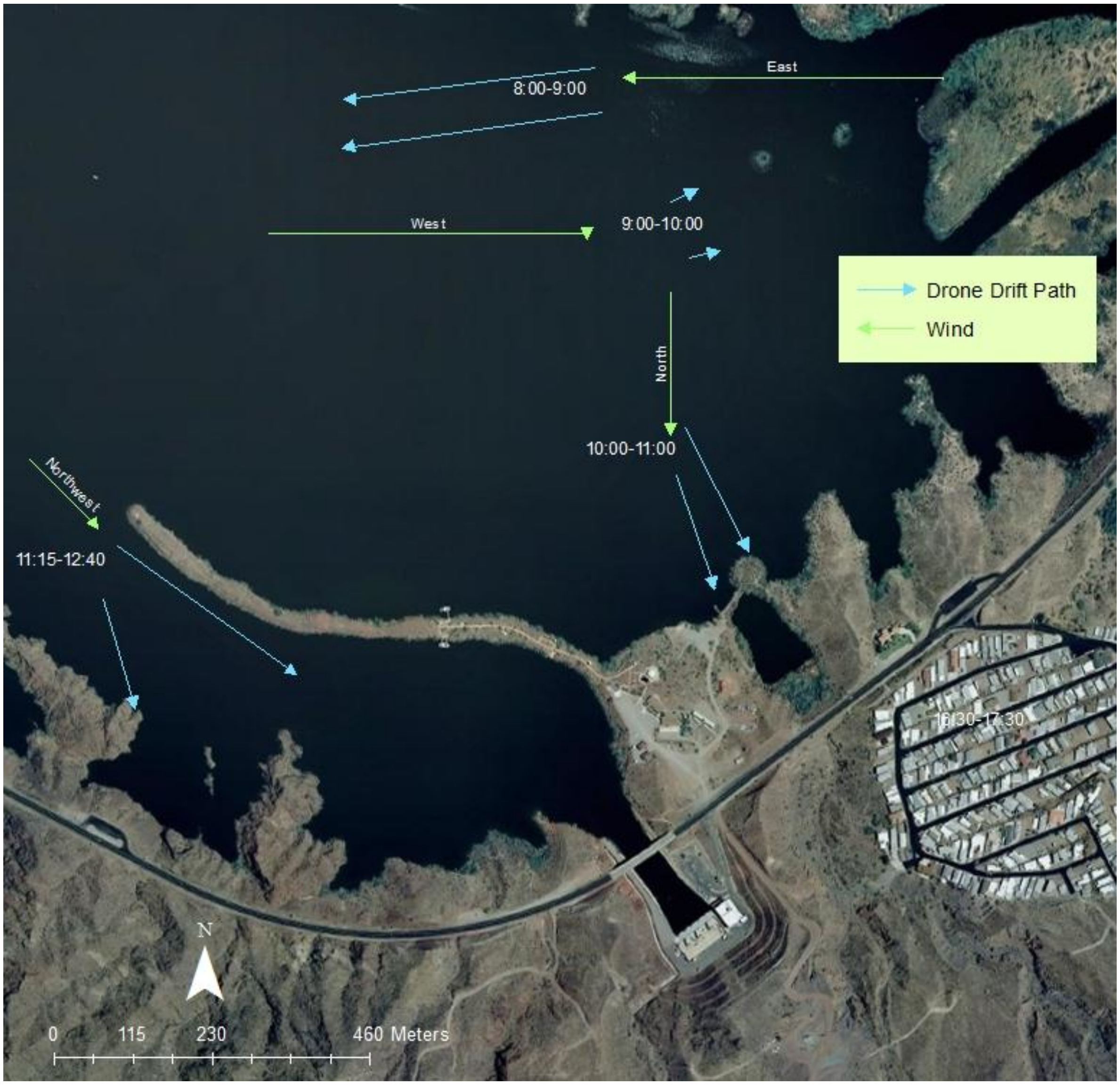

Figure 38. Morning drone drift paths and predominant wind direction observed in Bill Williams NWR on October 4, 2012. The length of the arrow tail is the scaled distance the drones traveled.

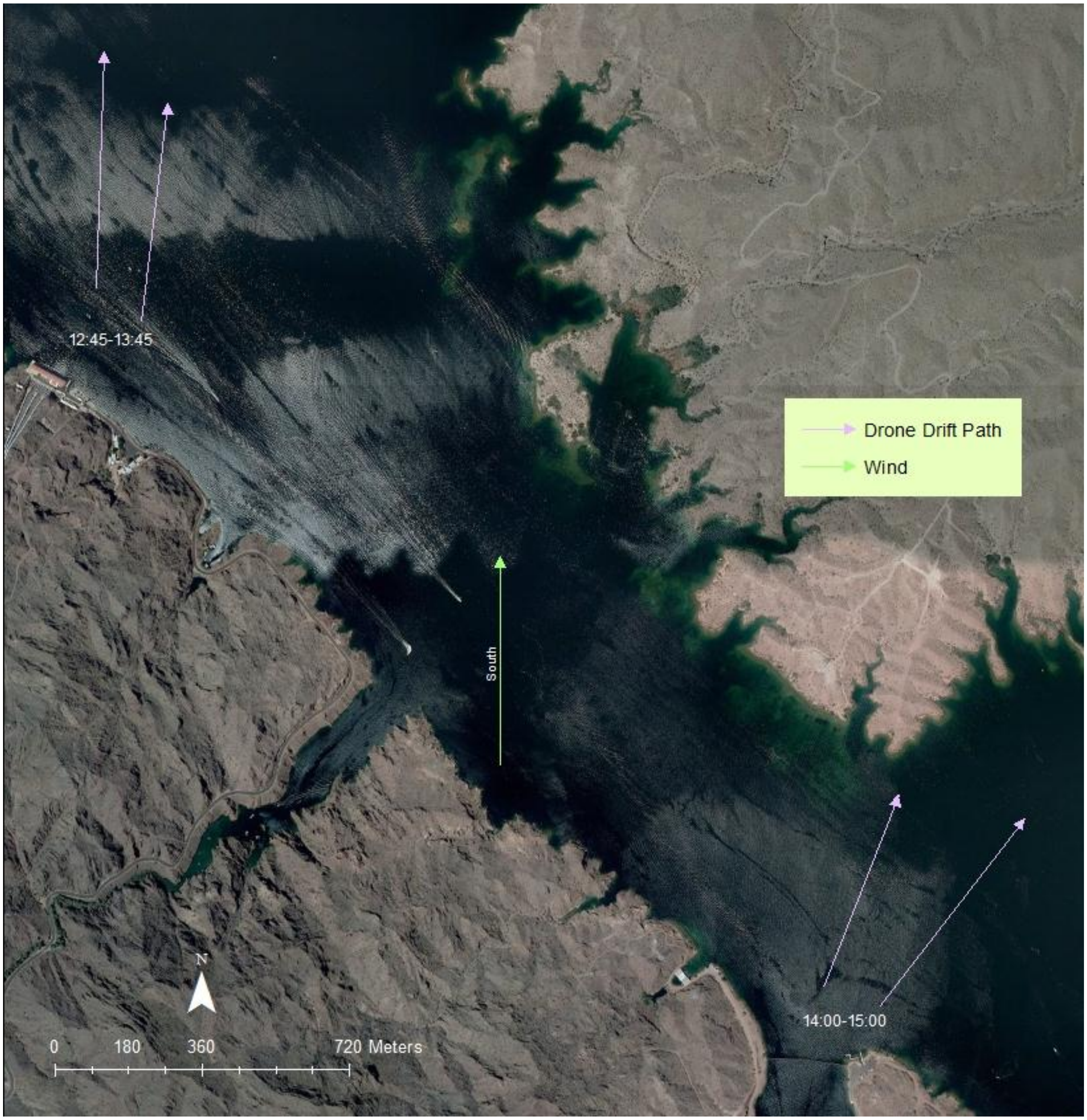

Figure 39. Afternoon drone drift paths and predominant wind direction observed near the Colorado River Aqueduct on October 4, 2012. The length of the arrow tail is the scaled distance the drones traveled.

Figure 40. Afternoon drone drift paths and predominant wind direction Bill Williams NWR on October 4, 2012. The length of the arrow tail is the scaled distance the drones traveled.

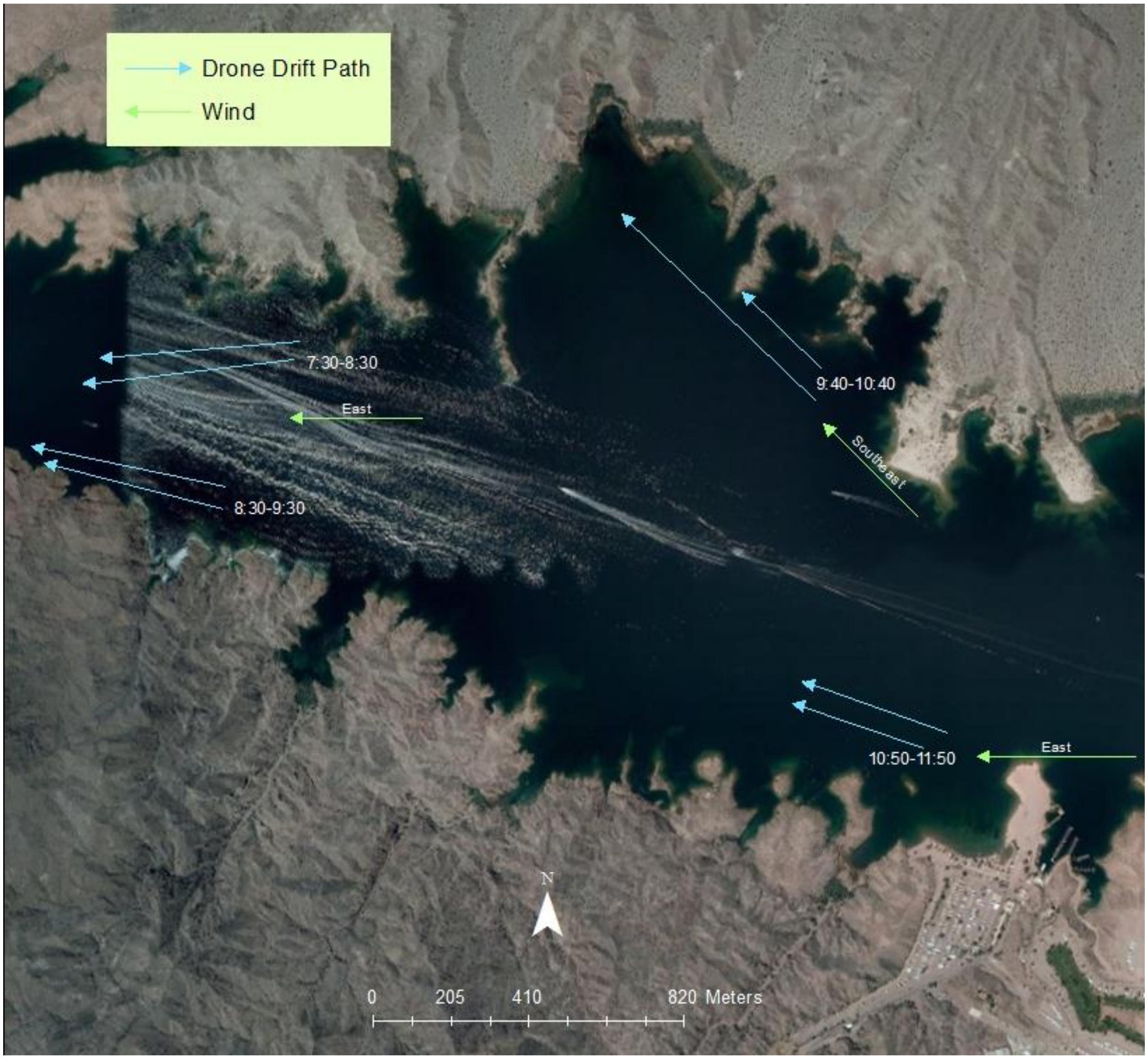

Figure 41. Morning drone drift paths and predominant wind direction observed in the river-like area of Lake Havasu that flows into Bill Williams on October 8, 2012. The length of the arrow tail is the scaled distance the drones traveled.

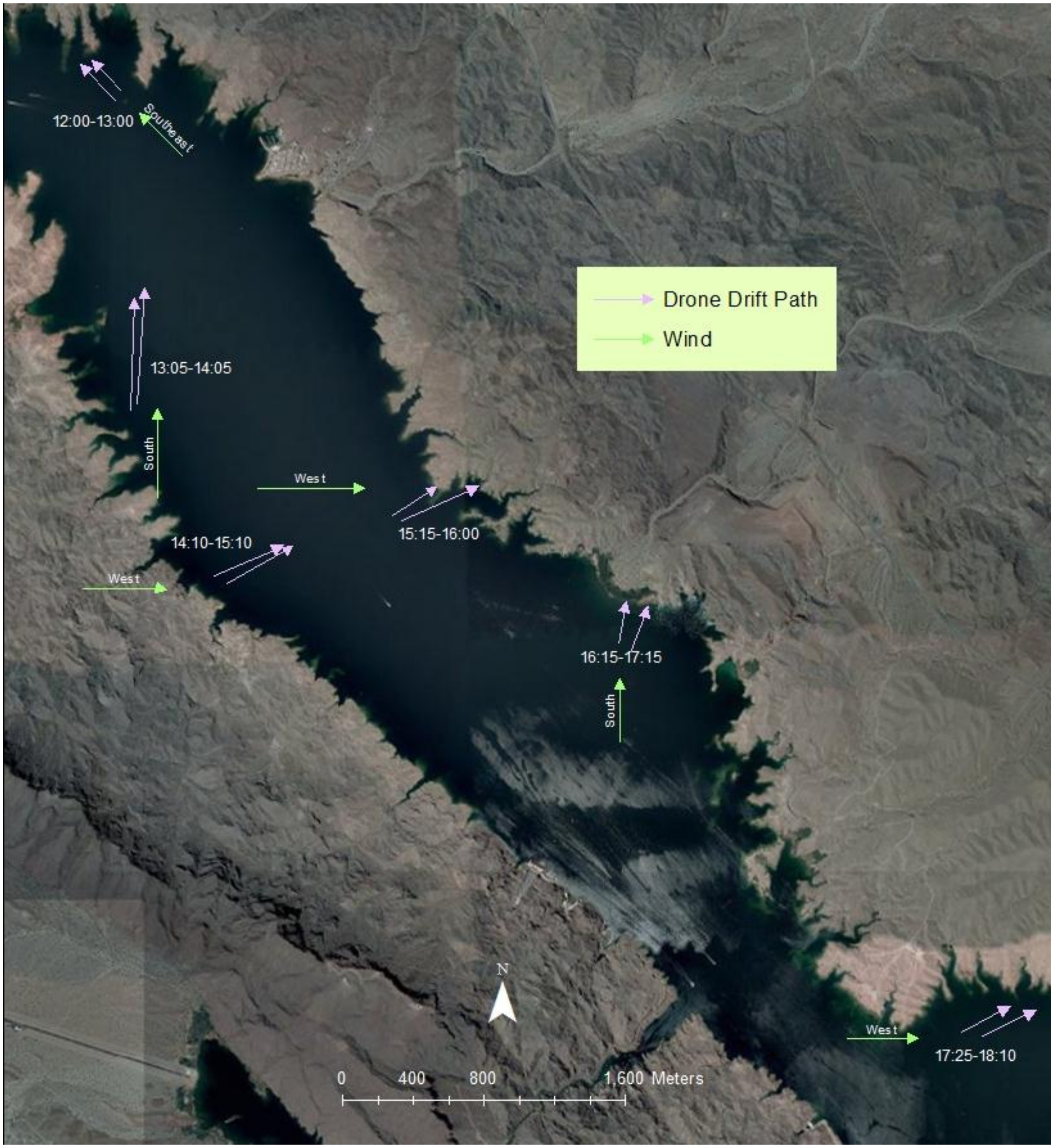

Figure 42. Afternoon drone drift paths and predominant wind direction observed in the river-like area of Lake Havasu that flows into Bill Williams on October 8, 2012. The length of the arrow tail is the scaled distance the drones traveled.

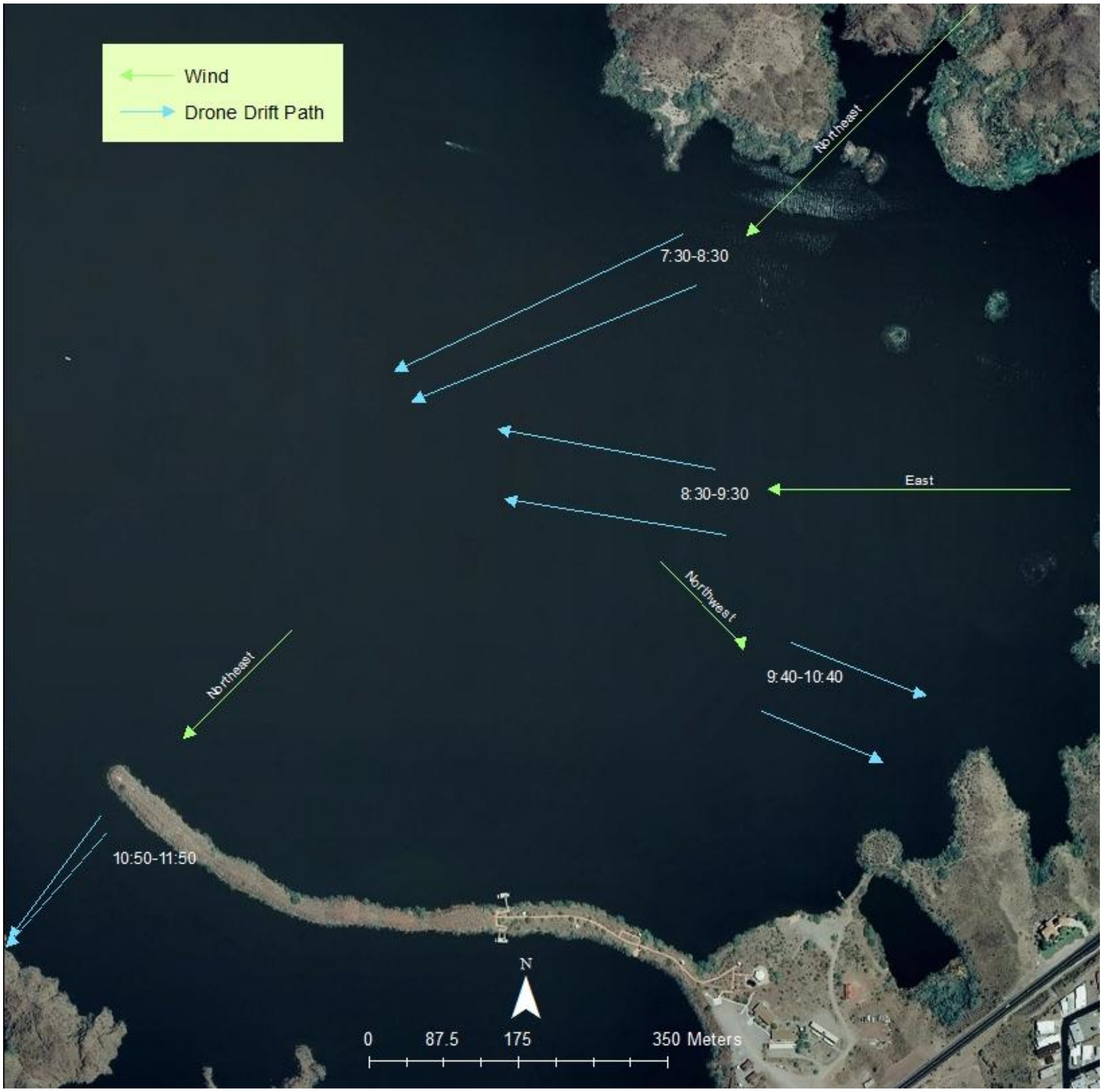

Figure 43. Morning drone drift paths and predominant wind direction observed in Bill Williams NWR on October 9, 2012. The length of the arrow tail is the scaled distance the drones traveled.

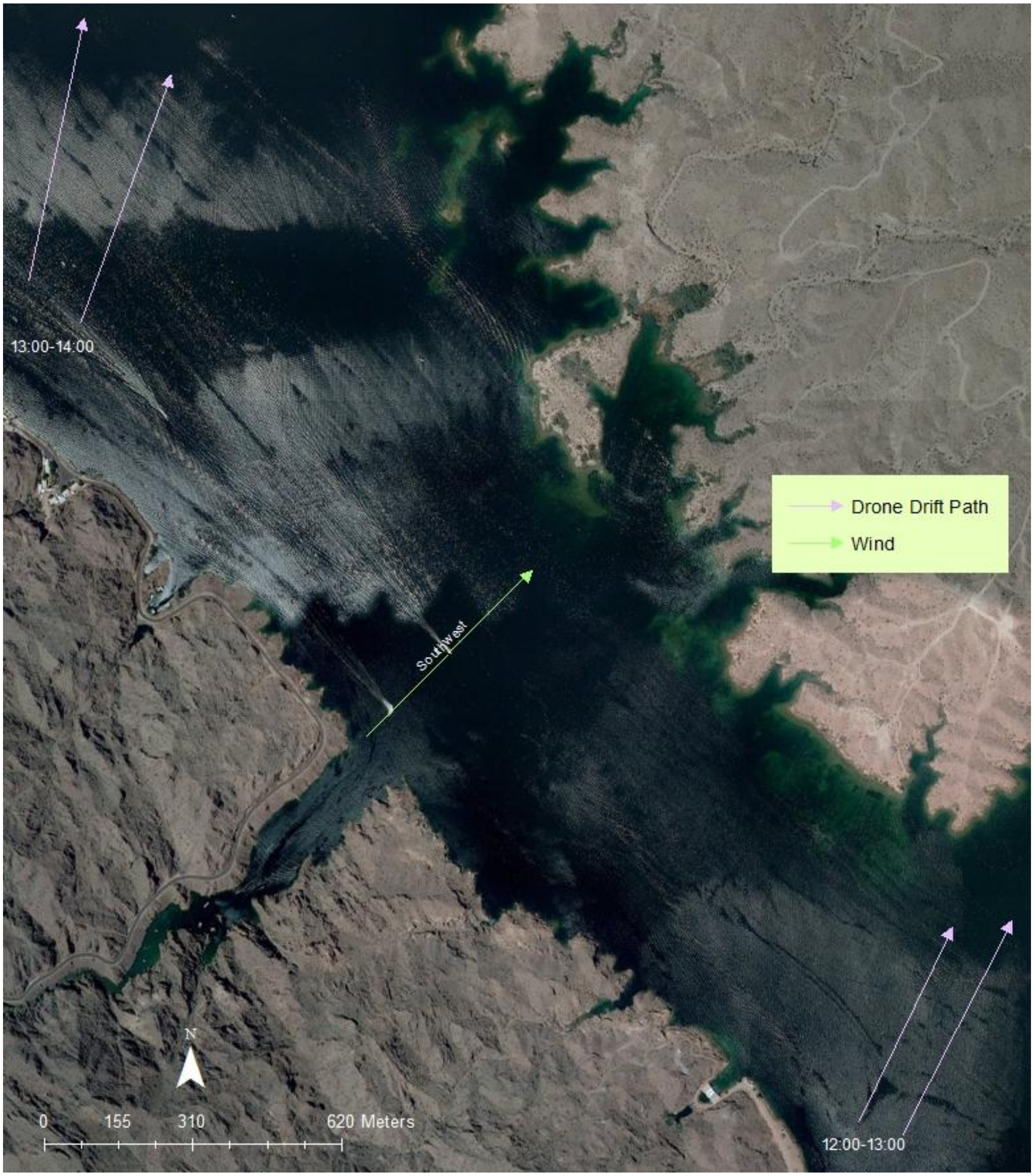

Figure 44. Afternoon drone drift paths and predominant wind direction observed near the Colorado River Aqueduct intake pump on October 9, 2012. The length of the arrow tail is the scaled distance the drones traveled.

Figure 45. Afternoon drone drift paths and predominant wind direction observed in Bill Williams NWR on October 9, 2012. The length of the arrow tail is the scaled distance the drones traveled.