Application and Utility of a Low-cost Unmanned Aerial System to Manage and Conserve Aquatic Resources in Four Texas Rivers

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Abstract: Low-cost unmanned aerial systems (UAS) have recently gained increasing attention in natural resources management due to their versatility and demonstrated utility in collection of high-resolution, temporally-specific geospatial data. This study applied low-cost UAS to support the geospatial data needs of aquatic resources management projects in four Texas rivers. Specifically, a UAS was used to (1) map invasive salt cedar (multiple species in the genus *Tamarix*) that have degraded instream habitat conditions in the Pease River, (2) map instream meso-habitats and structural habitat features (e.g., boulders, woody debris) in the South Llano River as a baseline prior to watershed-scale habitat improvements, (3) map enduring pools in the Blanco River during drought conditions to guide smallmouth bass removal efforts, and (4) quantify river use by anglers in the Guadalupe River. These four case studies represent an initial step toward assessing the full range of UAS applications in aquatic resources management, including their ability to offer potential cost savings, time efficiencies, and higher quality data over traditional survey methods.

Key words: instream habitat, riparian habitat, mapping, fish conservation

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Traditional remote sensing platforms (i.e., satellite, manned aircraft) can be costly to support (Mumby et al. 1999) and are often unable to provide geospatial imagery at a sufficient resolution to be of practical use in supporting local, project-specific fish and wildlife management needs (Lee and Lunetta 1995, Adam et al. 2010, Klemas 2011). The capability of traditional remote sensing platforms to monitor and accurately assess changes in fish and wildlife habitat conditions or populations is often limited due to the frequency at which these platforms can be deployed (Finlayson and Mitchell 1999, Chabot and Bird 2013). For instance, to effectively manage and conserve fish populations in regulated rivers, resource managers require access to high-quality geospatial imagery that delineate and quantify meso-habitats (e.g., pools, riffles, runs) and structural habitat features (e.g., shoals, large woody debris, boulder complexes) during multiple flows. Remotely-sensed imagery currently available to the Texas Parks and Wildlife Department (TPWD) for most areas of Texas is not of sufficient resolution to delineate instream habitats, nor is the imagery collected at the frequency needed to assess habitat under different flows (K. Ludeke, TPWD Geographic Information Systems Lab, personal communication). Furthermore, current approaches for collection of data and information needed to make flow recommendations in regulated rivers involve time-series field data collections that are time consuming and expensive (Texas Water Development Board 2008).

As a potential alternative or supplement to traditional geospatial data collection methods, low-cost unmanned aerial systems (UAS) have recently become available that have the ability to collect high-resolution, multispectral, georeferenced aerial imagery and other remotely sensed data on-demand (Chao et al. 2009, Jensen et al. 2009, Hoffer et al. 2014). In comparison to manned aerial surveys, low-cost UAS can often be operated with much reduced maintenance and operation costs and provide higher quality data with quicker overall turnaround times (Chao et al. 2009, Jensen et al 2009). Interest in the application of low-cost UAS for natural resources management has increased (Hardin and Jackson 2005, Dunford et al. 2009, Rango and Laliberte 2010, Breckenridge and Dakins 2011, Getzin et al. 2012, Koh and Wich 2012, Anderson and Gatson 2013). However, the range of potential applications is just beginning to be explored, especially those that directly relate to the data and information needs of fish and wildlife managers (Jensen et al. 2011, Zaman et al. 2011, Jensen et al. 2014).

Numerous UAS applications with the potential to fill science needs have been considered by TPWD, several of which could provide less costly alternatives to current assessment and monitoring techniques utilized by the agency. Furthermore, application of UAS by fish and wildlife management agencies have the potential to offer an alternative to manned aerial survey methods considered high-risk in terms of safety, such as low-elevation flights to conduct terrestrial wildlife population surveys. More than 3700 km of low-elevation, fixed-wing, manned aerial flights are flown annually by TPWD to monitor mule deer (*Odocoileus hemionus*) populations, and more than 8300 km of manned aerial surveys are flown annually to monitor waterfowl populations. As UAS technology advances, there remains the potential for these and other manned aerial surveys conducted by TPWD to be replaced by UAS, substantially reducing risk to human life.

As an initial step toward evaluating the utility and full range of UAS applications for fish and wildlife management, TPWD partnered with Texas State University to conduct eight UAS survey projects that addressed unique geospatial data needs for management of fish and wildlife resources in riverine, estuarine, and terrestrial systems. In some of the projects, comparisons with traditional on-the-ground data collection methods were made, although the primary objective was not to provide comparative quantitative data, but to provide an initial proof-of-concept for an emerging technology. The four UAS projects that were focused on riverine systems are highlighted as case studies in this paper. Each of these offered a unique set of goals and objectives specific to the management of aquatic resources, with the shared goal of assessing the ability of UAS to supplement or replace traditional ground-based survey methods.

Methods

We utilized a UAS developed by Utah State University known as the Flying Wing (Chao et al. 2009) to conduct the four UAS survey projects. The Flying Wing consisted of a basic, remote-controlled airplane that was upgraded to an autonomous data collection platform through addition of an autopilot, global positioning system, inertial measurement unit, onboard computer, and red-green-blue (RGB) and near infrared digital (NID) cameras. The Flying Wing weighed only 3.63 kg, had a wingspan of 1.82 m, and a predicted flight range of 40 km (<www.aggieair.usu.edu>, accessed 17 October 2014).

This UAS had the capability to fly pre-programmed flight paths and collect high-resolution, georeferenced aerial imagery at a relatively low cost for the resolution of the imagery collected. The cost to operate the Flying Wing (US\$121.19 km^{-2} of imagery collected), relative to spatial resolution, appeared to be a low-cost option for acquiring time-sensitive, high-resolution imagery. Published costs of comparable imagery available through manned aircraft ranged from \$175.00 km^{-2} to \$383.39 km^{-2} (Mumby et al. 1999, Klemas 2011, Birdsong 2014).

Methods for flight planning, deployment, and image processing followed those developed and employed by Utah State University in previous studies using the Flying Wing (Chao et al. 2009, Jensen et al. 2011, Jensen et al. 2014). For each of the UAS survey projects completed in association with this study, an imagery resolution was selected to meet the minimum data requirements for the intended use. Given flight altitude was inversely proportional to imagery resolution (Chao et al. 2009), a corresponding UAS flight altitude was determined that would provide the desired resolution. Aerial coverage flight lines were then overlaid in Google Earth Pro software to ensure that the full extent of each project area would be captured by onboard cameras. Coordinates for each node of the flight lines and geo-referenced base maps were exported from Google Earth Pro as keyhole markup language files and uploaded to Paparazzi flight planning software (Brisset et al. 2006) to create and simulate flight plans.

Upon arrival at each study location, pre-selected take-off and landing locations were changed as needed to avoid obstacles such as trees or other natural or manmade features. Previously developed flight plans were then reconfigured and final flight plans uploaded to the UAS onboard computer. A series of pre-flight checks were then completed to ensure proper functioning of the UAS and ground control equipment. Launch of the UAS was bungee cord assisted, giving the UAS the ability to quickly accelerate to standard flight speed and rise to the pre-determined above-ground elevation. During the flight, speed and position of the UAS were remotely monitored from the ground. Upon completion of the pre-determined flight path, a pilot took manual control of the UAS and safely guided it to the designated landing area.

Imagery collected during each flight was downloaded for further processing using National Aeronautic and Space Administration (NASA) World Wind software (<http://goworldwind.org/>, accessed 17 October 2014). This software was used to pair images with spatial data recorded by the onboard computer. Distorted images were deleted and the remaining images were organized into flight lines to ensure sufficient overlap existed among images for the mosaicking process. Processed NASA World Wind files were exported and used to develop high-resolution, georeferenced photomosaics in EnsoMOSAIC photogrammetric software (<http://www.mosaicmill.com/>, accessed 17 October 2014). This software was used to overlay UAS imagery onto reference imagery available through the Texas Natural Resources Information System (<http://www.tnris.org/get-data>, accessed 17 October 2014) or Google Earth. Landscape features shared by both sources of imagery were identified and images linked and converged to those features so a final orthorectified image mosaic could be produced. Where possible, lower resolution images were omitted from the mosaicking process, especially when adjacent, higher resolution images were available that could be linked and converged, without resulting in a data gap in the final mosaic.

Case Studies

Pease River, Texas

The Pease River flows approximately 160 km through the Southwestern Tablelands and Central Great Plains ecoregions of northwest Texas before reaching its confluence with the Red River near Vernon, Texas. The river is within the native range of Red River pupfish (*Cyprinodon rubrofluviatilis*), prairie chub (*Macrhybopsis australis*), and Red River shiner (*Notropis bairdi*), native fishes identified as Species of Greatest Conservation Need (Texas Conservation Action Plan (TCAP; TPWD 2012). Stands of invasive salt cedar (multiple species in the genus *Tamarix*) have become established within the riparian corridor (Nagler et al. 2001). Salt cedar alters stream morphology and instream habitat conditions (Nagler et al. 2001), and salt cedar control and native riparian plant restoration have been identified in the TCAP as priority conservation actions for rivers within the ecoregion (TPWD 2012). The Matador Wildlife Management Area, located near Paducah, Texas, contains multiple tributaries of the Pease River infested with salt cedar, providing the opportunity to evaluate the utility of UAS in delineating stands for the purpose of guiding ground-based management actions to restore and conserve habitat for native fishes.

Surveys were flown at an above-ground elevation of 450–650 m to collect a desired resolution imagery of 14–21 cm. Images were post-processed to produce a georeferenced photomosaic. Ground-based surveys were conducted at 171 control points in conjunction with the UAS surveys. Ground-based surveys collected spatial attribute data (x,y), surface feature type (bare ground or vegetation), plant species, tree height, and diameter at chest height with the use of Trimble GPS units. Georeferenced imagery collected by the UAS and ground-based survey data were imported into ERDAS Imagine software (<www.hexagongeospatial.com>, accessed 17 October 2014), which was used to classify stands of salt cedar, cross-reference, and calculate accuracy of the UAS imagery (and associated image processing techniques) in detection of stands of salt cedar.

The UAS collected 1448 images at a resolution of 12–18 cm of the Middle Pease River, Salt Creek, and the Tongue River (tributaries of the Pease River) within the Matador Wildlife Management Area. The mosaicking process resulted in georeferenced photomosaics with a resolution of 20–21 cm. Classified imagery delineated stands of salt cedar at 80% agreement with ground-based survey results.

Llano River, Texas

The Llano River is a clear, spring-fed tributary of the Colorado River located in the Edwards Plateau Ecoregion of central Texas. The river supports self-sustaining populations of Guadalupe bass (*Micropterus treculii)*, the official state fish of Texas and a Species of Greatest Conservation Need (TCAP 2012). In order to support the long-term persistence of Guadalupe bass and other native fishes, TPWD partnered with numerous state and federal agencies, non-governmental organizations, local municipalities, and private landowners to implement landscape-scale conservation of the Llano River watershed (Birdsong et al. 2015, Garrett et al. 2015). TPWD also partnered with the U.S. Geological Survey Texas Cooperative Fish and Wildlife Research Unit and Texas State University to establish a long-term monitoring program intended to assess cumulative changes in instream habitat conditions that may result from this initiative. This monitoring program offered a unique opportunity to test the utility of the UAS to support a detailed baseline inventory of instream habitat conditions.

To assess baseline instream habitat conditions in the South Llano River, approximately 47 km of the South Llano River and tributaries were photographed at an above-ground elevation of 400–600 m to obtain a desired resolution imagery of 11–16 cm. Images were post-processed to produce a georeferenced photomosaic. Additionally, instream habitat features (e.g., woody debris, boulders) and micro-habitats (e.g., bedrock, cobble, gravel, sand) of the South Llano River were mapped with a low-cost side-scan sonar unit following methods and micro-habitat classes described by Kaeser and Litts (2010). Meso-habitats (i.e., pools, runs, riffles) were delineated using a combination of the UAS and raw sonar imagery, recognizing that these designations were potentially subject to the influence of stream discharge. Pools and runs were classified by the changes in depth recorded in association with sonar images. Because the transducer was raised out of the water to prevent damaging the unit when approaching shallow riffles, the majority of this meso-habitat type was not captured with sonar imagery. The riffle locations and associated habitat features (e.g., boulders, large woody debris) were recorded with a handheld GPS unit and then cross-referenced in ArcMap 10 using the UAS georeferenced photomosaics.

Ground-based verification of micro- and meso-habitats was conducted either visually (in shallow areas), or with an underwater camera (in deeper areas) at approximately every 130 m longitudinally along the full extent of the study area. In addition, a subset (25%) of the habitat features, such as boulders and large woody debris, were selected for ground-based verification. Each feature was located, marked with a waypoint, and its location verified.

A total of 2145 images were collected of the South Llano River at a resolution of 11–16 cm. Imagery resulted in georeferenced photomosaics with a resolution of 12–25 cm. The UAS imagery supplemented micro-habitat data collected with side-scan sonar to provide a detailed assessment of baseline habitat conditions in the river. The UAS proved particularly useful in delineating riffles (and associated boulders and woody debris) too shallow to be effectively surveyed with side-scan sonar. These riffles encompassed approximately 17% of the available habitat in the South Llano River by area. The UAS imagery was also important for delineating the extent of beds of both submerged and emergent aquatic vegetation, as these beds tended to create acoustic shadows that prevented the entire width of the channel from being imaged with sonar. Microhabitats mapped with the use of side-scan sonar imagery were accurately delineated at 315 of 349 (90.3%) ground control sites and the incorporation of UAS imagery yielded an accuracy rate approaching 100%.

Guadalupe River, Texas

The Guadalupe River immediately below Canyon Reservoir is one of several river segments in the Edwards Plateau Ecoregion that offer high quality recreational opportunities for anglers, paddlers, tubers, and other water-based recreational enthusiasts (Bradle et al. 2006). This segment of the Guadalupe River receives particularly high use from tubers in the summer and anglers in the winter. Rivers of the Edwards Plateau Ecoregion host a number of species of concern including six species of mussels and 20 species of fish. The TCAP (TPWD 2012) identifies human disturbance from recreational uses as a priority issue affecting conservation of focal species in the region. Given its high level of recreational use, the Guadalupe River below Canyon Reservoir provided an ideal setting to evaluate the utility of the UAS as a tool to assess utilization of rivers in the Edwards Plateau Ecoregion.

In order to evaluate the utility of UAS to compliment historically used point-access creel surveys, approximately 13 km of the Guadalupe River tailrace below Canyon Reservoir was photographed at an above-ground elevation of 400–500 m to obtain a desired resolution imagery of 11–14 cm. Images were post-processed to produce a georeferenced photomosaic. Angling pressure on this section of the river has likely been underestimated in the past when point access surveys were used, as access sites are miles apart and anglers in more remote sections of the river are not counted. It was hoped the UAS could be used to include these anglers when estimating fishing pressure.

UAS surveys were timed to be flown in conjunction with on-the-ground counts of anglers at six access sites within the UAS survey area to provide comparative data. Numbers of bank, wade, and boat-based anglers, and numbers of non-anglers were recorded at six angler access sites every 15 min throughout the timeframe of the UAS survey. Imagery was visually inspected and compared to ground-based counts to determine if counts of anglers were in agreement.

A total of 1138 images at a resolution of 11–17 cm were collected of the Guadalupe River below Canyon Reservoir. A georeferenced photomosaic was produced with a resolution of 16 cm. Imagery collected by the UAS did not prove useful in accurately quantifying bank, wade, and boat-based anglers in the Guadalupe River. While some anglers were visible in the UAS imagery, angler counts conducted with UAS imagery were not consistent with ground-based counts. Factors which limited utility included camera views blocked by tree canopy and the inability to differentiate wade anglers from similarly sized boulders or other features in the river.

Blanco River, Texas

The Blanco River is a clear, spring-fed river in central Texas within the native range of Guadalupe Bass. Guadalupe bass were extirpated from the Blanco River following the introduction of non-native smallmouth bass (*Micropterus dolomieu*) and concomitant hybridization (Littrell et al. 2007). In 2011, exceptional drought conditions (U.S. Drought Monitor) in central Texas reduced the Blanco River to a series of enduring pools, affording an opportunity for removal of smallmouth bass and their hybrids. Smallmouth bass removal efforts were focused within a 10-km, fragmented segment of the Blanco River. All of the lands along this segment of the river were in private ownership. The need existed for on-demand high-resolution imagery that identified isolated enduring pools in the river to guide ground-based removal efforts.

To target enduring pools for removal of Smallmouth Bass and hybrids, a 10-km segment of the river located downstream of Blanco State Park was photographed at an above ground elevation of 600 m to collect the desired image resolution of 17 cm. Images were post-processed to produce a georeferenced photomosaic. The photomosaic was visually inspected and enduring pools were digitized in Google Earth Pro.

A total of 566 images were collected of the Blanco River with a resolution of 17 cm, resulting in a georeferenced photomosaic with a resolution of 20 cm. The UAS was highly effective at detecting enduring pools, and 43 enduring pools were visually identified from the photomosaic and digitized in Google Earth Pro. The identification of these pools guided smallmouth bass removal efforts and made identifying access to the river from private lands much more efficient. While most of the pools were visible from the imagery, a few smaller pools (<10) were not identified because tree canopy and shadows hid them from view. These pools encountered while researchers walked the river bed, often contained fish.

Discussion

We found the UAS platform used in this study (i.e., Flying Wing) to be capable of operating in wind conditions up to 40 kph. As a result of its lightweight design, however, it displayed difficulty maintaining horizontal stability in high crosswind conditions (i.e., >24 kph) and struggled to maintain altitude when encountering downdrafts, especially when flying near landscape features such as river bluffs. Consequently, images captured in high wind conditions were often distorted, dissimilar resolution, and difficult or impossible to post-process into a georeferenced photomosaic.

In addition to wind conditions, other environmental factors affected image quality and reduced post-processing capabilities and accuracy. For example, shadows from clouds or partial shading from flights conducted early in the day changed the spectral characteristics of imagery. Whereas partial shading did not increase mosaicking time, it drastically reduced vegetation classification output quality and increased vegetation classification processing time in ERDAS Imagine.

The anticipated relationship between above-ground elevation of the UAS flights and image resolution was as expected and resulted in the desired resolution imagery for each project. However, the final georeferenced photomosaics were lower quality than expected, limited not only by the resolution of the lowest-quality image included in each mosaic but also by other factors associated with the mosaicking process. For instance, the process involved in linking and converging images often shifted characteristics of adjacent images to smooth their transitions, altering the resolution of the images and reducing the overall resolution of the photomosaic.

While detailed side-by-side assessments of UAS technology versus traditionally used methods were not made in this study, it did provide valuable insight regarding the utility and limitations of relatively low-cost UAS for selected applications in aquatic resources management. The UAS proved particularly useful for providing imagery at adjustable resolutions for temporally-sensitive survey needs. Free online aerial imagery from entities such as Bing Maps and Google Earth continue to increase in resolution and overall quality. However, temporally-specific imagery remains unavailable through these sources, offering a unique niche that could be filled through low-cost UAS. The smallmouth bass removal project on the Blanco River is an excellent example of how on-demand imagery collected by UAS can be effectively used by aquatic resources managers. Without the use of this technology, it would have been much more logistically-difficult and time-consuming to locate isolated enduring pools.

Additional advantages of low-cost UAS are likely to be realized in the future as the technology advances. Increased flight range, improved camera quality, and improved stability in wind conditions over 40 kph are already being investigated by Utah State University with subsequent versions of the UAS technology used in this study (A. Jensen, Utah State University Water Research Laboratory, personal communication). Additionally, the Federal Aviation Administration recently designated six UAS test sites (<https://www.faa.gov/uas/legislative_programs/test_sites/>, accessed 17 October 2014), one of which is based at Texas A&M University at Corpus Christi. This test site became operational on 20 June 2014, and provides the opportunity for TPWD to collaborate with academic and industry UAS operators to ensure that the science needs of fish and wildlife managers are considered in future UAS research and development.

As UAS technology continues to advance, TPWD is hopeful that the technology will prove useful in meeting other geospatial data needs, including some of the more than 45,000 km of aerial surveys conducted annually in Texas to monitor and assess fish and wildlife populations and their habitats.

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