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Paul D. Thompson
Utah Department of Natural Resources

Emanuel A. Vasquez
Wild Utah Project

Ian Gowing
Utah State University, ian.gowing@usu.edu

Tim Edgar
University of Utah

Ann Neville
The Nature Conservancy

Allison Jones
Wild Utah Project, allieleejones@gmail.com

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Unmanned Aerial Vehicle technology proves an effective and efficient technique to identify critical native fish habitat

Authors:

Paul D. Thompson[1,] ,Emanuel A. Vasquez[2], Ian Gowing[3], Tim Edgar[4], Ann Neville[5,] Allison Jones[2]

1. Utah Department of Natural Resources. 1594 W North Temple. Salt Lake City, UT 84114
2. Wild Utah Project. 824 S. 400 W., Suite B-119. Salt Lake City, UT 84101
3. Utah Water Research Lab, Utah State University. 1600 Canyon Rd. Logan, UT 84321
4. Department of Geography, University of Utah. 260 Central Campus Dr. #4625. Salt Lake City, UT 84112

5. The Nature Conservancy – Utah Office. 559 E S Temple. Salt Lake City, UT 84102

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<Abstract>

Stream drying, especially in the western U.S., is becoming more common as climate warms and precipitation patterns become less predictable; consequently, fisheries managers need to prioritize conservation efforts where water (and fish) will persist in the future. Yellow Creek in the Upper Bear River watershed (Utah and Wyoming) contains one of the largest remaining populations of Northern Leatherside Chub (NLC) *Lepidomeda copei*, an imperiled fish. Lower reaches are drying during summer months, partly due to water withdrawals, thus reducing NLC populations and relegating remaining fish to isolated pools until water returns. This study utilized an Unmanned Aerial Vehicle (UAV) to capture high resolution and spatially explicit imagery over 19 km of Yellow Creek in a few weeks during late August when water is the most limiting to fish. Through imagery and subsequent GIS analysis, we identified 405 potential NLC refuge pool habitats, which were previously unknown, and determined their location, size, and spatial distribution thereby helping managers prioritize stream reaches for native fish conservation and restoration. While the cost of UAV flights was estimated to be 2.5 times higher than on-the-ground surveys in 2016, UAV technology continues to become more cost effective and unlike traditional surveys, provides high resolution and spatially referenced data.

<A> Introduction

Native fishes have declined steadily in distribution and abundance across western North American in the 20th century and these declines can be attributed in part to dams and diversions that prevent fish movement to different and necessary environments required for persistence (Williams et al. 1989; Moyle and Leidy 1992; Martinez et al. 1994). Small irrigation diversions are numerous throughout many western drainages and these structures not only remove water from streams, but also fragment populations, strand fish, and prevent dispersal and recolonization into new habitats (Mueller and Marsh 2002; Compton et al. 2008; Pess et al. 2014). As the climate warms, precipitation patterns will become less dependable, contributing to even more frequent and drier summer conditions further fragmenting fish populations (Olusanya and van Zyll de Jong 2018).

The Northern Leatherside Chub (NLC) *Lepidomeda copei* is a small cyprinid that occurs in mid-elevation (between 1280 and 2740 m) streams throughout the Bear River and portions of the Snake River drainages in Utah, Idaho, Nevada, and Wyoming (Sigler and Sigler 1996). Monitoring efforts and surveys have identified that, range-wide, some populations are isolated (Schultz and Cavalli 2012) and declining relative to historical levels; however the "patchy" distribution of this species makes sampling and determining population trends difficult (NLCCT 2018). These streams often provide water for agriculture and thus are susceptible to habitat fragmentation and reduced late summer stream flows. NLC typically are found in stream reaches with abundant deep pools (Quist et al. 2004; Schultz and Cavalli 2012; Schultz et al. 2016) and complex streamflows, in particular those controlled by beaver dams (Dauwalter and Walrath 2017). These fish also are found in systems that contain a high degree of depth variability (Wesner and Belk 2011; Schultz and Cavalli 2012; Schultz et al. 2016). Fragmentation of NLC habitat can limit access to preferred or necessary habitats and can lead to reduction in population size and distribution (UDWR 2009), which in turn, can increase the probability of local population extirpation from environmental (e.g., flood, fire, and drought) or demographic perturbations (Allendorf and Leary 1988; Lande 1988; Nagel 1991). To better coordinate and identify critical conservation actions across jurisdictions, the Northern Leatherside Chub Conservation Team (NLCCT) was assembled and a Northern Leatherside

Chub Conservation Agreement and Strategy (NLCCA&S) was signed in 2009 by all interested partners (UDWR 2009).

Yellow Creek is a tributary to the upper Bear River and contains one of the largest remaining populations of NLC in terms of stream distance occupied and relatively large population densities (UDWR 2009). Because the NLCCT identified population reconnection as a conservation priority in Yellow Creek, a barrier assessment was completed and identified more than 20 man-made barriers to fish movement - primarily irrigation structures and road crossings (Trout Unlimited 2011). It was during these surveys that late summer streamflow also emerged as a critical threat to the NLC population as large dewatered stream reaches due to irrigation withdrawals and natural water loss were identified. Prioritizing any reconnection efforts and/or protection of properties and stream reaches by acquisition, easement, MOU, and/or Cooperative Agreements would be futile without a better understanding of where water (and likely fish) persist during these summer low stream flow periods.

Lower Yellow Creek is largely private and obtaining access permission in the past has been difficult due to perceived access conflicts with ranching operations, so this study investigated the use of an Unmanned Aerial Vehicle (UAV) to capture high resolution imagery in order to identify critical in-stream habitat for the NLC over a large spatial extent. The use of UAVs to capture high resolution imagery has become increasingly prevalent in many fisheries projects, especially for capturing river channel morphology (Casado et al. 2015; Tamminga et al. 2015; Rusnak et al. 2018), quantifying submerged fluvial topography for in-stream flow studies (Woodget et al. 2014), estimating river depth (Fonstad et al. 2005; Lane and Carbonneau 2007), and delineating habitats and cataloging occurrence of species (Flynn and Chapra 2014; Kopaska 2014; Harris et al. 2019). Limitations of UAV technology do exist and for our study included a restriction to the flight elevation (120 m above ground level) which reduced the image width on the ground, wind conditions during some of the flights, and extremely tight flight turns with limited space. The primary goal for this study was to collect aerial imagery with UAVs in the lower 19 km of Yellow Creek during late summer to identify remaining pool habitats to prioritize NLC conservation efforts. The objectives for the study were to 1) obtain high resolution, multispectral aerial imagery (3-6 cm spatial resolution) to determine where perennial water persists in the lower 19 km of Yellow Creek and 2) compare cost and time requirements between UAV technology versus traditional field data collection.

<B>Methods

Study Area.-- We studied two stream reaches that total 19 km along lower Yellow Creek, Bear River watershed, in southwestern Wyoming (Figure 1). Elevations in the Lower Reach range from 2,052 - 2,103 m and in the Upper Reach from 2,156 – 2,241 m (USGS 2013a). Stream gradient is low with moderate to high sinuosity. Land cover types in the study area consist chiefly of shrub-grassland (U.S. Geological Survey 2013b; U.S. Department of Interior 2014) with vegetation communities principally dominated by multiple species of Sagebrush *Artemisia spp*., scattered Pinyon Pine *Pinus edulis* and Juniper *Juniperus spp.* trees in the uplands, with very few Cottonwood *Populus angustifolia* and sparse Willow *Salix spp.* in the riparian zones. Three-quarters of our Yellow Creek study area is utilized primarily for livestock grazing, and land ownership within the study area is mostly private (3,111 hectares or 92.3%) with a portion owned by the State of Wyoming (260.6 hectares or 7.7%; Uinta County 2017).

UAV methods and analysis. -- The AggieAir^{TM} Service Center, Utah State University, flew an UAV platform over Yellow Creek, WY, to acquire high-resolution aerial imagery of NLC habitat during August 2016. Seventeen flights were conducted as close to solar noon as possible and when the sun angle was directly overhead in order to minimize the effect of surface water reflectance. The UAV had a 2.7 m wingspan, could carry a payload of approximately 2 kg, and was capable of launching and flying fully autonomously. Image acquisition occurred at 120 m above ground level. The sensor payload for flights consisted of two Lumenera scientific grade cameras by Lumenera Corporation, a division of Teledyne Technologies. These cameras captured time-synchronized, high-quality raw images at 12 MP at full resolution, with three bands in the red, green, and blue (RGB) visible wavelengths and a single near infrared (NIR) wavelength band. Each image included a distinct set of coordinates of the UAV location at the moment of image acquisition. This information was then used in a camera alignment process whereby the image processing software (Agisoft Photoscan Professional) was able to distinguish between sequential images, and features (tie points) that were common in both images. After these tie points had been identified, the software created a 3d representation of the surface over which the UAV had flown and produced a uniform map combining the red, green, and blue spectral bands together (the NIR band was not used in the production of this map).

Additional ground control points, which are coordinates of known locations on the surface of the Earth, were used to geo-reference the final mosaic. These ground control points were extracted from the National Agriculture Imagery Program ArcGIS World Imagery Server 2014 and 2015. Elevation values were extracted from a 10 m Digital Elevation Model (DEM). The data (X, Y, Z) was imported into Agisoft and ground control point targets were created and identified in all corresponding imagery to create a more accurate real world geo-referenced final mosaic.

NDWI methods and analysis -- For detection of remaining water or pool habitat, we calculated Normalized Difference Water Index (NDWI) from the final mosaic of UAV-acquired imagery. The NDWI equation introduced by McFeeters (1996) has applications in the delineation, assessment of relative depth, and turbidity in water bodies, and is presented as NDWI = (NIR - Green) / (NIR + Green). The NDWI is estimated at the pixel level and ranges from -1 to +1. Positive values correspond to water features and zero to negative values are associated with soil and vegetation landscape elements.

We produced raster datasets from the NDWI output which were then stretched (piecewise linear contrast stretch) to visually enhance the variation of the positive pixel values in the output rasters. We opted to run an unsupervised image classification in a recursive manner on the NDWI rasters using the SLICE tool in ArcGIS (ESRI 2017). SLICE involves a set of numerical operations that search for natural groupings (clusters) of pixels in the input raster and the resulting classification raster matches thematic classes such as vegetation, soils and agriculture (Jensen 2005). Often, unsupervised image classification is used when the availability of training data is null or limited. After obtaining a sliced raster, we applied a reclassification by habitat types and extraction of the pool habitat. Figure 2 shows the workflow applied in the NDWI analysis process; a compiled model for ArcGIS is available from the authors.

To help prioritize native fish conservation efforts in Yellow Creek, we determined the spatial distribution of pool habitat relative to land ownership. Final pool location data was overlaid onto land parcel data (Uinta County 2017).

Cost and Time Comparison Between UAV and Traditional Habitat Surveys. -- We compared the cost for UAV aerial flights and post-flight imagery analysis to the anticipated cost for a field team collecting traditional (e.g., tape measurement estimates) habitat data required to map pool size and depth in the lower 19 km of Yellow Creek. Overhead, personnel benefits, and travel costs to the site were omitted from the analysis to better compare costs between techniques; costs were based on U.S. dollars in 2016. The UAV flights required a two-person crew (pilot and ground control station operator monitoring the UAV's flight performance) for the 17 flight plans that were completed. The flights and post processing image analyses were contracted for a set cost.

Traditional habitat data collection was estimated based on the authors' personal experience and the desire to obtain a high level of accuracy for the area and volume of each pool habitat. Width and depth are typically measured with 3-5 measurements (Platts et al. 1983), however, some researchers have utilized up to 20 evenly spaced measurements to obtain habitat area (Dauwalter et al. 2006). While the time required to map habitats will increase with habitat size, Dauwalter et al. (2006) reported that on average, 20 evenly spaced widths required 15 minutes/habitat to collect. Since we desired accuracy in actual habitat size, we completed this exercise based on 10 widths and depth/habitat and we felt this could be completed in 15 minutes/habitat. We allocated 16 hours to walk the channel (50.5 minutes/km) while looking for pools and 4 hours/person (8 hours total) for data entry. Average technician wages in Utah were estimated at \$15/hour. The total person hours needed for the project was calculated as follows: [(0.25 hours/habitat x number of pools mapped) + 16 hours walking time + 4 hours data entry] x 2 people. The total person hours was then multiplied by \$15/hour to obtain project cost. Finally, to get a cost per unit estimate for both techniques, the total project cost was divided by the number of pools mapped to get a cost per pool estimate.

<C> Results

UAV/NDWI Outcomes. -- Image analysis methods developed in this project allowed us to process a total of nine UAV-acquired imagery rasters decomposed into two input imagery bands (e.g., Green and NIR) and the computation of NDWI proved effective to detect various aquatic habitats relevant to NLC. We identified a total of 405 pools in a 19 km segment along Yellow

Creek, with pools ranging in size from < 1 m^2 to 150 m^2. Figure 3 shows pool density by land parcel. Mean pool size was estimated to be 13 m^2 and median size 5 m^2 (Figure 3).

Our NDWI calculations were performed on nine raster datasets; Figure 4(a) shows a close-up view of a portion of the resulting raster dataset. NDWI values on the positive side of the scale are directly related to water content or presence of water (McFeeters 1996). Figure 4(b) shows the stretching of positive pixel values of 0.70 to 0.95; the stretched raster indicated that areas with shallow waters tend to disappear from the raster and areas with deeper waters are revealed. Consequently, evaluating a signal of potential relative depth may be possible; deep portions of the stream could be associated with the highest pixel values and shallower areas with lower pixel values (Ozelkan 2019).

The unsupervised image classification (Figure 4c) of the NDWI rasters required a post-classification process in which each interval in the sliced output raster was matched to a thematic class. Therefore, we visually matched key output zones in the sliced raster to thematic features visually identified in the RGB UAV-imagery. Our visual assessment of these thematic features was centered on habitat components relevant to NLC (Table 1). Based on the values in Table 1, we reclassified the output slice raster (Figure 4d) using the RECLASSIFY tool in ArcGIS Desktop software (ESRI 2017).

TABLE 1. Image slice intervals and associated NDWI and thematic habitat class (as generally defined by Platts et al. 1983) values.

Output zone in sliced output	NDWI value range	Thematic habitat class
11	0.456 - 0.580	Very shallow water or bank
12	0.581 - 0.703	Shallow water or riffle
13	0.704 - 0.827	Channel or run
14	0.828 - 0.95	Pool

While the NDWI analyses did produce a potential signal indicating that the estimation of water depth may be possible, pool depth data was not verified with on-the-ground depth measurements.

In order to properly estimate actual depths, a correlation model between NDWI values and actual depth measurements would need to be developed and further evaluated.

Cost and Time Comparison Between UAV and Traditional Habitat Surveys. -- We identified 405 potential NLC refuge pools through 17 UAV flights throughout 19 km of Yellow Creek. Flights were completed over a two week period with 60 hours of UAV set up, pre-flight safety checks, and flight time, and 80 hours of image analyses for an estimated 140 person hours to complete the habitat surveys. The entire project (excluding overhead, personnel benefits, and travel costs) was contracted for $8,963, which equated to a cost of $22.13/habitat. The estimate of traditional habitat data collection was [(0.25 hours/habitat x 405 habitats) + 16 hours (walking) + 4 hours data entry] x 2 people or 242.5 person hours to measure and record pool area/depth and enter the data. At $15/technician hour, the estimated cost to complete traditional habitat surveys was $3,637.50 or $8.98/habitat.

<D> Discussion

This study demonstrated a unique and time effective application of UAV acquired imagery to assist with identifying critical Northern Leatherside Chub pool habitats during periods of low flow conditions in Yellow Creek and thus precluding the need for traditional on-the-ground surveys. The use of UAVs were able to capture high resolution and spatially explicit imagery over 19 km of stream in just a few weeks. Completion of traditional surveys for this study would have been difficult because the timeframe when late summer stream flow becomes critical typically occurs over a short (few week) period, consequently, traditional surveys would have taken too long. In addition, physical access was not possible for all stream reaches as some landowners did not want to grant physical access during late summer due to perceived conflicts with on-going ranching projects and operations. As climate warms and precipitation patterns become less predictable, dry conditions likely will become more common in Yellow Creek and similar mid-elevation western streams further highlighting the applicability of this technology (Olusanya and van Zyll de Jong 2018).

We analyzed UAV imagery and subsequent GIS analysis to identify 405 potential NLC refuge pool habitats, which were previously unknown, and determined their location, size, and spatial distribution along Yellow Creek. We did not ground-truth our image analysis results as UAV technology has been proven to accurately assess the size of habitat features similar to our study and we did not require exact measurements of habitat size because we only needed to understand where the relative amount of late summer water was spatially distributed per land parcel. Several studies that have used UAVs to collect imagery in aquatic and shoreline habitats have been ground truthed to verify that the imagery is relating accurate conditions found in the habitat being surveyed (e.g., McFeeters 2013; Casado et al. 2015; Broussard et al. 2018; Kalacska et al. 2018; Harris et al. 2019), thus serving as justification for the confident use of UAVs to map aquatic habitats. Broussard et al. (2018) used UAV imagery with spatial resolution of 2.6 cm to produce land-water maps of a coastal marsh. They compared results yielded by both UAV and satellite-based (spatial resolution of 31-46 cm panchromatic and 124-185 cm multispectral) imagery, in addition to establishing reference sites at 200 m on-the-ground sample stations. Broussard et al. (2018) obtained more detailed and accurate land-water interface maps based on UAV imagery with an estimated accuracy of 78% and 91% for land and water, respectively. The fine spatial resolution (3-6 cm in our study) is perhaps the greatest advantage of UAV technology (Harris et al. 2019) and helps overcome issues of mixed pixels that can lead to the non-detection of water or misclassification of pixels. Additionally, the low elevation at which UAV imagery is acquired reduces the effect of atmospheric contamination (e.g., cloud cover, scattered light, and water vapor) that can be detrimental to the quality of the imagery.

The NDWI is a well-established remote sensing based image analysis method used to detect and measure surface water extent in wetland environments (McFeeters 2013). When used as a method to delimit land-water boundaries and detect and characterize surface water, spatial resolution has a direct relationship with accuracy (McFeeters 2013; Broussard et al. 2018; Harris et al. 2019). By applying NDWI to the imagery and stretching positive pixel values, a potential signal for relative water depth emerged with deeper water being the highest pixel values, which if valid would allow the categorization of pools over other shallower water habitats (Table 1). We feel the NDWI measurements likely do provide an indication of relative water depth, but the accuracy of using NDWI to measure true water depth still needs to be field verified as stream substrate variability, water opacity, and other stream characteristics could affect NDWI values. A follow-up study to determine if NDWI can accurately measure water depth should be completed.

While traditional habitat surveys were estimated to be 2.5 times more cost effective than UAV flights in 2016, measuring (and analyzing) habitat through UAV flights was completed in 59% of the time that would have been required for on-the-ground surveys. The UAV technology utilized in this project was relatively new in 2016 and we estimate that flights and analyses for this same effort just a few years later would require considerably less time (Broussard et al 2018; Harris et al. 2019). For example, we estimate that in 2020, we could capture the UAV imagery in 11 flights (compared to 17 flights in 2016) and the time needed for post processing image analysis could be cut in half (40 vs 80 hours) and these savings would bring UAV flight/analysis costs essentially in line with traditional habitat surveys. The primary advantage of UAV technology are final products consisting of high spatial resolution data at spatial extents not possible through traditional surveys (Flynn and Chapra 2014; Dauwalter et al. 2017; Harris et al. 2019). In our study, UAV technology provided spatially explicit data that allow a spatial analysis of pool density by land parcel in lower Yellow Creek, which is critical knowledge for practitioners trying to reconnect functioning pool habitat through restoration efforts. These data are critical when prioritizing conservation decisions especially when compared to the final product from traditional surveys, which consist strictly of estimates on pool size with no spatial context. Additional products that could be derived from the UAV imagery include a dense point cloud, which could be used in floodplain analysis modelling as well as a digital elevation model (DEM) that provides a 3D representation of elevation data and illustrates terrain.

Unmanned Aerial Vehicles continue to grow in popularity for imagery acquisition. We believe the analysis of our UAV-imagery proved to be an effective and efficient technique that accomplished our first objective of determining NLC refuge pool size and density per land parcel. These data will help managers prioritize reconnection efforts and easement or land acquisitions in Yellow Creek. While pool location and size will change with flow level, the acquired data demonstrated that water (refuge pools) remain common to abundant in land parcels 1, 4, 5, 12, and 13 and these are the stream reaches that managers should prioritize habitat protection and restoration efforts for NLC (see Figure 3). For example, The Nature Conservancy is planning to negotiate conservation easements along these parts of Yellow Creek with the goal to keep water in the creek through the late summer, low-flow season.

Similar methods and analyses could be used by practitioners in other watersheds with comparable datasets to identify habitat conditions and prioritize restoration sites for other species of interest and our approach could be especially useful in situations where access is limited or terrain navigation is difficult. Unmanned Aerial Vehicles offer the spatial and temporal resolution for river feature identification that other remote sensing technologies (e.g., satellite and airborne) are not able to deliver (Casado et al. 2015) and they have the potential to supplement and replace traditional in situ and remotely collected data (Whitehead and Hugenholtz 2014; Broussard et al. 2018). Ultimately, our approach offered a simplified workflow to analyze UAV-acquired RGB and NIR imagery that delivered results in less time, reasonable costs, and with much higher spatial resolution than traditional on-the-ground habitat mapping. While we presented potential NDWI values to categorize relative water depth within pools, data from this technique should be verified through comparison with on-the-ground data collection, especially if accurate depth information is required for a project. The advantage of this UAV technology is highlighted when evaluating small habitat types and conditions for aquatic species such as Northern Leatherside Chub.

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