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MANAGEMENT BRIEF

Unmanned Aerial Vehicle Technology Proves an Effective and Efficient Technique for Identifying Critical Native Fish Habitat

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Abstract
Stream drying, especially in the western United States, is becoming more common as the 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 *Lepidomeda copei*, an imperiled fish. Lower reaches are drying during summer months, partly due to water withdrawals, thus reducing Northern Leatherside Chub populations and relegating the remaining fish to isolated pools until the water returns. This study used an unmanned aerial vehicle to capture high-resolution and spatially explicit imagery over 19 km of Yellow Creek in a few weeks during late August when the water is the most limiting to the fish. Through imagery and subsequent GIS analysis, we identified 405 previously unknown potential refuge-pool habitats for Northern Leatherside Chub and determined their location, size, and spatial distribution, thereby helping managers prioritize stream reaches for native fish conservation and restoration. While the cost of unmanned aerial vehicle flights was estimated to be 2.5 times that of on-the-ground surveys in 2016, unmanned aerial vehicle technology continues to become more cost effective and, unlike traditional surveys, provides high-resolution and spatially referenced data.

Native fishes have declined steadily in distribution and abundance across western North American during the 20th century, and these declines can be attributed in part to dams and diversions that prevent fish movement to the various environments that are required for their 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

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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 at midelevation (between 1,280 and 2,740 m) in 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, rangewide, some populations are isolated (Schultz and Cavalli 2012) and declining relative to their 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 streamflows in late summer. Northern Leatherside Chub are typically 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 that are 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). The fragmentation of NLC habitats can limit their access to preferred or necessary habitats and lead to reductions 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 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 the stream distance that is 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 that 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, memorandum of understanding, and/or cooperative agreements would be futile without a better understanding of where water (and likely fish) persists during these periods of low streamflow.

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 to identify critical in-stream habitat for 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 instream flow studies (Woodget et al. 2014), estimating river depth (Fonstad and Marcus 2005; Lane and Carbonneau 2007), and delineating habitats and cataloging occurrence of species (Flynn and Chapra 2014; Kopaska 2014; Harris et al. 2019). There are limitations to UAV technology, and for our study one of these was 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 for NLC conservation efforts. The objectives of 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 the cost and time requirements between UAV technology and traditional field data collection.

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 to 2,103 m and in the upper reach from 2,156 to 2,241 m (USGS 2013a). The stream gradient is low, with moderate to high sinuosity. The land cover types in the study area consist chiefly of shrub-grassland (USGS 2013b; DOI 2014) with vegetation communities that are 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 narrowleaf cottonwood *Populus angustifolia* and sparse willow *Salix* spp. in the riparian zones. Three-quarters of our Yellow Creek study area is used primarily for livestock grazing, and land ownership within the study area is mostly private (3,111 ha, or 92.3%), with a portion owned by the state of Wyoming (260.6 ha, or 7.7%; Uinta County 2017).

Unmanned aerial vehicle methods and analysis.— The AggieAir Service Center, Utah State University, flew a UAV platform over Yellow Creek, Wyoming, 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 megapixel 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 three-dimensional representation of the surface over which the UAV had flown and produced a uniform map, combining the RGB 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 georeference the final mosaic. These ground control points were extracted from the National Agriculture Imagery Program ArcGIS World Imagery Server 2014 and 2015. The elevation values were extracted from a 10-m digital elevation model. The data (X, Y, and Z) were imported into Agisoft, and ground-control-point targets were created and identified in all of the corresponding

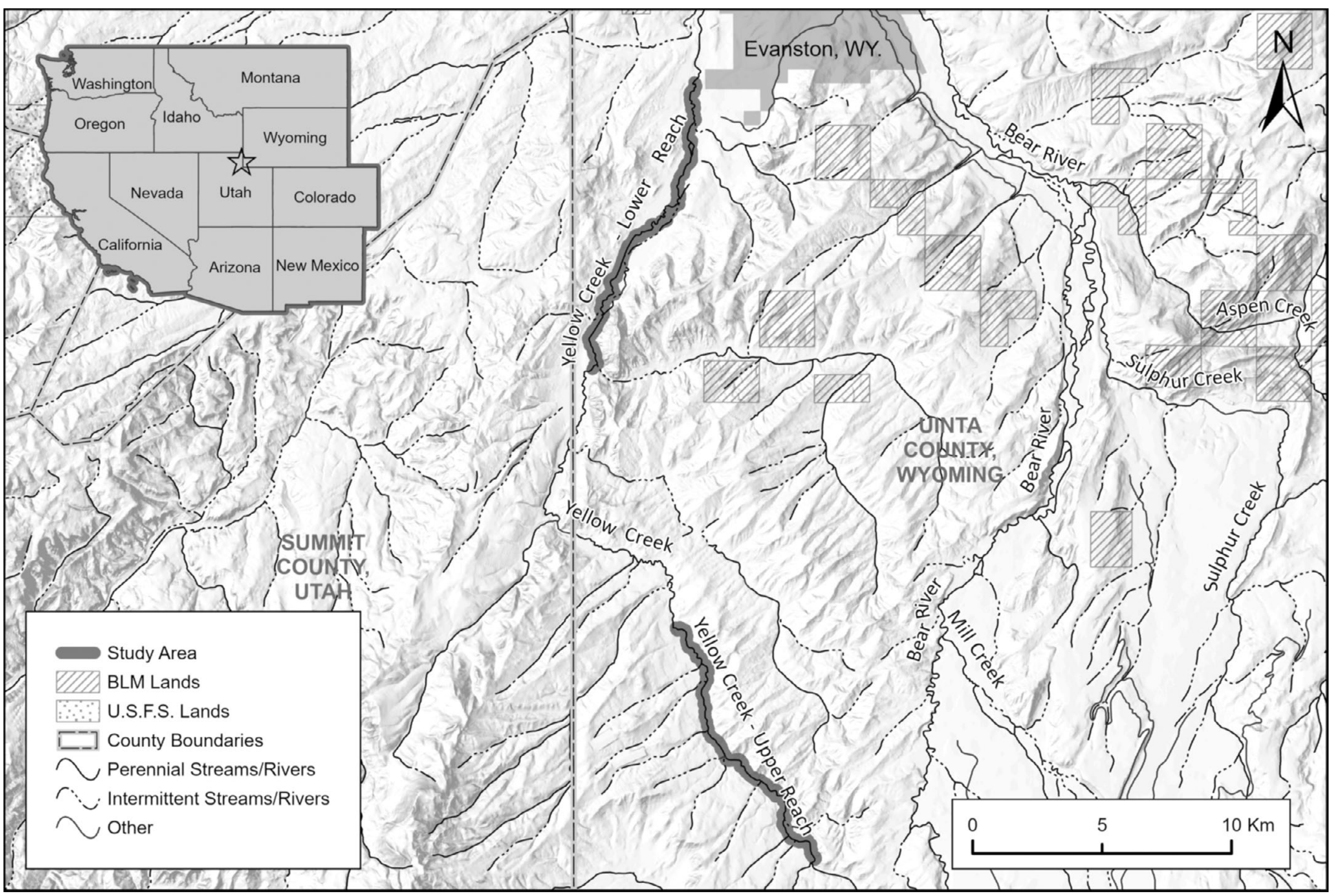

FIGURE 1. Map of the general location and extent of study area in the Bear River watershed. BLM = Bureau of Land Management; U.S.F.S. = U.S. Forest Service.

imagery to create a more accurate real-world georeferenced final mosaic.

Normalized difference water index methods and analysis.— For the detection of remaining water or pool habitats, we calculated the normalized difference water index (NDWI) from the final mosaic of UAV-acquired imagery. The NDWI equation that was introduced by McFeeters (1996) has applications in the delineation, assessment of relative depth, and turbidity in water bodies, and it 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 and negative values are associated with soil and vegetation landscape elements.

We produced raster data sets 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). The SLICE algorithm 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 that was 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. The final pool location data was overlaid onto the 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 postflight imagery analysis with the anticipated cost for having a field team collect the traditional (e.g., tape measurement estimates) habitat data that are 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 the techniques; costs were based on U.S. dollars in 2016. The UAV flights required a two-person crew (a pilot and a ground control station operator monitoring the UAV's flight performance) for the 17 flight plans that were completed. The flights and postprocessing 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

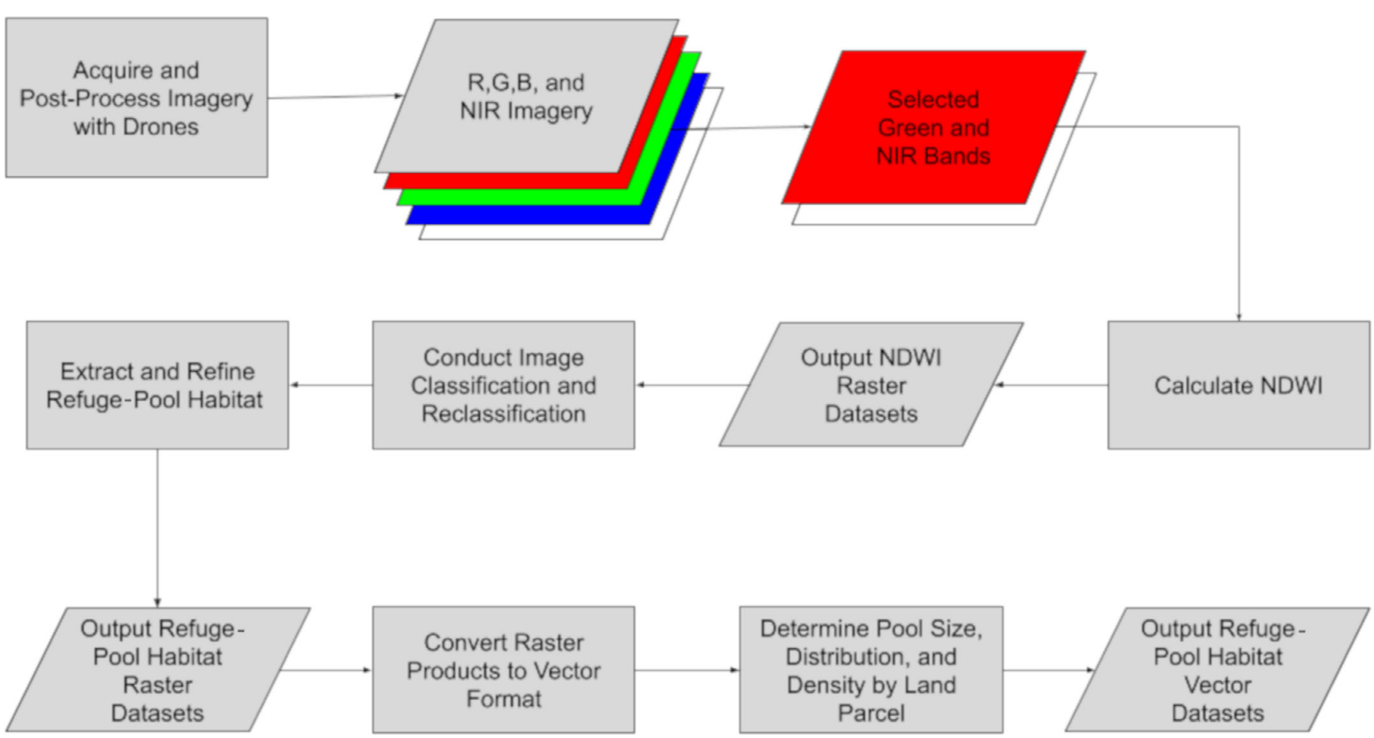

FIGURE 2. Implemented methods for detecting refuge-pool habitat for Northern Leatherside Chub.

measured with 3–5 measurements (Platts et al. 1983); however, some researchers have used up to 20 evenly spaced measurements to obtain habitat area (Dauwalter et al. 2006). While the time that is required to map habitats will increase with habitat size, Dauwalter et al. (2006) reported that, on average, 20 evenly spaced widths required 15 min/habitat to collect. Since we desired accuracy in actual habitat size, we completed this exercise based on 10 widths and depth/habitat and we believed that this could be completed in 15 min/habitat. We allocated 16 h to walk the channel (50.5 min/km) while looking for pools and 4 h/person (8 h total) for data entry. Average technician wages in Utah were estimated at US$15/h. The total for person hours that would be needed for the project was calculated as follows: [(0.25 h/habitat × number of pools mapped) + 16 h walking time + 4 h data entry] × 2 people. The total for person hours was then multiplied by $15/h 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 that were mapped.

RESULTS

UAV/NDWI Outcomes

The image analysis methods that we 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 to be effective for detecting various aquatic habitats that are 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. The mean pool size was estimated to be 13 m^2, with a median size of 5 m^2 (Figure 3).

Our NDWI calculations were performed on nine raster data sets; Figure 4A shows a close-up view of a portion of the resulting raster data set. The NDWI values on the positive side of the scale are directly related to water content or the presence of water (McFeeters 1996). Figure 4B 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 postclassification process in which each interval in the sliced output raster was matched to a thematic class. Therefore, we visually matched the key output zones in the sliced raster to the thematic features that were visually identified in the RGB UAV imagery. Our visual assessment of these thematic features was centered on habitat components that are 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).

While the NDWI analyses did produce a potential signal indicating that the estimation of water depth may be possible, the pool depth data was not verified with on-the-ground depth measurements. To properly estimate the actual depths, a correlation model between the NDWI values and the 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. The flights were completed over a 2-week period, with 60 h of UAV set-up, preflight safety checks, and flight time and 80 h 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 for traditional habitat data collection was [(0.25 h/habitat × 405 habitats) + 16 h (walking) + 4 h data entry] × 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.

DISCUSSION

This study demonstrated a unique and time-effective application of UAV-acquired imagery to assist with identifying critical pool habitats for NLC during periods of low-flow conditions in Yellow Creek, thus precluding the need for traditional on-the-ground surveys. The use of UAVs allowed us to capture high-resolution and spatially explicit imagery over 19 km of stream in just a few weeks. Completing traditional surveys for this study would have been difficult because the period during which the late-summer streamflow becomes critical is typically short (a few weeks); consequently, traditional surveys would have taken too long. In addition, physical access was not possible for all of the stream reaches because some landowners did not want to grant physical access during late summer due to perceived conflicts with ongoing ranching projects and operations. As the climate warms and precipitation patterns become less predictable, dry conditions are likely to become more common in Yellow Creek and western streams at similar elevations, further

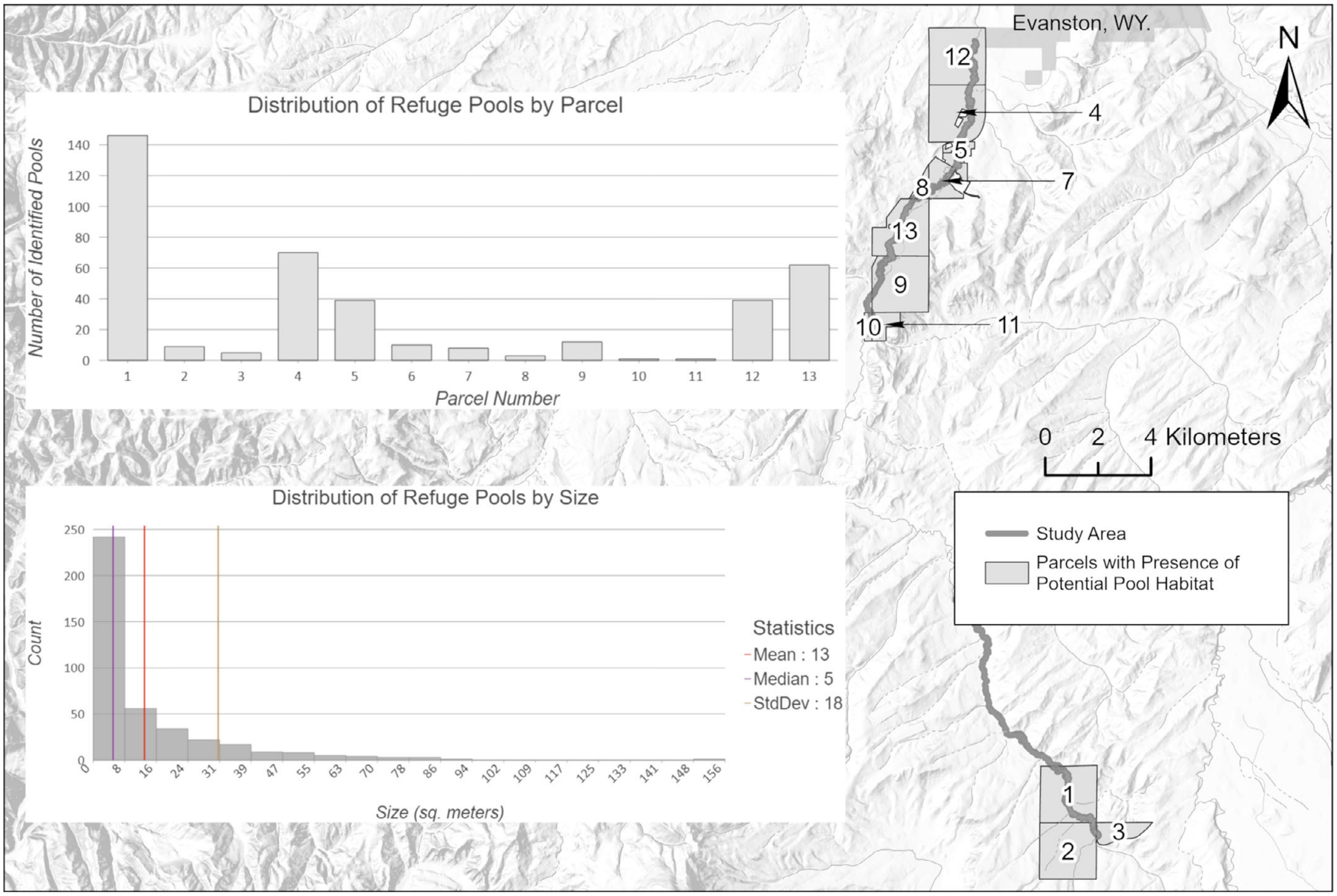

FIGURE 3. Map of the density and spatial distribution of pool habitats by parcel and land ownership. Std Dev = standard deviation.

highlighting the applicability of this technology (Olusanya and van Zyll de Jong 2018).

We analyzed UAV imagery and used a subsequent GIS analysis to identify 405 potential refuge-pool habitats for NLC, which were previously unknown, and determined their location, size, and spatial distribution along Yellow Creek. We did not ground-truth the results of our image analysis because UAV technology has been proven to assess the size of habitat features that are similar to those in our study accurately. Also, 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 accurately relating the conditions that are found in the habitat that is 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 the results from analyses of 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 nondetection 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), which can be detrimental to the quality of the imagery.

The NDWI is a well-established remote-sensing-based method for image analysis that is used to detect and measure surface water extent in wetland environments

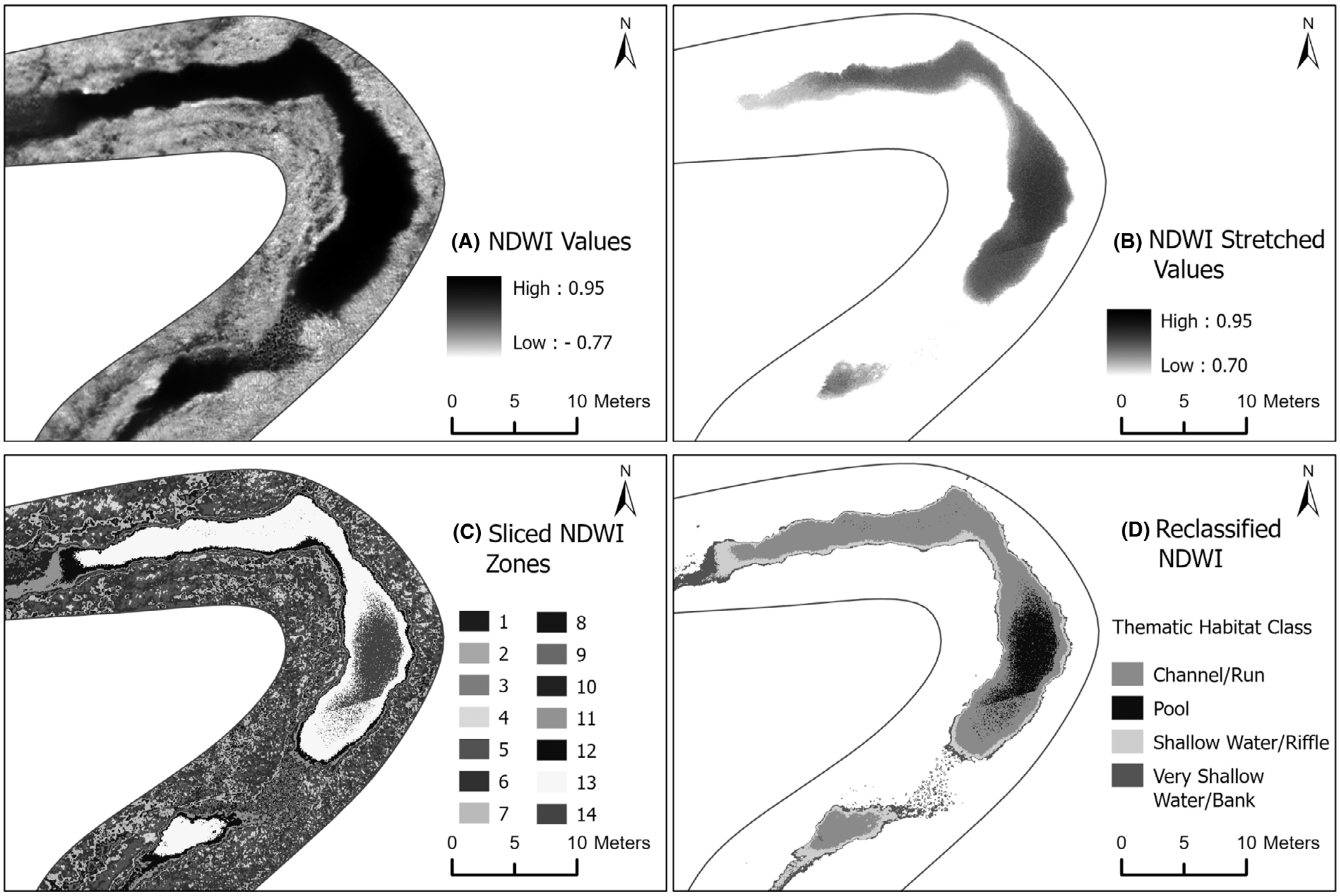

FIGURE 4. Estimated normalized difference water index values (NDWI), for (**A**) stretched raster, (**B**) revealing pool habitat within 0.70 and 0.95 NDWI values, (**C**) sliced NDWI raster, and (**D**) raster reclassified into theme classes.

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

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

(McFeeters 2013). When it is used 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 the 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 believe that 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 whether 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 that was used for this project was relatively new in 2016, and we estimate that flights and analyses for the 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 with 17 flights in 2016) and the time needed for postprocessing image analysis could be cut in half (40 vs. 80 h). These savings would bring UAV flight/analysis costs essentially in line with traditional habitat surveys. The primary advantage of UAV technology is that it offers final products that consist of high-spatial-resolution data at spatial extents that are 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 allowed a spatial analysis of pool density by land parcel in lower Yellow Creek, which is critical knowledge for practitioners that are trying to reconnect functioning pool habitat through restoration efforts. These data are critical for prioritizing conservation decisions, especially when compared with the final product from traditional surveys, which consists strictly of estimates on pool size, with no spatial context. Additional products that could be derived from UAV imagery include a dense point cloud, which could be used in floodplain analysis modeling, as well as a digital elevation model that provides a three-dimensional representation of elevation data and illustrates terrain.

Unmanned aerial vehicles continue to grow in popularity for imagery acquisition. We believe that the analysis of our UAV imagery proved to be an effective and efficient technique that accomplished our first objective of determining the size and density per land parcel of NLC refuge pools. 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) remains common to abundant in land parcels 1, 4, 5, 12, and 13, and these are the stream reaches that managers should prioritize for 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 of keeping water in the creek through the low-flow season during late summer.

Similar methods and analyses could be used by practitioners in other watersheds with comparable data sets 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 identifying river features that other remote sensing technologies (e.g., satellite and airborne) cannot 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 for analyzing UAV-acquired RGB and NIR imagery that delivered results in less time, with reasonable costs and with much higher spatial resolution than would be obtained with 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 NLC.

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