Comparison of Angler Pressure Counts by Manned and Unmanned Aircraft on an Arkansas Tailwater Fishery

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Abstract: The Arkansas Game and Fish Commission (AGFC) budgeted approximately $US250,000 for air operations in fiscal year 2017, 74% of which was for aerial observation by manned aircraft. Small unmanned aircraft (sUAS) have lower operating costs than manned aircraft, and thus significant cost savings could be experienced were sUAS to replace manned aircraft. However, it is first necessary to evaluate that data from sUAS are comparable to data from manned aircraft. Therefore, angler pressure counts were conducted simultaneously using both manned aircraft and sUAS within the four management zones of Beaver Dam Tailwater, Arkansas. Counts of boats, boat anglers, boat occupants, and non-boat anglers were compared between methods using a Wilcoxon paired signed rank test. More boat anglers were recorded using the manned aircraft than the sUAS ($v = 55$, $P < 0.01$); observers in the manned aircraft appeared to have recorded some non-fishing boat occupants as anglers. Counts of the other variables were similar between methods (v range 7 to 32, $P > 0.05$), but there was a noticeable trend for higher counts of all variables to be recorded with the sUAS method. Observers using sUAS may better be able to discriminate whether a boat occupant is actively fishing than observers using manned aircraft. Annualized costs of the manned aircraft observation program were estimated at US$30,684. Depending on labor assumptions, annualized costs of an unmanned aircraft observation program ranged $23,887–$49,212. Substituting an unmanned aircraft for manned aircraft when estimating angler effort may result in substantial savings in some, but not all, circumstances. However, because unmanned aircraft may allow for better discrimination between anglers and other boat occupants, using sUAS may lead to more accurate data.

Key words: sUAS, drone, survey, fisheries management, cost effectiveness

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The ability to carry a sensor or observer above a study area has made manned aircraft essential tools in natural resource management. However, manned aircraft, both helicopters and light, fixed-wing airplanes, have disadvantages. Manned aircraft are complex machines that are costly to operate and require highly trained personnel. For example, in fiscal year 2016–2017, the Fisheries and Wildlife divisions of the Arkansas Game and Fish Commission (AGFC) budgeted approximately US$250,000 for air operations. Most of these funds (74.2%) were for aerial observation of anglers or wildlife (unpublished AGFC division budget reports). The AGFC does not own manned aircraft and relies on third parties, such as contractors and other government agencies, to provide and operate the aircraft, but AGFC personnel frequently fly during these operations as observers or sensor operators. Relying on third parties can constrain or hinder development of rigorous, statistically valid surveys due to conflicts with other clients. Finally, aircraft crashes are the leading cause of job-related mortality among field biologists (Sasse 2003), and safety concerns about this method can lead to more logistical challenges.

Small unmanned aerial systems (sUAS) have the potential to reduce both risk and cost in natural resource management aviation operations. Although a sUAS crash may cause damage to objects on the ground, the crew is inherently safe because the vehicle is operated remotely. The current generation of consumer-oriented sUAS are inexpensive and easy to operate in comparison to manned aircraft. Flight training costs for new commercial pilots may exceed $100,000 (Government Accountability Office 2014); whereas, a new remote pilot may be trained and certified for less than $500. Current sUAS may be purchased for less than $2000, but a new manned aircraft can cost in excess of $100,000. As a result, natural resource management agencies have become interested in using sUAS to replace manned aircraft (Chabot and Bird 2015). Evaluating whether the data being generated by the sUAS are comparable to those obtained through conventional means is necessary prior to wide scale adoption of sUAS.

Use of sUAS in natural resource management has only recently been adopted, and agencies are still evaluating their uses. Counts of colonial birds, salmon redds, and grey seals (*Halichoerus gry-*

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pus) conducted with sUAS have been shown to be substantially similar to conventional counts (Ratcliffe et al. 2015, Groves et al. 2016, Hodgson et al. 2016, Johnston et al. 2017). Michez et al. (2016) found that sUAS-imagery based analysis underestimated crop damage from wild hogs, but suggested that sUAS-based techniques would be useful for surveying larger areas. Although Texas Parks and Wildlife (TPWD) found that sUAS were successful at conducting a number of natural resource management functions, they determined that sUAS were ineffective at counting anglers in small to medium sized rivers (Birdsong et al. 2014).

Manned aircraft have been used to count anglers since the 1940s (Schmidt 1975). In the field of fisheries management, counts of anglers are known as pressure counts, which are used to estimate overall angler effort. Fisheries managers use angler effort estimates for a variety of applications, including estimating angler total and targeted catch and determining stocking rates of fish. Instantaneous counts assume the entire study area can be viewed at the same time (Malvestuto 1983), which is rare in larger systems. More commonly, progressive counts are used, where the counter is moving through the entire study area at a fixed speed. Both instantaneous and progressive counts are used to calculate angler-hours in the same manner (Murphy and Willis 1996), and in practice, pressure counts that take less than one hour to complete are considered to be instantaneous (Lambou 1961, Malvestuto 1983, Soupir et al. 2006). Despite the TPWD experience (Birdsong et al. 2014), sUAS appear to have the capability to conduct angler counts in larger systems at a significantly lower cost. Therefore, the objective of this study was to evaluate the current potential for sUAS to replace manned aircraft for the task of instantaneous angler pressure counts in Arkansas trout fisheries, which generally occur downstream of mainstem dams.

Methods

Study Area

Beaver Dam was built in 1965 by the U.S. Army Corps of Engineers (USACE) at river kilometer (rkm) 980 of the White River, Arkansas, for the purposes of power generation and flood control (Williams et al. 2003, 2012). Beaver Tailwater consists of 10.6 km of river extending from the dam downstream towards Table Rock Lake. Hypolimnetic discharge from the dam made the area downstream unsuitable for warmwater species supporting recreational fisheries (Williams et al. 2003, 2012). To mitigate this loss, AGFC has stocked salmonids in the tailwater since 1966; currently it is stocked with brown trout (*Salmo trutta)* and rainbow trout (*Oncorhynchus mykiss).*

For management purposes, Beaver Tailwater is divided into four zones (Williams et al., 2003, 2012). Zone 1 is 0.7 rkm long, extending from 0.1 km downstream of the dam to 0.8 km downstream of the dam. Zone 2 extends approximately 1.7 rkm from 0.8 km downstream of the dam to 0.1 km (100 yards) upstream of the Parker Bend Access Area. Zone 3 extends 4.5 rkm, running from the downstream end of Zone 2 to the U.S. Highway 62 bridge. Zone 4 extends 3.6 rkm from the bridge to a downstream access ramp. Throughout the study area, almost no canopy extends from the shoreline over the river. Depth, flow, and turbidity vary based on the discharge schedule of the hydroelectric dam. Mean channel width generally increases moving downstream from the dam, ranging from approximately 60 m in Zone 1 to 90 m in Zone 4.

Manned Aerial Counts

Instantaneous pressure counts have been conducted on Beaver Tailwater since 1998 as part of ongoing management activities. These manned flights were conducted by a third-party contractor who provided an observer for half of the flights, and the remainder were conducted by an AGFC observer. Flights were conducted using a Cessna 172N, which flew over the tailwater at approximately 152 m above ground level (AGL). Observer training consisted of a briefing by the AGFC biologist, who instructed the observer in use of the observation form and how to determine whether occupants of a boat were anglers. The observer recorded the number of non-boat anglers, boats, and boat anglers in each zone on a tally sheet which was ultimately submitted to AGFC. The observer had the option of requesting that the pilot circle back over a section of river if additional counting time was needed.

Unmanned Aerial Counts

The sUAS used in this study was a Mavic Pro (Dá-Jiāng Innovations dba DJI, Shenzen, China), which has an integral 4k video camera. Flights using the Mavic Pro were conducted manually with the sUAS in "sport" mode, which allowed for higher speeds than other flight modes. Five days (three weekday and two weekend) were randomly selected by assigning each manned flight scheduled for September and October 2017 a random number using the rand() function in Excel. The flights were then sorted by the assigned random number and the first three weekday and first two weekend flights were selected for comparative unmanned flights. Takeoff of the sUAS was timed to coincide with the manned aircraft beginning its angler-count run. The sUAS crew moved in an upstream direction from the lowest access point, with the sUAS manually piloted both up and downstream from four takeoff points, each located within one of the four Beaver Tailwater management zones. Flights were conducted at 61 m AGL, and cameras were set to record 4k-resolution video at 24 frames sec^{-1}, which was captured on an onboard SD card during the entire flight. Because the Federal Aviation Administration requires that all sUAS flights be conducted within visual line of sight, the sUAS flight crew included a pilot and a visual observer who aided in keeping the sUAS in sight during flight. The sUAS crew was equipped with a handheld aviation transceiver to facilitate communications with the manned aircraft.

Video from the sUAS was transferred to an external hard drive upon completion of each day's flight activities and was watched simultaneously by two recorders on a computer with an integral 5.7k-resolution monitor. Both recorders used a tally sheet to count anglers and boats identical to that used by the manned aircraft observer. No specific training was provided to these recorders (first and second authors of the present study). During initial screening of videos, it was determined that it was necessary to record "boat occupants" separately from "boat anglers," which was not done for the manned aircraft flights.

Cost Estimates

The contract with the third-party aerial surveillance vendor was reviewed to determine the operating cost of the manned flights. The labor costs for manned aircraft flights included travel time for the observer and were determined based on the prevailing "extra-labor" rate, reflecting the use of part-time technicians as observers on flights when AGFC is required to provide the observer. The cost of the sUAS flights was divided into capital and operational costs. Capital costs were estimated as the average purchase price of a Mavic Pro, including its controller, based on quotes from three vendors. Operational costs consisted of labor costs and average replacement cost based on three quotes of parts expected to wear out over the course of an angler pressure-count study. These parts consisted of two sets of propellers and three batteries. Minimum labor cost was determined assuming the use of two "extra-labor" technicians as the pilot and observer, while the maximum labor cost was determined assuming the crew would be composed of two biologist-supervisors. Labor costs for the sUAS included time on site, travel time, and time to review video.

Travel times were estimated using Google Maps. For the manned aircraft observer, travel time was estimated as the driving time between the AGFC Mountain Home office (where the AGFC trout program is based) to the Springdale Municipal Airport (where the aircraft was based). For the unmanned aircraft, travel time was estimated as the driving time between the AGFC West Central Regional Office in Russellville, Arkansas (where the flight crew was based) to the first takeoff location.

Analysis

To estimate error between the two recorders viewing the sUAS video, a Wilcoxon paired signed rank test was used to determine whether estimated numbers of non-boat anglers, boats, boat occupants, and boat anglers differed between recorders. The experimental unit was the paired count for each zone on each date, providing a total of 24 comparisons. Average percent error (APE) was calculated for each count of bank anglers, boats, boat occupants, and boat anglers with the formula (Campana 2001):

$$APE_{obs} = 100\% \times \frac{1}{R} \sum_{i=1}^{R} \frac{|X_i - X_{obs}|}{X_{obs}}$$

Where R was the number of recorders, X_i was the count by the i^{th} recorder, and X_{obs} was the mean of counts by both recorders for the observation. Mean APE was then determined by averaging the APE of individual observations.

The mean of counts between recorders was calculated for each count variable for each day-zone combination. Mean counts from the sUAS were compared to the single count from manned aircraft using a Wilcoxon paired signed rank test, and 95% confidence intervals of the mean difference between paired counts by the manned aircraft and sUAS were calculated for each characteristic. Pearson's correlation was calculated for each characteristic to investigate the presence of a linear relationship between averaged sUAS counts and manned aircraft counts. All statistical calculations were performed in R (R Core Team 2018). The threshold of statistical significance (α) was set at 0.05.

Results

After arriving on site, it took an average of 9 ± 1.5 (SD) min for the manned aircraft to complete counts of all four zones each day. (Time for takeoff to landing was approximately 1 h for each flight, but takeoff and landing times were not recorded.) The sUAS required 51 ± 6.2 min to capture video of all four zones (including travel time between access points) each day. Travel time to the airport for the manned aircraft observer was 2 h 18 m each way. Travel time to the site for the sUAS flight crew was 2 h 37 m each way. It took 6 h to review video for all 5 d of flights.

Counts of boats, boat occupants, boat anglers, and non-boat anglers were similar between sUAS recorders for all date/zone combinations (ν range 0 to 15, $P > 0.05$). Counts of non-boat anglers and boats were exactly the same between recorders on all sample date/zone combinations (Mean APE 0.00%). Mean APE was 0.36% for boat anglers, 3.53% for boat occupants, and 2.69% for boat anglers and occupants combined.

Observers in the manned aircraft counted significantly more boat anglers than counted by the sUAS ($\nu = 55$, $P < 0.01$). Counts of bank anglers, number of boats, boat occupants, or the sum of boat anglers and occupants were similar between sUAS and manned aircraft (ν range 7 to 32, $P > 0.05$). All 95% confidence intervals for the mean difference between manned aircraft counts and sUAS counts overlapped zero except counts of boat anglers (Figure 1). However, the mean difference for between-reader counts of bank anglers, boats, and boat anglers, plus occupants, were all less than zero, suggesting a trend toward higher counts using the sUAS. Pearson's correlation suggested only weak or moderate correlation between counts from manned aircraft observers and the sUAS counts ($r = 0.335–0.731$, Figure 2). In most paired observations, the sUAS counted more boats and bank anglers than the observer in the manned aircraft, evidenced by more points above the unity line than below (Figure 2). Manned aircraft observers tallied more boat anglers than the sUAS, but the sUAS counts of boat anglers summed with boat occupants generally equaled or exceeded the boat angler count by manned aircraft observers (Figure 2).

Cost estimates were determined assuming one year of operation. Historically, there have been 10 flights per month every year. Aircraft rental price for the year is fixed by contract at $26,400. Because the contractor provides the observer on half the flights, labor costs for the manned aircraft only accrue on half the flights, and are assumed to be 1 hour of flight time plus 4.6 h of travel time. Analysis of the manned aircraft contract determined the manned flights at Beaver Tailwater cost $30,684 per year, 86% of which was for airplane rental from the third-party (Table 1). Based on three quotes, the average cost of the Mavic Pro was $972 ± 46 (Mean ± S.D.), ranging $919–$999. The average price of a Mavic Pro battery was $83.99 ± 4.59, ranging $80–$89. The average price

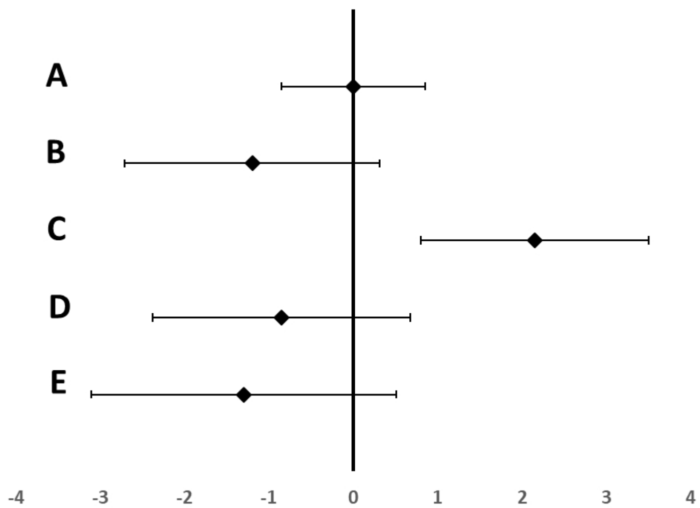

Figure 1. Mean difference in angler counts at the Beaver Tailwater, Arkansas, over five dates in September and October 2017 between manned and small unmanned aircraft (sUAS) with 95% confidence intervals. A—number of non-boat anglers, B—number of boats, C—number of boat anglers, D—number of boat occupants (sUAS) compared to boat anglers (manned aircraft), E—number of boat anglers + boat occupants (sUAS) compared to boat anglers (manned aircraft)

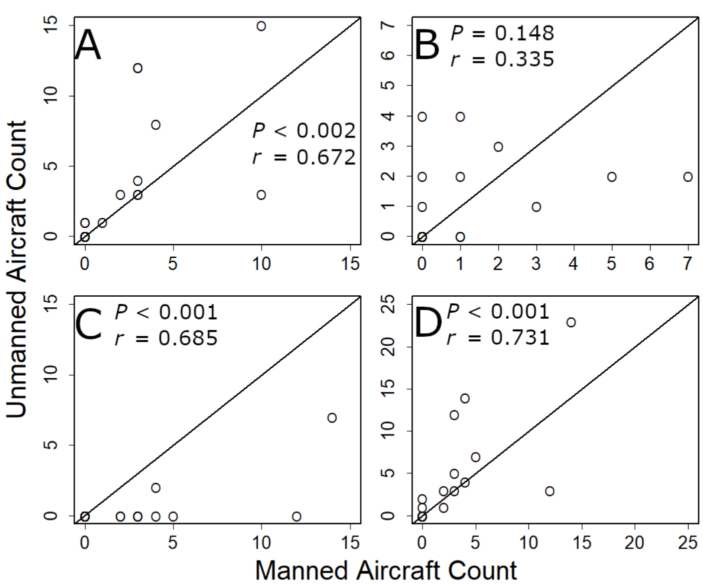

Figure 2. Scatter plots of angler counts by manned aircraft and small unmanned aircraft (sUAS) at the Beaver Tailwater, Arkansas, over five dates in September and October 2017. Solid line represents 1:1 relationship. A—count of boats, B—count of non-boat anglers, C—count of boat anglers, D—count of boat anglers and boat occupants (sUAS) vs boat anglers (manned aircraft). Pearson's correlation (*r*) and significance (*P*) indicated on panel.

Table 1. Estimated capital and ongoing costs for one year of manned and unmanned pressure counts at Beaver Tailwater, Arkansas. Total column rounded to nearest whole dollar.

Item	Unit price ($)	Qty	Total ($)
Manned aircraft			
Contract expense	26,400 y^{-1}	1 y	26,400
Labor (airborne)	12.75 h^{-1}	60 h	765
Labor (travel time)	12.75 h^{-1}	276 h	3,519
Total			30,684
Unmanned aircraft			
Capital			
Mavic Pro	972 $unit^{-1}$	1 unit	972
Consumable items			
Flight batteries	83.99 $unit^{-1}$	3 units	252
Propellers	9.33 set^{-1}	2 sets	19
Subtotal			271
Labor (onsite)			
Minimum	12.75 h^{-1}	240 h	3,060
Maximum	27.01 h^{-1}	240 h	6,482
Labor (travel)			
Minimum	12.75 h^{-1}	1,248 h	15,912
Maximum	27.01 h^{-1}	1,248 h	33,708
Labor (video review)			
Minimum	12.75 h^{-1}	288 h	3,672
Maximum	27.01 h^{-1}	288 h	7,779
Total			
Minimum			23,887
Maximum			49,212

of a set of propellers was \$9.33 ± 0.57, ranging \$9–\$10. Based on three quotes, the average yearly cost of these items was \$271. Based on recorded times, onsite time for the flight crew was estimated as 2 h per day of operation (1 h per flight crew member). Travel time was 10.4 h per day of operation (5.2 h per flight crew member). The time for video review was assumed to be 6 h per 5 d of operation for each reviewer, with two reviewers for a total of 288 h. Labor costs varied from \$22,644 to \$47,969 per year. By far, the largest component of the labor expense was travel time. The estimated cost of acquisition and operation of a sUAS angler count program varied from \$23,887 to \$49,212 (Table 1).

Discussion

Angler pressure count data obtained by sUAS in the Beaver Tailwater was similar to angler pressure count data from manned aircraft. This is in contrast to the findings of Birdsong et al. (2014); however, in that study the aircraft was operated at a higher altitude (400–500 m above ground level) than in the present study and used a lower resolution sensor. Additionally, there were significant differences between the study area of the TPWD study and the present study. Shoreline vegetation in the Canyon Tailrace of the Guadalupe River is characterized by Cypress trees which likely obscured bank anglers (Birdsong et al. 2014), in comparison to the shortleaf pine/oak forest in the Beaver Tailwater. Additionally, it was likely more difficult to distinguish anglers in still photographs as used in that study compared to video used in our study. Notably, the act of casting a line is very distinctive in video. Improvements in sUAS technology has greatly increased the ability of sUAS to conduct angler counts, at least in some circumstances.

Although the 95% confidence intervals for the mean difference between manned and unmanned aircraft counts overlapped zero, it appeared that counts using sUAS were generally higher than those with manned aircraft. Higher counts could be explained by the sUAS observing boats and anglers which were obscured from the manned aircraft by riparian vegetation, consistent with difficulties experienced by the TPWD at higher altitudes (Birdsong et al. 2014) An alternate explanation could be boats or people entering the study area in the time after the manned aircraft had completed its survey but the sUAS was still operating. The low between-recorder APE (<4% for all characteristics) for the counts conducted by sUAS suggested relatively high precision from the sUAS. Between-recorder APE has been reported as 7.4% in counts of fish species presence in underwater video, which is likely a more difficult task (Patterson et al. 2008).

Observers on the manned aircraft were instructed to record occupants of boats as boat anglers only if they were actively engaged in fishing. However, the manned aircraft was flown at an altitude too high to reliably identify fishing equipment such as rods or reels, resulting in the observer classifying anglers based on boat type or formation of boat aggregations. In contrast, although there were disagreements between recorders when watching the video from the sUAS, fishing equipment was generally discernable. Manned aircraft observers consistently tallied more boat anglers than those viewing the sUAS video. However, the fact that counts of boat anglers on manned flights and the sum of boat anglers and boat occupants on unmanned flights were similar suggested that at least some observers on AGFC manned flights were recording all boat occupants as anglers. Having a video record of what was seen that can be reviewed after a flight has occurred is useful for QA/QC procedures, which were not possible with AGFC's manned aircraft data. Having the ability to review what was observed during a flight also allows computation of data quality metrics such as APE. If sUAS are not used for conducting pressure counts, a similar benefit may be obtained by equipping observers on manned airplanes with a high-resolution video camera. Although aircraft mounted cameras have been used in wildlife counts by manned aircraft (e.g., Johnston et al. 2017), such cameras have not been routinely employed by agencies conducting angler surveys (Smallwood et al. 2012, Smith et al. 2015).

Current U.S. regulations on sUAS flight do not generally permit flight beyond visual line of sight (Fernando et al. 2019). Although the ground control system used by our sUAS also requires line of sight to the remote aircraft, sUAS in general is capable of fully autonomous flight. Had the flights been conducted autonomously, no time would have been lost due to the crew moving between take-off points. This would have increased data accuracy, as boat and anglers would be less likely to move between zones unobserved. Beyond-visual-line-of-sight flights are expected to be approved by the Federal Aviation Administration at some point in the future, with pilot programs planned to commence in 2018 (FAA 2012). Additionally, although all sUAS flights in this study were conducted in less than an hour, had the study area been larger it may have been necessary to treat the counts as progressive roving counts rather than as instantaneous counts. Fixed wing, autonomous sUAS may be a superior solution for angler counts than the current generation of quadcopters.

The cost estimate to acquire and run a sUAS program suggests that such a program may be able to replace the existing AGFC manned aircraft program at 77.8% to 160.4% of the current expense. The lower estimate is comparable to the 20% cost savings projected by models using drones rather than ground vehicles to deliver vaccines (Haidari et al. 2016), and models of using infrared camera equipped drones rather than helicopters to detect wildfires (Christensen 2015). If flight crews happened to be based closer to the study site, travel costs, which are a major component of the labor expense, would be reduced. Additionally, as reviewers gain experience, it is likely that video review would take less time to complete. At the operating unit level, savings would be even higher as salary for full-time personnel is accounted for at higher organizational levels within AGFC. Additional savings may be obtained if the sUAS is able to be used on other projects, thus allowing capital costs to be spread among projects. In contrast, existing aerial fixed wing surveillance contracts allow for little flexibility to accommodate sites other than those specified by contract. The operating lifespan of consumer type sUAS aircraft and components is currently unknown, but a well-made sUAS may well last for several years of careful operation. By far, the largest component of the cost of the sUAS program is labor. Using lower ranking personnel minimizes cost; however, retaining such personnel after training them as pilots may become difficult depending on the demand for qualified drone pilots in other industries. For specific use cases, better discrimination between anglers and non-anglers may also justify the use of sUAS even if cost benefits are marginal.

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