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Comparison of Electrofishing and PIT Antennas for Detection of Hatchery-reared Roundtail Chub (*Gila robusta*) Stocked into a Desert Stream

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Abstract

Stocking of rare native fishes for conservation purposes is a common practice in the southwestern United States. Monitoring typically occurs after hatchery-reared fish are released to assess post-stocking movement and survival. We conducted a two-year study, in which tow-barge electrofishing and portable, flat-bed passive integrated transponder (PIT) antennas were used to monitor PIT-tagged, hatchery-reared roundtail chub (*Gila robusta*) following release into the upper Verde River in Arizona. Specifically, our study aimed to compare the performance of PIT antennas and electrofishing in detecting PIT tagged fish released in a small desert river and to examine the behavioral response of hatchery-reared roundtail chub after stocking. In both years, more fish were detected by antenna arrays (84%) than by electrofishing (30%). roundtail chub were significantly more likely to be detected by antennas than electrofishing each year; however, when antenna data were evaluated only during the few days in which electrofishing took place, there was no significant difference (Year 1, p=0.1784; Year 2, p=0.6295) in detection between gear types for the same time interval, suggesting that electrofishing and antennas are equally likely to detect fish during 48-72 hour time frames. Within 72 hours of release, antennas detected 100% of fish that moved upstream and 93.8% of fish that moved downstream from the stocking location. Overall, less than half (45.6% in Year 1; 41.1% in Year 2) of the stocked roundtail chub were detected using both methods in both years. Utilization of both active capture gear (electrofishing) and passive gear (antennae) had advantages over monitoring with a single method. PIT antennae can be especially useful for managers who lack the personnel or time to implement more intensive methods of capture but want to monitor post-stocking movement and survival of stocked fish.

Introduction

Stocking is a prevalent practice in fisheries management for conservation, enhancement, and maintenance of fish populations (Cowx 1994, Welcomme and Bartley 1998). Native fishes are commonly reared at hatcheries and stocked to restore or supplement rare populations throughout the southwestern United States (Johnson and Rinne 1982, Minckley and Deacon 1991, Minckley et al. 2003). Most native, endangered, hatchery-reared fish are stocked in large rivers, reservoirs, and lakes with established monitoring programs. Unique passive integrated transponder (PIT) tags are frequently implanted into hatchery-reared fish prior to stocking (Gibbons and Andrews 2004). Recapture of tagged animals over time yields valuable insights into movement, behavior, physiology, and survival (Parker et al. 1990).

A variety of active and passive sampling methods are available and used to recapture or detect fish tagged with PIT tags for monitoring efforts. Electrofishing is a technique that has been available for at least half a century and the most widely used method to actively recapture fish (Bohlin et al. 1989). Several electrofishing gear types exist (e.g., backpack, shore-based, boat electrofishing) with effectiveness of each governed by water body size, conductivity, and discharge (Temple and Pearsons 2007). Within the last 20 years, PIT antenna technology was developed as a passive method to detect PIT tagged fish. Biologists are using passive antennas more commonly since they are an effective way to non-invasively monitor fish populations (Nunnallee et al. 1998, Zydlewski et al. 2001, Sloat et al. 2011). A variety of antenna types exist, where antennas can be actively moved around by researchers (e.g., portable "PITpacks"; Hill et al. 2006), or set at fixed locations to detect tags autonomously (e.g., pass-through or pass-by antennas; Armstrong et al. 1996, Zydlewski et al. 2006).

Many gear evaluations have been conducted in freshwater systems for various active and passive gear types, and limitations of each have been determined (Hill and Willis 1994, Zydlewski et al. 2001, Aymes and Rives 2009, Sloat et al. 2011). However, continued evaluation of sampling gears is essential in fisheries studies because detection and catchability of fish is influenced by species characteristics, behavioral response, and gear type. Furthermore, aquatic systems vary in size, structure, and complex-

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ity which can affect gear performance (Temple and Pearsons 2007, Cooke et al. 2013). We evaluated the advantages and disadvantages of using tow-barge electrofishing and portable, flat-bed PIT antennas when conducting monitoring of fish post-stocking.

The goal of this study was to compare the detection efficiency of portable, flat-bed PIT antennas and barge electrofishing methods in detection of PIT tagged, hatchery-reared roundtail chub (*Gila robusta*, Baird & Girard 1853) after release into the upper Verde River, Arizona. PIT antennas, and towable, barge-mounted electrofishing were used to track fish after an annual stocking event in two consecutive years. In Year 2 of sampling, the study area was enclosed with fyke nets to document emigration of individuals from the study site within 72-h and to assess submersible antennae effectiveness at detecting recently released fish. The PIT antennas utilized in this study have not been previously used in small streams or rivers, and are typically used for long-term monitoring of stocked native fishes, such as razorback sucker (*Xyrauchen texanus*, Abbott 1860), in large rivers and reservoirs (Wisenall et al. 2015, Humphrey et al. 2016, Kesner et al. 2017). Specifically, our study aimed to compare the detection efficiency and ease of deployment for PIT antennas versus electrofishing and to examine post-stocking dispersal of hatchery-reared roundtail chub in a small desert stream.

STUDY SITE

The Verde River is a perennial river that flows 300 km from its headwaters near Paulden, AZ, to its confluence with the Salt River near Phoenix, AZ. Much of the perennial discharge is provided by a large network of springs near the headwaters. The first 60 km of river are relatively free-flowing, with no dams or diversions and minimal anthropogenic disturbances (Wirt 2004b). This study was conducted near the headwaters of the upper Verde River, where a series of pool-riffle-run complexes characterizes the study site. The river is typically narrow (3-6 m wide) and shallow (<0.91 m deep) in most areas. Mean base flow at the site is 0.54 m/s3, with periodic increases in flow that occurs in response to seasonal precipitation (Wirt 2004b). Mean turbidity of the upper Verde River is below 50 Nephelometric Turbidity Units (NTU; Medina 2012) and specific conductance of water ranges from 350-700 microSiemens per centimeter (µS/cm; Wirt 2004a).

METHODS

Fish Specimens and Stocking

In December 2015 (Year 1, 2015-2016), young-of-the-year roundtail chub were acquired from the Bubbling Ponds Native Fish Conservation Facility, an Arizona Game and Fish Department hatchery located in Cornville, AZ. Fish were held in two indoor circular tanks (1.83 m diameter, 1892.7 L) at the U.S. Forest Service Rocky Mountain Research Station in Flagstaff, AZ. PIT tags (BioMark, 12.5 mm 134.2 kHz FDX) were implanted into 341 roundtail chub which ranged from 60 - 210 mm total length (TL), with an average size of 153 mm TL. Fish were held for 15-d to assess tag retention and mortality.

In December 2016 (Year 2, 2016-2017), PIT tags were implanted into 2,199 young-of-the-year roundtail chub acquired from the Bubbling Ponds Native Fish Conservation Facility. Sample sizes differed between years because several variables (e.g., predation by otters) affected spawning and recruitment in 2015. PIT tagged roundtail chub ranged from 75-192 mm TL, with an average size of 110 mm TL. Fish were held in two outdoor circular tanks (1.83 m diameter, 1892.7 L) for approximately 72-h post-tagging to account for any immediate mortality.

Fyke Nets

To assess the amount of immediate emigration from the study site and assess antennae effectiveness at detecting recently released PIT tagged fish, two fyke nets (H. Christiansen Co., Duluth, MN, constructed of 6.35 mm mesh netting and 1.52 m long× 0.91 m wide frames with 15.24 m long × 0.91 m wide wings) were placed upstream and downstream of the stocking site prior to release of fish in 2016 (Year 2). This ensured that the study area was closed. One net was located 1.08 km downstream and one 0.72 km upstream from the stocking site. Nets were set up at natural channel constraints where the net spanned the entire wetted width of the river. Both nets were checked for debris every five to seven hours and remained in place for three days after fish were stocked. All roundtail chub captured were measured to the nearest mm total length and scanned with a BioMark HPR Plus PIT tag reader to determine unique PIT identification numbers. After processing, fish were released outside of the enclosed study area in the direction of assumed travel.

Stationary PIT Antennae

We used small rectangular (Marsh & Associates, LLC, Tempe, AZ, 0.9 m length x 0.7 m height) and large rectangular (Marsh & Associates, LLC, Tempe, AZ, 1.3 m length × 0.7 m height) portable, flat-bed PIT antennas that lie flat on the substrate of the riverbed (similar to pass-by antennas). Antenna frames were built of polyvinyl chloride (PVC) while the scanner, logger, and battery (10.4 ampere-hour lithium-ion battery) were self-contained in watertight

PVC/acrylonitrile butadiene styrene piping. During deployment, antennas were tethered to a stationary object with nylon rope to prevent movement.

Seven small PIT antennas were placed in the Verde River prior to stocking fish in Year 1. Antennas were installed upstream and downstream of the stocking site and programmed to continuously record the date and time of contact as well as PIT tag numbers. All antennas were installed as pairs in areas where the river has natural channel constraints (3.4 - 5.6 m wide) with water depth never exceeding 60 cm. Paired antennas were placed side by side across the river bottom directly on the river substrate approximately 30-60 cm from one another. To funnel fish over the antennas, rock dams were constructed from the shoreline, at the wetted width (i.e., riverbank in contact with the aqueous body) and extended into the water to meet the edges of the antennas. Each site where antennas were paired was considered a "gate" in which fish moving past the location would have to pass over the field of the two antennas. After fish were released, antennas were visited every five days to download recorded information and to change batteries. The initial visit to antennas post-stocking revealed that some paired antennas interfered with one another because of proximity. The interfering antennas (within a pair) were repositioned at different locations, while the other antennas from a pair remained in the original locations.

Pairs of antennas were tested before installation in the river in Year 2. We found that antennas worked best when isolated (>6 m from one another). Based on this finding, antennas were arranged into a serial array (one downstream from another) when deployed. Ten antennas (6-small and 4-large) were installed, with eight initially installed prior to stocking fish and two others added 24-h after stocking. Five antennas were placed up to 1.08 km downstream, and five were placed up to 0.72 km upstream from the stocking site, where fyke nets were also located. Methods for antenna installation and programming were repeated from Year 1.

Electrofishing

In Year 1 of the study, electrofishing surveys were conducted at 19, 26, and 83 days post-stocking. Surveys were conducted with pulsed DC using a generator-powered pulsator (Smith Root 5.0 GPP with two anodes) electrofisher mounted in a towable barge (Smith Root model SR-7). The study site was continuously sampled from the most downstream antenna and working upstream for 1.2 km, briefly ceasing to process fish as needed. We measured total length in mm of all captured roundtail chub and scanned them with a BioMark HPR Plus PIT tag reader to determine unique PIT identification numbers. Fish were released downstream of the processing site. In Year 2, electrofishing surveys were conducted at 2, 16, 25, 52, and 85 days post-stocking. Each electrofishing event was comprised of three consecutive days of sampling, which is the time required for crews to push the electrofishing barge upstream through the entire study area. Roundtail chub were collected and processed using the same equipment and methods as Year 1. The study site was continuously sampled for 1.8 km, from below the placement of the downstream fyke net to past the placement of the upstream fyke net. In both years all antennas were operating during electrofishing surveys.

Data Analyses

Because methods changed slightly between each year of sampling, comparisons of gear types were only made within a given year. A Pearson's chi-square test was performed to determine if fish were more likely to be detected by PIT antennas than electrofishing within a given year of the study. We also grouped data from each gear type into discrete sampling events (i.e., when electrofishing sampling events occurred) to further compare detection efficiency of both gear types during sampling events. A sampling event consisted of all antennae detections that occurred during the three consecutive days it took to electrofish the entire sampling area. Grouped data were analyzed using Pearson's chi-square test as well. Logistic regression was performed to determine if probability of detection differed temporally by gear type.

Data from Year 2 fyke net captures were used to determine how efficient antennas were in detecting recently released fish. A closed system was maintained for three days while fyke nets were in place, allowing us to document individuals emigrating from the study site and to calculate detection efficiency of upstream and downstream antennas. When calculating detection efficiency of antennas, it was assumed that 100% of fish captured in the fyke nets passed over PIT antennas when traveling either upstream or downstream. Detection efficiency was calculated by dividing the total number of detections of tagged fish for the antennas by the number of fish captured in each of the fyke nets, multiplied by 100. Individual antenna accuracy was also calculated by dividing the total number of detections of tagged fish for each antenna by the number of fish captured in either the downstream or upstream fyke net, multiplied by 100. We also considered stream channel width as a variable that may affect antenna performance. Because the channel width covered by small and large antennas varied in Year 2, it could have affected the number of tagged fish contacted. A linear regression was conducted with data from when fyke nets were in place to determine if there was a relationship between the percent of tagged roundtail chub contacted and the percent channel covered by an antenna. We divided antennae length by the total wetted width of the stream and multiplied by 100 to calculate percent channel coverage. Percent fish contacted was calculated by taking the total number of detections on an antenna divided by the known number of fish that passed the antennae (individuals that were captured in each of the fyke nets), multiplied by 100. Data generated during this study are available from the USGS Science-Base Catalog (Tennant 2020).

RESULTS

Prior to stocking roundtail chub in the upper Verde River, we assessed PIT tag retention and survival. In Year 1, four PIT tags were shed from roundtail chub, while four of 341 fish perished from tagging, resulting in 98.8% survival and tag retention. In Year 2, 16 of 2,199 roundtail chub perished within 72-h of tagging, constituting a survival rate of 99.3%. We did not evaluate tag retention in Year 2 and assume it was similar to Year 1 fish.

When referring to physical encounters of tagged fish during electrofishing surveys, the term “captured” is used, while “contacted” is used to exclusively describe observations of tagged fish by antennas. “Detected” is used interchangeably, typically referring to observations of tagged fish by both gear types. To further clarify, detection of a tagged fish by an antenna does not confirm the status of a fish being alive, whereas physical capture when electrofishing confirms that the fish is alive. Detection efficiency was defined in this study as the percentage of PIT tagged fish that were detected when fish passed an antenna or were captured by electrofishing.

Year 1 (2015-2016)

Three electrofishing surveys were conducted within the same 1.2 km reach (from the most downstream to most upstream antenna) of river after fish were released. Antennas were deployed the day before stocking fish and active for 1,656 hours (69 days). Of the 333 fish initially stocked, 152 fish (45.6%) were subsequently detected. Antenna arrays accounted for 84.2% (n=128) of all fish detected during the study period, while electrofishing accounted for 30.3% (n=46) of all fish detected (Table 1; Fig. 1). The percentage of fish detected sums to >100 because 22 individuals were detected using both gear types.

We determined there was a significant difference (Pearson's chi-square, χ^2=52.31, df=1, p<0.0001) in detection between antennas and electrofishing, being that fish were more likely to be detected by antennas than electrofishing throughout the study period. However, antennas were active for a much longer period than the three days it took to electrofish the entire sampling area. When antennae detections were grouped into comparable three day sampling events and gear types compared overall, there was no significant difference (Pearson's chi-square, χ^2=1.81, df=1, p=0.1784) in detection between gear types. Electrofishing and antenna data were selected from two discrete sampling events for analysis. Although three electrofishing sampling events occurred, we

Table 1. Number of hatchery-reared roundtail chub (*Gila robusta*) stocked in the upper Verde River, Arizona, in 2015 and 2016. Tow-barge electrofishing and portable, flat-bed PIT antenna arrays were employed to detect tagged fish after stocking. Number of unique ID detections for each gear type by sampling year are provided.

	Year 1 (2015-2016)	Year 2 (2016-2017)
Total fish stocked	333	2177
Total fish detected by antennas	128	750
Total fish detected by electrofishing	46	298
Total fish detected by both methods	22	155
Total fish detected	152	893
% of population detected	45.6%	41.1%

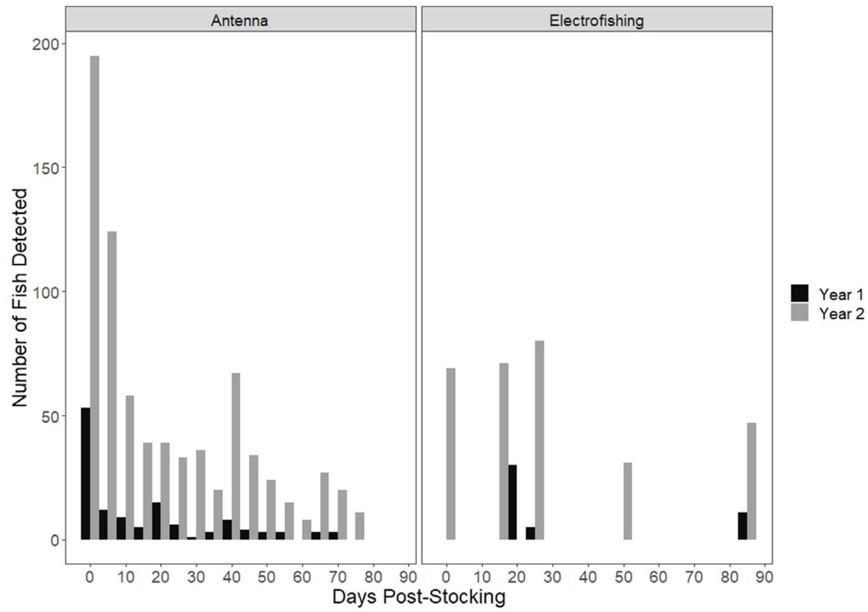

*Figure 1. Number of individual roundtail chub (*Gila robusta*), detected by passive integrated transponder (PIT) antenna arrays or electrofishing surveys for each year after stocking in the upper Verde River, Arizona. In Year 1 (2015-2016) of sampling, 152 of 333 fish initially stocked were detected. Antennas detected 128 fish, while 46 fish were captured through electrofishing surveys. In Year 2 (2016-2017) of sampling, 893 fish were detected of the 2,177 fish initially stocked. Antennas detected 750 fish, while 298 fish were captured through electrofishing surveys.*

excluded the third sampling event from the analysis when comparing gear types because all antennas had been removed prior to the last electrofishing event. The probability of detecting PIT tagged roundtail chub after stocking was low for any single sampling event ($p<0.15$) and decreased over time for both gear types (logistic regression, electrofishing, $p<0.0001$; antenna, $p=0.0150$; Fig. 2).

Year 2 (2016-2017)

Five electrofishing surveys were conducted after fish were released with the same 1.8 km reach of

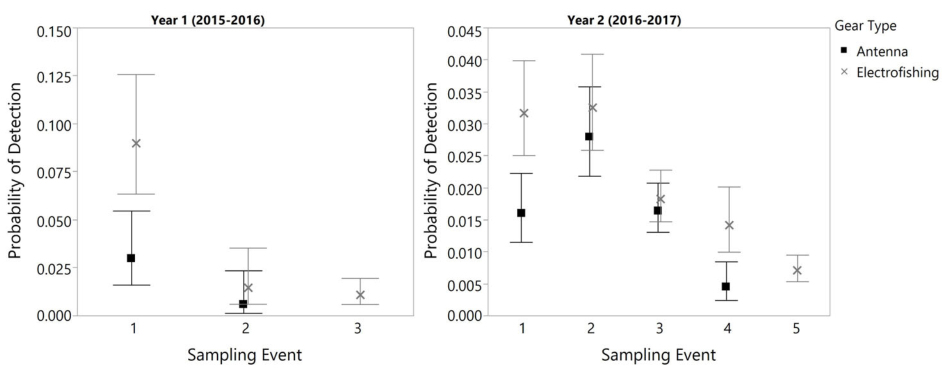

*Figure 2. Probability, with 95% confidence intervals, of detecting passive integrated transponder (PIT) tagged roundtail chub (*Gila robusta*) by tow-barge electrofishing or portable, flat-bed PIT antennas after two stocking events in the upper Verde River, Arizona. Because methods changed slightly between each sampling year, data were grouped into discrete sampling events and gear types compared by year. Sampling events correspond with days post-stocking (e.g., Year 1 sampling events 1, 2, and 3 correspond with electrofishing surveys at 19, 26, and 83 days post-stocking, and Year 2 sampling events 1, 2, 3, 4, and 5 correspond with electrofishing surveys at 2, 16, 25, 52, and 85 days post-stocking). Note, x and y axes scales differ between sampling years, and antenna data are not present for the last sampling event in each year because antennas were removed prior to the last electrofishing survey.*

river sampled during each survey. Antennas were deployed the day before stocking fish and active for 1,944 hours (81 days). Of the 2,177 fish initially stocked, 893 fish (41.1%) were detected. Antenna arrays accounted for 84.0% (n=750) of all fish detected during the study period, while electrofishing accounted for 33.4% (n=298) of all fish detected (Table 1; Fig. 1). The percentage of fish detected sums to greater than 100 because 155 individuals were detected by both gear types.

Results from Pearson's chi-square tests in Year 2 coincide with findings from Year 1. There was a significant difference (χ^2=256.75, df=1, p<0.0001) in detection between antennas and electrofishing throughout the study period, and when data were grouped into discrete sampling events and gear types compared overall, there was no significant difference (χ^2=0.23, df=1, p=0.6295) in detection between gear types. Electrofishing and antenna data were selected from four discrete sampling events for analysis. Although five electrofishing sampling events occurred, we excluded the fifth sampling event from the analysis when comparing gear types because all antennas had been removed prior to the last electrofishing event. We found that the probability of detecting roundtail chub after stocking was low for any single sampling event (logistic regression, p<0.05), yet probability increased from the first to second sampling event, but then generally decreased over time for both gear types (electrofishing, p<0.0001; antenna, p < 0.0001; Fig. 2).

Two objectives of this study in Year 2 were to document individuals immediately emigrating from the study site and to assess antennae effectiveness at detecting recently released PIT tagged fish. We used fyke nets placed upstream and downstream of the stocking site prior to release of roundtail chub, which provided the opportunity to contain fish within the field site for up to three days post-stocking. Within 72 hr of stocking, 65 fish were captured in the downstream fyke net, and 15 fish were captured in the upstream fyke net. When calculating detection efficiency of antenna arrays, it was determined that arrays contacted 100% (n=15) of fish moving upstream and 93.8% (n=61) of the fish moving downstream within 72 hr of stocking. Overall, antenna arrays were 95.0% (n=76) effective in contacting fish moving upstream or downstream of the stocking site. Interestingly, some individual antennas appeared to be more effective at contacting tagged fish than others, with 33.8% being the lowest rate of contact and 86.7% being the highest rate of contact (the two largest antennas had the highest rates of contact; Fig. 3).

Because small and large antennas were used for our study in Year 2 and the channel width covered by each antenna varied, we were concerned that stream channel coverage by an antenna may have affected the number of tagged fish contacted. We used data from fyke net catches to conduct a linear regression to evaluate if the percent channel covered by an antenna affected contact of tagged fish. We found that antennas that physically cover a greater percentage of the channel were more effective at

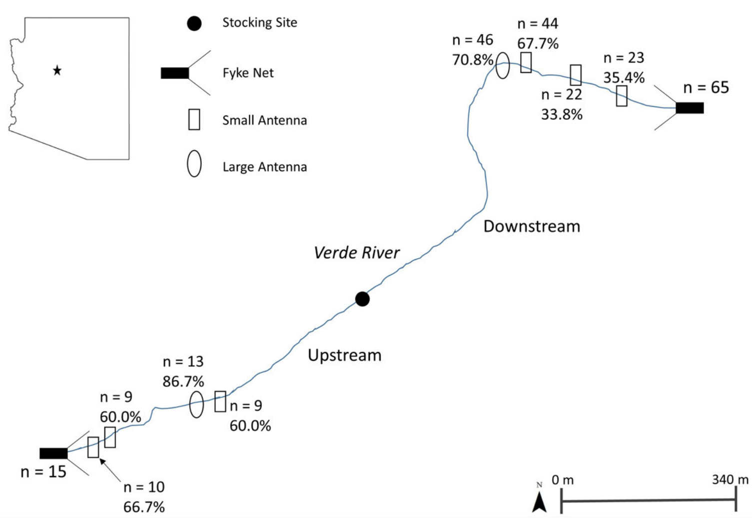

*Figure 3. Small (Marsh & Associates, LLC, Tempe, AZ, 0.9 m length x 0.7 m height) and large (Marsh & Associates, LLC, Tempe, AZ,1.3 m length x 0.7 m height) rectangular passive integrated transponder (PIT) antenna and fyke net locations in the upper Verde River, Arizona, in Year 2 (2016-2017) of the study. Numbers of hatchery-reared, PIT tagged roundtail chub (*Gila robusta*) captured by fyke nets and contacted by antennas within 72-h of stocking are represented next to the associated symbol. Detection efficiency of individual antennas are represented in percentages.*

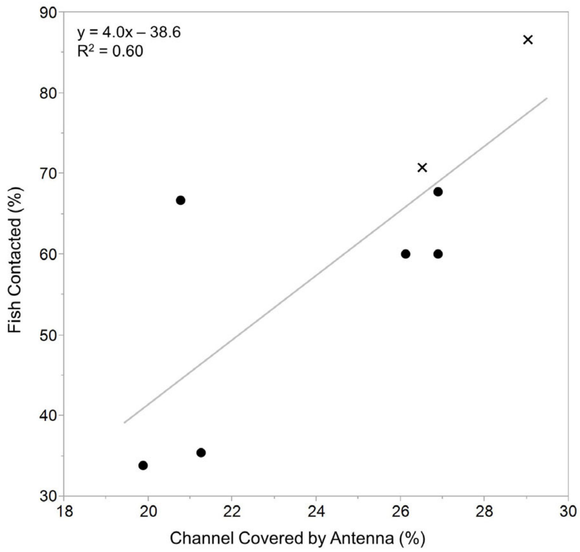

*Figure 4. Linear relationship of channel coverage (%) and PIT tagged roundtail chub (*Gila robusta*) contacted (%) for both small rectangular (Marsh & Associates, LLC, Tempe, AZ, 0.9 m length x 0.7 m height) and large rectangular (Marsh & Associates, LLC, Tempe, AZ,1.3 m length x 0.7 m height) PIT antennas in the upper Verde River, Arizona. Small antennas are denoted with a circle and large antennas are denoted with an "X". Note that the x and y scales do not begin at zero. The variation in the percent of tagged roundtail chub contacted can be explained by channel coverage, which is the physical area covered by an antenna. Generally, antennas that spanned a larger portion of the channel contacted more tagged roundtail chub.*

detecting fish ($r=0.78$; $R^2=0.60$; $p<0.0229$, Fig. 4). Although a strong correlation exists and the variation in the percent of tagged roundtail chub contacted can be explained by channel coverage, there was one apparent outlier where only 20.7% of the channel was covered yet the PIT antenna had 66.6% rate of contact, the second highest detection rate from small antennas.

DISCUSSION

We evaluated PIT tag retention and survival of juvenile roundtail chub while fish were held in captivity prior to stocking. Although not a primary objective of our study, tag retention and survival has not been reported for this species before. We found that PIT tag retention and tagging survival of roundtail chub was high (>98%). This finding coincides with results from other PIT tag retention and survival studies using *Gila* spp., where survival was >98% and retention was >97% over a 30-d period (Ward et al. 2008). Other lab studies with related species indicate that highest tag loss and mortality typically occurs within 48-h of tagging (Ward et al. 2015).

In both years of this study, we determined that roundtail chub were more likely to be detected by submersible PIT antennae when compared to tow-barge electrofishing. This is likely because antennas can be operated continually, whereas electrofishing only occurs during discrete daily events typically consisting of 6-8 hr of effort. When data were grouped into discrete comparable sampling events of approximately 3 d, and gear types compared, there was no significant difference in detection of tagged fish between gear types in both years. This finding suggests that electrofishing and antennas are equally likely to detect fish over an equivalent time period. We found that using PIT antennas of this type is an effective way to continuously monitor recently released fish for a relatively short time period in a shallow desert stream with generally consistent base flow and a narrow channel. In both years, antenna arrays accounted for 84% of all stocked roundtail chub detected. The addition of PIT antennas increased the number of detections of roundtail chub in the Verde River by 68% in both years after stocking occurred, demonstrating that antennas can be a valuable and practical sampling tool. If only electrofishing had been used, more than half of the fish would not have been detected; however, electrofishing accounted for 30% of all fish detected in both years. When we compared probability of detection by gear type for each year temporally, we found that detecting roundtail chub after stocking was low and generally decreased over time for both gears. Therefore, we believe that the use of both gear types can be valuable when attempting to detect recently released hatchery-reared fish in a small desert river. Combining sampling gears may offset gear limitations and yield more detailed information on fish behavior, physiology, and ecology (Zydlewski et al. 2001).

Stocked fish were observed moving downstream or upstream of the stocking site within 72-h of release. Antennas proved to be a reliable and efficient method to monitor fish movement in that antennas detected 95% of fish moving upstream and downstream of the stocking site. Fish orientation, swimming speed, environmental conditions (e.g., similar frequencies from ambient electromagnetic fields, and water conditions), and the inability of PIT scanners to detect two tags at once can influence tag detection efficiency (Nunnallee et al. 1998, Greenberg and Giller 2000, Zydlewski et al. 2001, Aymes and Rives 2009) and may be responsible for 5% of fish not being detected. Alternative studies conducted with antennas have also found that detection efficiency is >95% (Nunnallee et al. 1998, Axel et al. 2005, Connolly et al. 2008). Most notably, aquatic systems were not closed in any of these studies to test detection efficiency of antennas, which makes our findings novel and validates detection efficiency of PIT antennas in both closed and open environments.

Within 72-h of stocking, more emigrating roundtail chub (n=65) were captured in the downstream fyke net, compared to the number of fish (n=15) captured in the upstream fyke net. Movement studies with hatchery-reared salmonids and percichthyids have also reported that fish predominately move downstream after release (Bettinger and Bettoli 2002, Ebner and Thiem 2009). Hatchery-reared fish are typically raised in ponds or raceways with virtually no water current. Typically, stocked fish move downstream rather than moving upstream after release because captive-bred fish are not conditioned for sustained swimming and are naïve to water currents (Schuck 1948, Cresswell and Williams 1983). Fish may also attempt to conserve energy by using downstream water flow to passively relocate (Taverny et al. 2002, Acolas et al. 2012). Examing fish movement after stocking provides some insight into the behavioral response of fish species after release, and movement can affect detection estimates. Emigrating individuals are no longer available for capture and without the inclusion of these individuals in more robust analyses (e.g., mark-recapture), parameter estimates can be biased (Fujiwara and Caswell 2002).

We were concerned that stream channel coverage by small or large antenna may have affected the number of tagged fish contacted. We found that the antennas that had greater channel coverage were the most effective at detecting fish migrating upstream or downstream. Interestingly, two of the small antennas detected almost as many fish (67.7% and 66.7%) as one of the large antennas (70.8%) when covering more or less than a quarter of the channel. This observation suggests that small antennas may be used in lieu of large antennas when circumstances are relevant.

Overall, the PIT antennas used in this study are easily placed and manipulated by one person. Batteries had to be replaced every five days but were small enough to allow one person to carry multiple batteries at once. In comparison, other types of PIT antennas, such as shore-based, flatbed, and pass-through antennas can be quite large, and some require permanent or semi-permanent installment with extensive shore-based battery systems (Lucas et al. 1999, Zydlewski et al. 2006, Bond et al. 2007, Johnston et al. 2009). In general, using PIT antennas to detect tagged fish requires less field labor and fewer person-hours to operate (Sloat et al. 2011). In contrast, traditional capture efforts typically involve crews of at least two or more people and multiple days of sampling effort. Active methods, such as electrofishing, require handling of fish, which induces stress to the animal (Paukert et al. 2005) and can often cause incidental mortalities or injuries (McMichael 1993, Dalbey et al. 1996, Reynolds 1996). Passive methods of detection reduce disturbance to study animals (Sloat et al. 2011), which allows animals to behave naturally and allows for more frequent sampling. These circumstances generate less sampling bias compared to other methods. Antennae also provide the ability to continuously collect information which can be important when dealing with nocturnal or crepuscular species. Similar to active methods of capture, antenna detections have been used to estimate fish abundances, habitat use, movement, and behavior (Lucas et al. 1999, Riley et al. 2003, Zydlewski et al. 2003, Roussel et al. 2004).

Electrofishing is able to gather ancillary data such as fish condition (e.g., length and weight) which can be important for interpreting survival of critical life stages (Zydlewski et al. 2001, Sloat et al. 2011). Using electrofishing as a detection method also allows for the capture of unmarked animals, whereas PIT antennas can only detect fish previously tagged. Although detection efficiency of fish was lower for electrofishing when compared to antennas in our study, fish may have been actively avoiding the electrofishing apparatus and wading field technicians. Repeated electrofishing events may condition fish to recognize various cues (e.g., auditory cue from generator), thus eliciting escape behaviors, where fish flee from the site to avoid the negative stimulus (electroshock, see Gleitman and Rozin 1971, Mesa and Schreck 1989), which can bias capture estimates (Zarnoch 1979, Lettink and Armstrong 2003). Small fish, such as the size of fish released in this study, may also be more difficult for field technicians to see during electrofishing surveys because they are less conspicuous (Reynolds 1996) and may be more easily obscured by aquatic vegetation.

Both active and passive fisheries gear types have limitations and advantages, and it is important to consider trade-offs when designing a sampling plan. This study compared portable PIT antennas and tow-barge electrofishing and found that antennas can be an effective tool to continuously monitor recently released fish. For managers who lack the resources to implement more intensive methods of capture, such as electrofishing, but are interested in monitoring post-stocking movement and behavior of recently released fish, stand-alone PIT antennae may be useful. However, if collecting ancillary data is necessary, such as fish condition or marking fish to obtain population estimates, then additional sampling methods will still be required. Combining gear types, such as electrofishing and antennae, provides for more robust data collection and yields more detailed information than by using any one method alone.

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