Post-release movements and habitat use of robust redhorse transplanted to the Ocmulgee River, Georgia†

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ABSTRACT

1. Robust redhorse *Moxostoma robustum* is an imperiled, potadromous fish in the south-eastern USA. Initial recovery efforts have focused on supplementing existing populations and establishing refugial populations through extensive stocking programmes. However, assessment of the success of these programmes has not yet been conducted, and there are few reports evaluating the effectiveness of such programmes with other potadromous species.

2. Radio telemetry was employed to assess the effectiveness of a stocking programme aimed at addressing whether stocked individuals would remain in an area free of introduced predators and ascertaining the ability of stocked fish to integrate into a resident population.

3. Hatchery-reared robust redhorse were captured from refugial populations established in other river systems and were transferred to the Ocmulgee River, Georgia where a population of hatchery-reared individuals and an unknown number of wild fish reside.

4. These transferred robust redhorse exhibited an exploratory phase for the first 3 months before adopting behaviour patterns, including spawning migrations, that were consistent with those reported for wild fish in other systems. However, some individuals seemed unable to locate suitable spawning habitat.

5. Approximately half of the radio-tagged fish remained within the area free of introduced predators.

6. At least some radio-tagged robust redhorse fully integrated into the resident population as evidenced by their presence in spawning aggregations with resident individuals.

7. The effectiveness of a stocking programme is dependent upon the ability of stocked individuals to integrate into an existing population or replicate the behaviour and functionality of a resident population. Evaluations of stocking programmes should incorporate assessments of behaviour in addition to surveys to estimate abundance and survivorship and genetic assessments of augmentation of effective population sizes.

INTRODUCTION

The use of hatchery-reared fish has become a common and controversial conservation strategy to supplement existing or to establish new populations of threatened and endangered species (Levin et al., 2001; Brannon et al., 2004). Numerous studies demonstrate that hatchery-reared fish are not necessarily equivalent to their wild counterparts (for reviews see Munro and Bell, 1997 and Huntingford, 2004). Frequently hatchery-reared fish exhibit higher energy expenditures, higher mortality rates or lower reproductive success than wild individuals; this apparent reduced fitness has been attributed.

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to both their naivete and unfamiliarity with the local environment, such as the location of refuge, foraging, and spawning habitats (Cresswell, 1981; Helfrich and Kendall, 1982; McGinnity et al., 2004); the presence of predators or competitors (Olla et al., 1998; Kellison et al., 2000; Bettinger and Bettoli, 2002; Schooley and Marsh, 2007); and fluctuating or unfamiliar abiotic conditions (Bettinger and Bettoli, 2002; Ward and Hilwig, 2004). The differences in performance and survival between hatchery-reared individuals and their wild counterparts become less pronounced as hatchery-reared fish acclimatize to local conditions (for a review see Huntingford, 2004).

Often, the long-term success of a stocking effort may be defined during the acclimatization process as hatchery-reared fish become integrated into the existing population (Huntingford, 2004). For potadromous and diadromous species, integration into an existing population must include learning both the appropriate cues for initiating migratory behaviour in a particular system and the locations of suitable spawning habitat used by resident fish. Attempts to use hatchery-reared individuals as part of a conservation strategy for potadromous or diadromous fish have yielded mixed results. Despite efforts to imprint individuals to ‘natal’ spawning habitats, hatchery-reared salmonids and sturgeon exhibit a much greater propensity to stray or wander than wild fish (Quinn, 1993; Smith et al., 2002; Jonsson et al., 2003a,b). Hatchery-reared individuals also tend to exhibit much higher activity levels immediately after stocking than at later post-stocking times, often leading to the dispersal of a significant proportion of sexually immature stocked individuals out of the population they were meant to augment (Cresswell, 1981; Mueller et al., 2003).

Robust redhorse is an imperiled catostomid species listed as endangered by the state of Georgia, and has a conservation and recovery strategy heavily dependent upon the use of hatchery-reared individuals. Like many catostomid species, there is relatively little information available upon which to base an assessment of the strategy’s success (Cooke et al., 2005). Robust redhorse was originally described in 1869, but was ‘lost to science’ until its ‘rediscovery’ in 1991 (Cope, 1869; Bryant et al., 1996; Ruetz and Jennings, 2000). The species seems to have been extirpated from much of its range, but native populations persist in the Piedmont and upper coastal plain regions of three Atlantic Slope rivers (the Altamaha, Savannah, and Pee Dee drainages) in North Carolina, South Carolina, and Georgia (Bryant et al., 1996; Ruetz and Jennings, 2000). Conservation and recovery efforts have identified the goal of locating and/or establishing six evolutionarily significant units as the reintroduced population served. Fish become integrated into an existing population without having to account for the history of hatchery-reared individuals in the system. The use of these transplanted individuals has enabled evaluation of the ability of stocked fish to acclimatize to a new river system and integrate into an existing population without having to account for the effects of hatchery fish adjusting to the natural conditions, such as navigating in flowing water and locating food and shelter.

**METHODS**

**Study area**

The Ocmulgee River is about 400 km long and drains approximately 9900 km$^2$ in the Piedmont and Coastal Plain physiographic provinces of central Georgia. It is one of two major tributaries that merge to form the Altamaha River (Figure 1). This study focused primarily on a 30-km reach of the Ocmulgee River bounded upstream by Lloyd Shoals Dam near the city of Jackson, Georgia and downstream by Juliette Dam in the town of Juliette, Georgia (Figure 1). Lloyd Shoals Dam is a main-stem hydroelectric facility and is an impassable barrier to upstream fish migration, whereas Juliette Dam is a low-head dam passable only in the downstream direction. This 30-km reach was selected for the Robust Redhorse Conservation Committee as a suitable location for establishing a refugial population because it contains suitable robust redhorse habitat, including several potential spawning sites, and was thought to be free of introduced predators (DeMeo, 2001). Predation by flathead catfish *Pylodictis olivaris* has been hypothesized to be a contributing factor in the decline of robust redhorse in the Altamaha River system since its introduction in the 1970s (Bart et al., 1994; Cooke et al., 2005). Although the species is prevalent throughout much of the system, Juliette Dam had apparently blocked its upstream movement (DeMeo, 2001).

However, recent reports suggest that flathead catfish may be present and in the process of becoming established in this reach of the Ocmulgee River (J. Evans, Georgia Department of Natural Resources, personal communication). Robust
redhorse were first stocked into this reach of the Ocmulgee River in 2002 and 13,095 individuals ranging from fingerlings to young adults (age 5) have been stocked as of 2005 (J. Evans, Georgia Department of Natural Resources, personal communication). These fingerlings are the progeny of broodstock captured from the Oconee River, Georgia, another component of the Altamaha River basin.

**Data collection**

Standard boat electrofishing techniques were used to collect adult and subadult robust redhorse from refugial populations established in the Broad River and Ocmulgee River of Georgia during March and early April 2006. Like the Ocmulgee River population, these populations were established with the progeny of broodstock collected from the Oconee River. A total of 30 adult and subadult robust redhorse were captured from the Broad River (n = 10; 8 males, 2 females) and the Ogeechee River (n = 20; 16 males, 4 females). Individuals captured from the Broad River were larger (513–573 mm TL, 1644–2778 g) than those from the Ogeechee River (429–502 mm TL, 1021–1843 g). All fish were transported to outdoor holding facilities at the University of Georgia.

A frequency-coded radio transmitter with trailing wire antenna (Advanced Telemetry Systems, Isanti, Minnesota) was surgically implanted into each fish. Transmitters weighed approximately 26.0 g in air and did not exceed the maximum 2.0% of the body weight of the fish as recommended by Winter (1996). The transmitters had a manufacturer guaranteed battery life of 360 days. Each fish was anaesthetized by immersion in a 140 mg L\(^{-1}\) buffered MS-222 solution. The fish was removed from this solution, placed in a surgical cradle, and kept sedated by pumping a 70 mg L\(^{-1}\) buffered MS-222 solution over the gills. A radio transmitter was implanted into the peritoneal cavity, and the whip antenna exited the body via a separate incision (Ross and Kleiner, 1982). The entire surgery for each individual was completed in 5–7 min, and all radio-tagged fish were allowed to recover for 8 days before release.

Thirty radio-tagged robust redhorse were released into the Ocmulgee River immediately below Lloyd Shoals Dam at river kilometre (rkm) 393.95 on 19 April 2006 and subsequently were relocated weekly by boat or canoe for the duration of the transmitters’ battery life. Shoals and other obstructions rendered approximately 10 rkm between Lloyd Shoals Dam and Juliette Dam and 40 rkm between Juliette Dam and Macon, Georgia navigable only by canoe when flows and water levels allowed (Figure 1). Therefore, radio-tagged robust redhorse occupying these river segments were relocated less often relative to their counterparts in more navigable portions of the river. Fish were located by using an ATS R2100 programmable scanning radio receiver (Advanced Telemetry Systems, Isanti, Minnesota\(^1\)) with a loop antenna. The precise location of the fish was determined by disconnecting the coaxial cable from the antenna and using it as a low-sensitivity, low-gain antenna to determine the position of the tagged fish to within 1 m. When the end of the coaxial cable was dipped into the water and pointed straight downwards, the signal from a radio-tagged individual could only be detected when directly above it. Once the position of the fish had been fixed, latitude and longitude were determined with a hand-held GPS receiver and recorded. Later, fish position was converted from latitude and longitude to rkm with ArcGIS 9.2 mapping software (Environmental Systems Research Institute, Redlands, California\(^2\)). Depth, temperature, dissolved oxygen (DO), turbidity, and bottom current velocity also were recorded at each location. In addition, the substrate composition (muddy, sandy, or rocky) and dominant available cover (none, woody debris, boulders) with which each fish was associated was assessed qualitatively.

**Data analysis**

Absolute distance moved, displacement, and estimates of minimum daily movement were calculated for each radio-tagged robust redhorse by season. Absolute distance moved was defined as the absolute value of distance moved between relocations and calculated as \(|P_{t+1} - P_t|\), where \(P_t\) is an individual’s position in rkm at time \(t\) and \(P_{t+1}\) is that same individual’s position at time \(t+1\). Displacement, defined as the net distance moved, was calculated as \(P_{t+1} - P_t\). Upstream movements are indicated by a positive number and downstream movements by a negative one. Seasonal absolute movement and displacement were calculated by summing for each individual over a season. Student’s \(t\)-tests were used to evaluate the null hypotheses that mean seasonal displacement was not different from zero (Zar, 1996), which would suggest that movement was not directional. The hypothesis that these values differed seasonally (fixed effects) was tested with a mixed model analysis of variance (ANOVA) while controlling for individuals and position relative to Juliette Dam (random effects) (Zar, 1996). Dunnett’s means separation was used to identify differences in treatment means (Zar, 1996). ANOVA was used to evaluate seasonal and positional (relative to Juliette Dam) differences in mean depth, temperature, DO, and turbidity. Seasonal and positional differences in substrate and cover were assessed with a \(\chi^2\) analysis. All means are reported ± 1 SE unless otherwise noted. A significance level of \(z = 0.05\) was used for all tests.

**RESULTS**

Radio-tagged fish were relocated 1041 times between April 2006 and May 2007. Individuals were relocated from four to 83 times, averaging 37.2 ± 4.4 observations per individual. Two of the radio-tagged fish met with unknown fates. These individuals were not relocated during the course of this study and were presumed dead. An additional four fish died or shed their transmitters during this study (one in May 2006; two in August 2006; one in September 2006) and were removed from further analysis. The mortality rate for the radio-tagged robust redhorse stocked into the Ocmulgee River was 20.0%.

**General movement patterns**

The radio-tagged robust redhorse transplanted to the Ocmulgee River can be roughly separated into two groups: those that remained in the study reach between Lloyd Shoals Dam (hereafter referred to as upstream fish) and Juliette Dam and those that passed Juliette Dam (hereafter referred to as...
downstream fish). Eighteen of the 28 surviving individuals remained upstream of Juliette Dam. These fish seemed to undergo an exploratory period that lasted until mid-June 2006, and made frequent movements between Lloyd Shoals Dam and Juliette Dam (Figure 2). The majority of upstream fish seemed to establish home ranges near their release point after this initial exploratory period. A few individuals made seasonal shifts in home range, spending summer, fall and winter near Juliette Dam and moving up to Lloyd Shoals during spring (Figure 2). In late July and early August, the oxygenation system at Lloyd Shoals Dam failed, which resulted in hypoxic conditions for several kilometres downstream. During this period, the radio-tagged robust redhorse left this area and resettled in positions either in the non-navigable portion of the river or near Juliette Dam and returned to their previous locations within 2 weeks after DO levels had returned to normal. The 10 downstream fish exhibited a similar exploratory period of consistent downstream movement interspersed with erratic upstream movements. During this period, individuals below Juliette Dam were located as far downstream as rkm 167.95. Most of the downstream fish seemed to complete their exploratory period by mid-June 2006, but two individuals apparently did not establish long-term home ranges (Figure 2). All remaining analyses excluded these exploratory periods from consideration.

**Habitat-use patterns**

In general, radio-tagged robust redhorse remained within the confines of the main channel of the Ocmulgee River regardless of their position relative to Juliette Dam. However, there were two notable exceptions. On 10 May 2006, a fish was located in the Tonaliga River, a small tributary of the Ocmulgee River approximately 5.5 km upstream of Juliette Dam. This individual moved back into the Ocmulgee River some time before it was relocated again on 24 May 2006. During high water events in mid-January 2007, one downstream fish was found on the floodplain about 50 m from the edge of the main river channel. This fish was not found in association with any smaller streams or tributaries of the Ocmulgee.

The habitat occupied by radio-tagged robust redhorse differed by season and/or their position relative to Juliette Dam. The type of substrate fish were associated with was related to position relative to Juliette Dam ($\chi^2 = 170.7$; d.f. = 2; $P < 0.0001$) but did not differ by season ($\chi^2 \leq 7.5$; d.f. = 6; $P > 0.05$).
Upstream fish were found primarily in association with sandy substrate (82.0%), whereas relocations of downstream fish were split among mud (20.0%), sand (39.0%), and rocky or gravel (41.0%) substrates (Figure 3). Likewise, the available cover a radio-tagged fish was likely to associate with was related to position relative to Juliette Dam ($\chi^2=108.1$; d.f. = 3; $P < 0.0001$). Downstream fish were located primarily in proximity to woody debris (80.0%), but their upstream counterparts were found primarily near rocks (51.9%) and woody debris (39.5%). Regardless of position relative to Juliette Dam, radio-tagged robust redhorse demonstrated seasonal shifts in the available cover with which they associated ($\chi^2=101.6$; d.f. = 9; $P < 0.0001$). A larger number of individuals were observed in association with rocks during spring (63.0%) than other seasons (28.1–46.7%) (Figure 4). Downstream fish were consistently found in deeper ($F_{7,856}=19.33$; $P < 0.0001$) and faster-flowing ($F_{7,507}=6.68$; $P < 0.0001$) water than their upstream counterparts regardless of season. On average downstream fish were located in water that was $2.53 \pm 0.09$ m deep and flowing at $0.21 \pm 0.02$ m s$^{-1}$, whereas upstream fish were found in $1.82 \pm 0.03$ m of water with a current velocity of $0.11 \pm 0.01$ m s$^{-1}$. Both upstream ($F_{3,693}=4.25$; $P = 0.006$) and downstream ($F_{3,163}=8.45$; $P < 0.0001$) fish exhibited seasonal differences in water depth and tended to be located in the deepest water during winter. Current velocity at locations occupied by radio-tagged robust redhorse upstream ($F_{3,89}=0.017$; $P<0.41$) or downstream ($F_{3,118}=0.004$; $P = 0.94$) of Juliette Dam did not differ seasonally.

Seasonal movement patterns

These seasonal changes in habitat association seem to correspond to seasonal movement patterns of the radio-tagged robust redhorse. Radio-tagged robust redhorse exhibited seasonal differences in absolute movement ($F_{3,390}=5.50$; $P = 0.002$) and were most active in the summer ($t_{390}=3.21$; $P \leq 0.002$) when mean absolute movement was $49.0 \pm 9.2$ km (Figure 5). Individuals exhibited about the same level of activity across the other three seasons ($t_{390} \leq 0.00$; $P > 0.89$), moving approximately 16–17 km in autumn, winter, and spring. However, this movement was not directed upstream or downstream. Displacement also varied seasonally ($F_{3,90}=3.19$; $P = 0.03$) with spring being the only season where net movement was upstream. Displacement for the other three seasons did not differ statistically from zero ($t_{90} \leq 0.90$; $P \geq 0.08$) (Figure 5).

DISCUSSION

Radio-tagged fish transplanted to the Ocmulgee River adopted behavioural patterns that were consistent with those reported...
for wild fish (Grabowski and Isely, 2006) within 90–120 days of their release. Before they were fully acclimatized to the Ocmulgee River, the radio-tagged fish exhibited an exploratory pattern of movement and behaviour, mostly in the downstream direction. A similar pattern was noted in younger, hatchery-reared robust redhorse stocked directly from rearing facilities in 2002 at the same location on the Ocmulgee River (Jennings and Shepard, 2003). These juveniles were still exhibiting consistent downstream movements 80 days after release when the radio-transmitters reached the end of their battery life. Approximately one-third of study fish passed after release when the radio-transmitters reached the end of their battery life. Approximately one-third of study fish passed after release when the radio-transmitters reached the end of their battery life. Approximately one-third of study fish passed after release when the radio-transmitters reached the end of their battery life. Approximately one-third of study fish passed after release when the radio-transmitters reached the end of their battery life. Approximately one-third of study fish passed after release when the radio-transmitters reached the end of their battery life.

Examples of similar periods of exploratory behaviour in stocked individuals can be found for numerous taxonomically diverse species including razorback sucker Xyrauchen texanus (Mueller et al., 2003), brown trout Salmo trutta (Aarestrup et al., 2005), and paddlefish Polyodon spathula (Pitman and Parks, 1994). However, the length of the exploratory period observed in the individuals transplanted to the Ocmulgee River suggest that many of these studies cited may have been of insufficient duration to determine if the study fish eventually settled into a pattern of behaviour typical of a wild fish.

After the radio-tagged robust redhorse completed their exploratory phase, differences in their habitat-use patterns seemed to be dependent upon their position relative to Juliette Dam. However, hydrologic and geomorphic differences between the two areas are the most probable explanation for the observed differences in habitat use. The Ocmulgee River above Juliette Dam is characteristic of a large Piedmont river with high gradient, shallow water, primarily gravel and sand substrate, and frequent shoals. Below Juliette Dam particularly downstream of Macon, Georgia, the Ocmulgee River becomes a coastal plain river and has a relatively low gradient, a meandering channel, predominantly sand and mud substrate, and frequent sand bars and deep pools that are typical of coastal plain rivers. A similar pattern was observed in the Savannah River where fish exhibited different habitat selection depending upon their position relative to a dam that served as a division between the piedmont and coastal plain regions of the river (Grabowski and Isely, 2006). Regardless of their position relative to Juliette Dam, radio-tagged robust redhorse were consistently found in the main channel associated with current, deep water, and physical structure, particularly woody debris. Occasionally, individuals left the main channel during high water events. This movement and habitat-use pattern is similar to the habitat preferences previously described for this species (Jennings and Shepard, 2003; Grabowski and Isely, 2006; R. Heise, North Carolina Wildlife Resources Commission, personal communication). In the Ocmulgee River, robust redhorse seem to be able to find suitable non-spawning habitat in both piedmont and coastal plain habitats that meet species-specific minimum standards of cover, depth, current velocity, and water quality.

Although the upstream-downstream differences seen in habitat use by radio-tagged robust redhorse probably are an artefact of differences of habitat quality and availability, the observed seasonal differences in movement and habitat use were consistent with those described for wild radio-tagged robust redhorse in other systems (Grabowski and Isely, 2006; R. Heise, North Carolina Wildlife Resources Commission, personal communication). The robust redhorse stocked into the Ocmulgee River eventually adopted behaviour patterns in which individuals were mostly sedentary and spent the majority of their time within a relatively small linear home range. This was demonstrated by the low mean seasonal absolute movement and dispersal, and the small seasonal ranges during spring, full and winter. Late spring and early summer was the only exception to this sedentary lifestyle as fish generally became more active and most individuals initiated upstream migrations, presumably for the purpose of locating spawning habitat.

Despite many tagged robust redhorse making upstream movements in the spring, only two were observed as part of an aggregation of spawning resident fish. These two fish were found in shoul habitat approximately 1.0 km downstream of Juliette Dam. It was not possible to determine if the other radio-tagged fish below Juliette Dam participated in spawning activities. The radio-tagged robust redhorse above Juliette Dam did move upstream into Lloyd Shoals during spring. However, visual surveys by divers did not find suitable spawning habitat as described by Freeman and Freeman (2001) and Grabowski and Isely (2007) in the areas occupied by these individuals. This habitat in the form of mid-channel gravel bars is present above Juliette Dam; however, this study was conducted during a period of severe drought in central Georgia. Gravel bars upstream of Juliette Dam similar to those used by robust redhorse in other rivers (Freeman and Freeman, 2001; Grabowski and Isely, 2007) that potentially could have served as spawning habitat for robust redhorse were left exposed during spring and early summer. On the other hand, rocky shoal habitat similar to that used by spawning fish below Juliette Dam was readily available to the upstream individuals during the course of this study but did not seem to be used. Other hatchery-reared catostomids, such as razorback sucker (Marsh et al., 2005; Modde et al., 2005), have been observed associated with spawning aggregations of wild counterparts. However, the proportion of transplanted individuals able to successfully locate and participate in a spawning aggregation was not addressed in these studies.

The radio-tagged robust redhorse transplanted to the Ocmulgee River suffered a 20% mortality rate. This rate is comparable with mortality rates of wild radio-tagged robust redhorse in the Savannah River (Grabowski and Isely, 2006) and with hatchery-reared pallid sturgeon Scaphirhynchus albus (Jordan et al., 2006). Determining whether death was because of complications related to the surgical procedure performed on these individuals, unfamiliarity with local conditions, or natural causes was impossible. However, the relatively low mortality of transplanted fish acclimatized to natural conditions suggest that the majority of mortality experienced by stocked fish may be related to their naive about life outside the hatchery environment and not to their unfamiliarity with local conditions. The radio-tagged individuals transplanted to the Ocmulgee River had been living in natural conditions in other river systems for several years before being relocated and thus had been exposed to predators, competitors, fluctuating abiotic conditions, and patchy resources.

The use of hatchery-reared robust redhorse to establish a refugial population in the Ocmulgee River seems to be a viable strategy to aid in the recovery of this species. The stocked individuals did not leave the Ocmulgee River to enter the Altamaha or Oconee rivers, even during their exploratory.
period. Most of the fish that passed Juliette Dam adopted a behavioural pattern similar to that seen in wild fish (Grabowski and Isely, 2006; R. Heise, North Carolina Wildlife Resources Commission, personal communication), and a few even integrated into an existing population of robust redhorse, located suitable spawning habitat, and participated in spawning within a year of release. However, the presence of introduced predators such as flathead catfish raises concerns as to how successful these individuals will be in contributing to a self-sustaining population (Bart et al., 1994; Cooke et al., 2005).

At the conclusion of this study, about two-thirds of the fish released remained in the predator-free reach of the Ocmulgee River above Juliette Dam. These upstream individuals behaved comparably with their downstream counterparts and with wild robust redhorse in other systems, but whether they will be able to establish a self-sustaining population remains to be seen. In addition to concerns about the arrival of flathead catfish in this portion of the river, results indicate that radio-tagged robust redhorse in this portion of the river did not spawn successfully. They did initiate upstream spring migrations, presumably in preparation for spawning, but the fish either did not find suitable spawning habitat as described by Freeman and Freeman (2001) and Grabowski and Isely (2007) or environmental cues necessary to trigger spawning were absent. In other systems, such upstream migrations end at a spawning aggregation (Grabowski and Isely, 2006), but whether such aggregations occur in the Ocmulgee above Juliette Dam is unclear.

The results of this study suggest hatchery-reared individuals can be used to establish or augment a population of potadromous riverine fish. However, the results also demonstrate the importance of long-term monitoring programmes, including behavioural assessments for determining the success of stocking programmes. Relatively few stocking programmes, regardless of whether they are for economically important species or non-game species, are critically assessed beyond the level of a count survey to determine if the stocking has enabled the population to achieve a target size. Although this approach may be appropriate for programmes designed to augment or establish populations of recreationally or commercially important fish, ensuring the recovery and long-term viability of threatened and endangered species ultimately requires an assessment of both the genetic composition/contribution and the ecological functionality and equivalence of stocked populations before success can be declared. This study suggests that a population census may indicate that the stocking programme in the Ocmulgee River was very successful. There was high survivorship among the transplanted individuals, which would suggest that a large proportion of the individuals stocked into the river may have survived. However, relatively few of the radio-tagged individuals seemed to locate suitable spawning habitat and participate in spawning activities. Whether robust redhorse stocked in the Ocmulgee will eventually spawn in the study reach of the river remains to be seen, but this population cannot be considered self-sustaining until the stocked fish are able to reproduce successfully with sufficient numbers of the offspring eventually recruiting to the adult population. These results emphasize the importance of applying multiple methodologies to assess the success of a stocking programme intended to augment or establish populations of imperiled fishes.

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