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

TIMOTHY B. GRABOWSKI[a,†] and CECIL A. JENNINGS[b,*]

[a] *Georgia Cooperative Fish and Wildlife Research Unit, Warnell School of Forestry and Natural Resources, The University of Georgia, Athens, GA, USA*

[b] *US Geological Survey, GA Cooperative Fish and Wildlife Research Unit, Warnell School of Forestry and Natural Resources, The University of Georgia, Athens, GA, USA*

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.

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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

*Correspondence to: C. A. Jennings, Georgia Cooperative Fish and Wildlife Research Unit, Warnell School of Forestry and Natural Resources, The University of Georgia, Athens, Georgia, 30602-2152, USA. E-mail: jennings@warnell.uga.edu

[†]Present address: Institute of Biology, University of Iceland, Askja, Sturlugata 7, Is-101 Reykjavik, Iceland.

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to both their naiveté 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 self-sustaining populations of robust redhorse as a top priority (Robust Redhorse Conservation Committee, 2002). The captive propagation and release of individuals has been the primary means by which this target is being reached. To this end, robust redhorse have been introduced to the Broad and Ogeechee rivers in Georgia and in the Wateree and Broad rivers in South Carolina. In addition, a candidate conservation agreement with assurances (CCAA) for the robust redhorse was developed as a collaborative effort between Georgia Power, Georgia Department of Natural Resources, and the US Fish and Wildlife Service to expedite the stocking of the robust redhorse into the Ocmulgee River, Georgia to supplement an existing population of unknown size (DeMeo, 2001; R. Self, South Carolina Department of Natural Resources, personal communication). However, there has been little assessment of the post-release dispersal, movements, and habitat use of robust redhorse at this time, and there has not yet been long-term monitoring of these populations. Wild adults are potadromous and make long-distance upstream migrations (>100 km) to spawning habitat in spring (Grabowski and Isely, 2006). Adult robust redhorse also demonstrate a high degree of fidelity and specificity to both spawning sites and home ranges (Grabowski and Isely, 2006, 2007). Whether hatchery-reared, stocked fish can adopt a similar behavioural pattern without imprinting on local conditions during early life history stages is unclear. This uncertainty also can be associated with the reintroduction and conservation efforts for this species in rivers where hatchery-reared individuals have been used to augment existing populations or establish new ones.

Radio telemetry was used to assess the movement patterns and habitat use of robust redhorse stocked into the Ocmulgee River. The study fish were naturalized, hatchery-reared individuals collected from stocked populations in other river systems; these individuals originated from the same evolutionarily significant unit as the reintroduced population in the Ocmulgee River. The use of these transplanted naturalized individuals 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 by 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 portal created by a lopher surgical needle 3–4 cm posterior to the 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[1]). 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 χ^2 analysis. All means are reported $\pm$ 1 SE unless otherwise noted. A significance level of $\alpha = 0.05$ 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

[1]Reference to trade names does not constitute US Government endorsement of commercial products.

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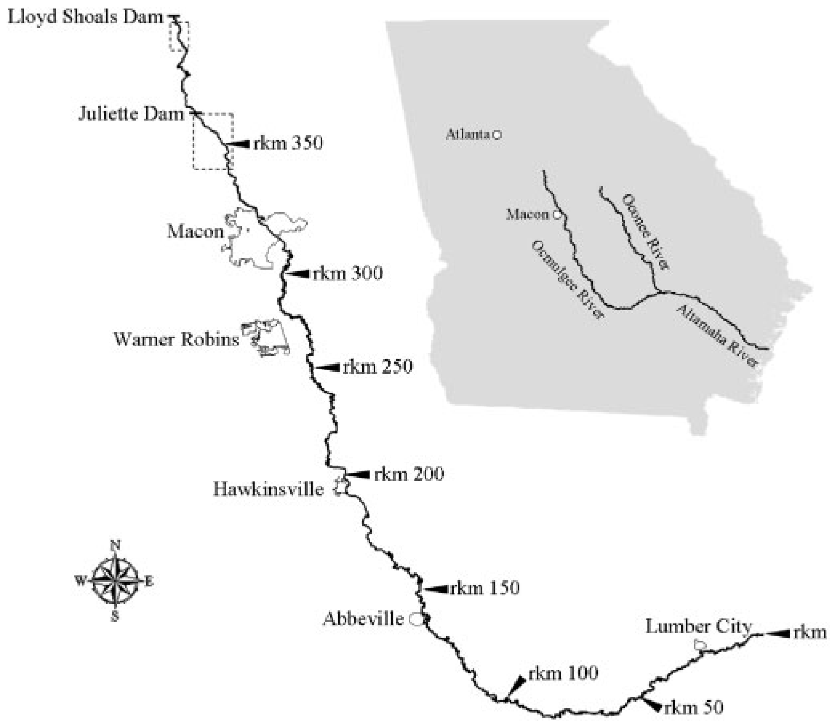

Figure 1. The Ocmulgee River from its confluence with the Oconee River at rkm 0 to Lloyd Shoals Dam at rkm 394.5. Areas highlighted by dashed lines indicate non-navigable portions of the river. Inset shows the position of the Altamaha River systems in the state of Georgia.

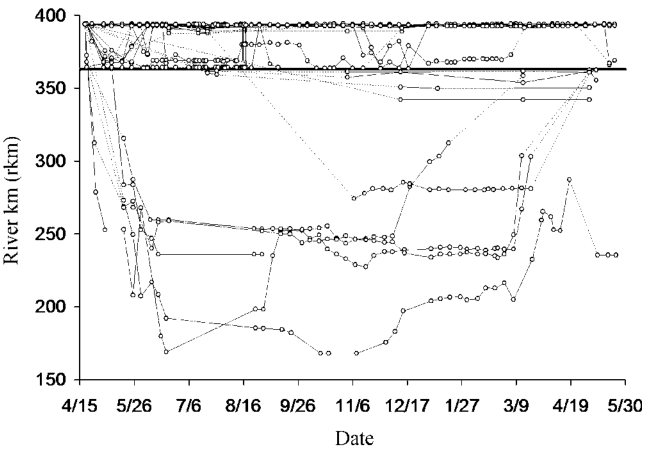

Figure 2. Location (rkm) of radio-tagged robust redhorse released in the Ocmulgee River, Georgia April 2006–June 2007. Location of Juliette Dam is represented by the solid horizontal line at rkm 362.5. Dashed lines indicate periods where that individual was not found.

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 Towaliga 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 ($\chi^2 \leqslant 7.5$; d.f. = 6;

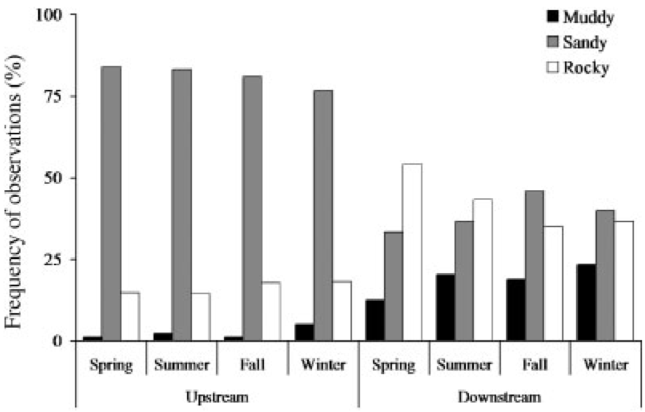

Figure 3. Seasonal frequency of observations over muddy, sandy, and rocky substrates of stocked radio-tagged robust redhorse upstream and downstream of Juliette Dam in the Ocmulgee River, Georgia, April 2006–June 2007.

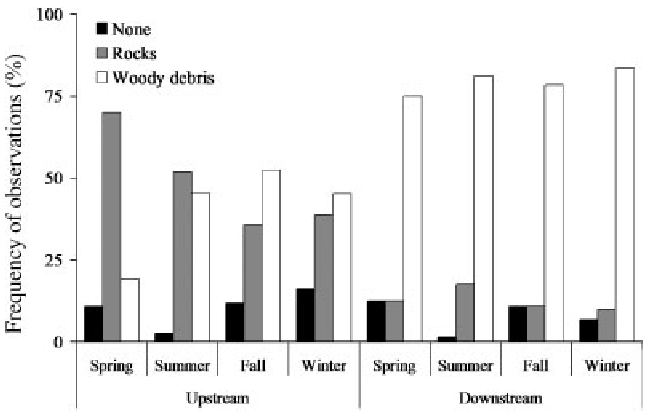

Figure 4. Seasonal frequency of observations of the cover (none, rocks, woody debris) used by stocked radio-tagged robust redhorse upstream and downstream of Juliette Dam in the Ocmulgee River, Georgia, April 2006–June 2007.

$P \geqslant 0.27$). 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 ± 0.09 m deep and flowing at $0.21 \pm 0.02\,\mathrm{m\,s^{-1}}$, whereas upstream fish were found in 1.82 ± 0.03 m of water with a current velocity of $0.11 \pm 0.01\,\mathrm{m\,s^{-1}}$. 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 ($F_{3,90} = 5.50$; $P = 0.002$) and were most active in the summer ($t_{90} \leqslant 3.21$; $P \leqslant 0.002$) when mean absolute movement was 49.0 ± 9.2 km (Figure 5). Individuals exhibited about the same level of activity across the other three seasons ($t_{90} \leqslant 0.00$; $P \geqslant 0.89$), 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 ($t_{90} \leqslant 0.90$; $P \geqslant 0.08$) (Figure 5).

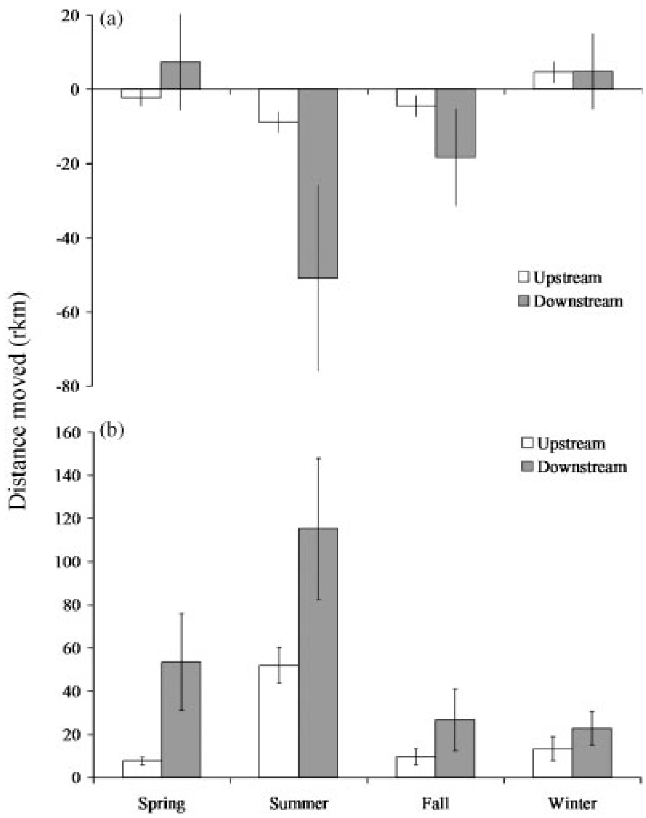

Figure 5. Mean seasonal displacement (a) and absolute movement (b) of stocked radio-tagged robust redhorse upstream and downstream of Juliette Dam in the Ocmulgee River, Georgia, April 2006–June 2007. Error bars represent standard error.

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 Juliette Dam during the course of the 2002 study (Jennings and Shepard, 2003). 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, fall 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 shoal habitat approximately 1.0 rkm 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 naiveté 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

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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 estbablish 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 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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REFERENCES

Aarestrup K, Jepsen N, Koed A, Pedersen S. 2005. Movement and mortality of stocked brown trout in a stream. *Journal of Fish Biology* **66**: 721–728.

Bart HL, Taylor MS, Harbaugh JT, Evans JW, Schleiger SC, Clark W. 1994. New distribution records of Gulf slope drainage fishes in the Ocmulgee River system, Georgia. *Southeastern Fishes Council Proceedings* **30**: 4–9.

Bettinger JM, Bettoli PW. 2002. Fate, dispersal, and persistence of recently stocked and resident rainbow trout in a Tennessee tailwater. *North American Journal of Fisheries Management* **26**: 425–432.

Brannon EL, Amend DF, Cronin MA, Lannan JE, LaPatra S, McNeil WJ, Noble RE, Smith CE, Talbot AJ, Wedemeyer GA, Westers H. 2004. The controversy about salmon hatcheries. *Fisheries* **29**: 12–31.

Bryant RT, Evans JW, Jenkins RE, Freeman BJ. 1996. The mystery fish. *Southern Wildlife* **1**: 26–35.

Cresswell RC. 1981. Post-stocking movements and recapture of hatchery reared trout released into flowing waters—a review. *Journal of Fish Biology* **18**: 429–442.

Cooke SJ, Bunt CM, Hamilton SJ, Jennings CA, Pearson MP, Cooperman MS, Markle DF. 2005. Threats, conservation strategies, and prognosis for suckers (Catostomidae) in North America: insights from regional case studies of a diverse family of non-game fishes. *Biological Conservation* **121**: 317–331.

Cope ED. 1869. Partial synopsis of the fishes of the fresh waters of North Carolina. *Proceedings of the American Philosophical Society* **11**: 448–495.

DeMeo T. 2001. Report of the Robust Redhorse Conservation Committee Annual Meeting. October 3–5, 2001, South Carolina Aquarium, Charleston, SC [online]. Available from http://www.robustredhorse.com/f/2001 AnnualMeetingReport RRCC.pdf [accessed 16 July 2007].

Freeman BJ, Freeman MC. 2001. Criteria for suitable spawning habitat for the robust redhorse. A report to the US Fish and Wildlife Service, Athens, Georgia.

Grabowski TB, Isely JJ. 2006. Seasonal and diel movement and habitat use of robust redhorse in the lower Savannah River, Georgia and South Carolina. *Transactions of the American Fisheries Society* **135**: 1145–1155.

Grabowski TB, Isely JJ. 2007. Spatial and temporal segregation of spawning habitat by catostomids in the Savannah River, Georgia and South Carolina, U.S.A. *Journal of Fish Biology* **70**: 782–798.

Helfrich LA, Kendall WT. 1982. Movements of hatchery-reared rainbow, brook, and brown trout stocked in a Virginia mountain stream. *Progressive Fish-Culturist* **44**: 3–7.

Huntingford FA. 2004. Implications of domestication and rearing conditions for the behaviour of cultivated fishes. *Journal of Fish Biology* **65**(Suppl. A): 122–142.

Jennings CA, Shepard DC. 2003. Movement and habitat use of hatchery-reared juvenile robust redhorse *Moxostoma robustum* released in the Ocmulgee River, GA. Report prepared for Georgia Power Company, Environmental Affairs Division, Atlanta, Georgia.

Jonsson B, Jonsson N, Hansen LP. 2003a. Atlantic salmon straying from the River Imsa. *Journal of Fish Biology* **62**: 641–657.

Jonsson B, Jonsson N, Hansen LP. 2003b. The marine survival and growth of wild and hatchery-reared Atlantic salmon. *Journal of Applied Ecology* **40**: 900–911.

Jordan GR, Klumb RA, Wanner GA, Stancill WJ. 2006. Poststocking movements and habitat use of hatchery-reared juvenile pallid sturgeon in the Missouri River below Fort Randall Dam, South Dakota and Nebraska. *Transactions of the American Fisheries Society* **35**: 1499–1511.

Kellison GT, Eggleston DB, Burke JS. 2000. Comparative behaviour and survival of hatchery-reared versus wild summer flounder (*Paralichthys dentatus*). *Canadian Journal of Fisheries and Aquatic Sciences* **57**: 1870–1877.

Levin PS, Zabel RW, Williams JG. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon. *Proceedings of the Royal Society of London* **268B**: 1153–1158.

Marsh PC, Kesner BR, Pacey CA. 2005. Repatriation as a management strategy to conserve a critically imperiled fish species. *North American Journal of Fisheries Management* **25**: 547–556.

McGinnity P, Prodohl P, Maoileidigh NO, Hynes R, Cotter D, Baker N, O'Hea B, Ferguson A. 2004. Differential lifetime success and performance of native and non-native Atlantic salmon examined under communal natural conditions. *Journal of Fish Biology* **65**(Suppl. A): 173–187.

Modde T, Bowen ZH, Kitcheyan DC. 2005. Spatial and temporal use of a spawning site in the Middle Green River by wild and hatchery-reared razorback suckers. *Transactions of the American Fisheries Society* **134**: 937–944.

Mueller GA, Marsh PC, Foster D, Ulibarri M, Burke T. 2003. Factors influencing poststocking dispersal of razorback sucker. *North American Journal of Fisheries Management* **23**: 270–275.

Munro JL, Bell JD. 1997. Enhancement of marine fisheries resources. *Reviews in Fisheries Science* **5**: 185–222.

Olla BL, Davis MW, Ryer CH. 1998. Understanding how the hatchery environment represses or promotes the development of behavioural survival skills. *Bulletin of Marine Science* **62**: 531–550.

Pitman VM, Parks J. 1994. Habitat use and movement of young paddlefish (*Polyodon spathula*). *Journal of Freshwater Ecology* **9**: 181–189.

Quinn TP. 1993. A review of homing and straying of wild and hatchery-produced salmon. *Fisheries Research* **18**: 29–44.

Robust Redhorse Conservation Committee. 2002. Robust Redhorse Conservation Committee policies [online]. Available from http://www.robustredhorse.com/f/policies.pdf [accessed 16 July 2007].

Ross MJ, Kleiner CF. 1982. Shielded-needle technique for surgically implanting radio-frequency transmitters in fish. *Progressive Fish Culturist* **44**: 41–43.

Ruetz III CR, Jennings CA. 2000. Swimming performance of larval robust redhorse *Moxostoma robustum* and low velocity habitat modeling in the Oconee River, Georgia. *Transactions of the American Fisheries Society* **129**: 398–407.

Schooley JD, Marsh PC. 2007. Stocking of endangered razorback suckers in the lower Colorado River Basin over three decades: 1974–2004. *North American Journal of Fisheries Management* **27**: 43–51.

Smith TIJ, McCord JW, Collins MR, Post WC. 2002. Occurrence of stocked shortnose sturgeon *Acipenser brevirostrum* in non-target rivers. *Journal of Applied Ichthyology* **18**: 470–474.

Ward DL, Hilwig KD. 2004. Effects of holding environment and exercise conditioning on swimming performance of southwestern native fishes. *North American Journal of Fisheries Management* **24**: 108–1087.

Winter JD. 1996. Advances in underwater biotelemetry. In *Fisheries Techniques* (2nd edn), Murphy BR, Willis DW (eds). American Fisheries Society: Bethesda, Maryland; 555–590.

Zar JH. 1996. *Biostatistical Analysis* (3rd edn). Prentice-Hall: Upper Saddle River, NJ.