Assessment of mark-recapture and RFID approaches for monitoring fish passage on the Daniel Boone National Forest

Report prepared by:
Craig Roghair, Colin Krause and C. Andrew Dolloff
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USDA Forest Service
Southern Research Station
Center for Aquatic Technology Transfer
1710 Research Center Dr.
Blacksburg, VA 24060
540.231.0078
http://www.srs.fs.usda.gov/catt/

List of Figures 2
List of Tables 3
Introduction 4
Methods 5
Site selection 5
Sample Reach Layout 6
2010 6
2012 6
Mark Recapture 6
RFID 7
2010 7
2012 7
Results 8
Mark-Recapture 8
RFID 8
2010 8
2012 8
Discussion 9
Comparison of methods 9
Observations on movements 10
Additional sampling 11
Summary 11
Acknowledgements 12
Literature Cited 13
Figures 15
Tables 29
Appendix A – Coarse Filter Models 39

List of Figures

Figure 1. Road-stream crossing and waterfall monitoring sites 16
Figure 2. Reach layout and RFID antenna configuration at non-tributary sites in 2010. 17
Figure 3. Reach layout and RFID antenna configuration at tributary sites in 2010. 18
Figure 4. Reach layout and RFID antenna configuration at non-tributary sites in 2012. 19
Figure 5. Reach layout and RFID antenna configuration at tributary sites in 2012. 20
Figure 6. Full-duplexand half-duplex swim-through antenna designs 21
Figure 7. Number of Creek Chubs collected during mark and recapture sampling, 2010..... 22
Figure 8. Number of *Chrosomus* species collected during mark and recapture sampling, 2010 22
Figure 9. Number of Rainbow Darters collected during mark and recapture sampling, 2010..... 23
Figure 10. Number of Central Stonerollers collected during mark and recapture sampling, 2010 23
Figure 11. Percentage of Creek Chubs marked with RFID tags detected moving, 2010 24
Figure 12. Time to first detection at the downstream antenna for RFID marked Creek Chubs, 2012 25
Figure 13. Percentage of Creek Chubs marked with RFID tags that were later detected, 2012 25
Figure 14. Percent of RFID marked Creek Chubs detected at sites 17, 18, and 19, 2012 26
Figure 15. Percent of RFID marked Creek Chubs detected at sites 05, 09, and 13, 2012..... 27
Figure 16. Percent of planted RFID marked Creek Chubs detected moving, 2012..... 28

List of Tables

Table 1. Location of road-stream crossing and waterfall monitoring sites 30

Table 2. Description of road-stream crossing and waterfall monitoring sites. 31

Table 3. Site attributes used to calculate passage ratings 32

Table 4. Passage ratings of road-stream crossing and waterfall monitoring sites 33

Table 5. Methods tested at road-stream crossing and waterfall monitoring sites 34

Table 6. Number of fish marked at each site in 2010 35

Table 7. Dates RFID antennas monitored for fish movement in 2010 and 2012 37

Table 8. Number of fish marked with RFID tags, and number of fish with RFID tags detected moving past antennas between Reaches A and B and Reaches B and C in 2010.. 38

Table 9. Number of Creek Chubs marked with RFID tags and later detected at antennas placed downstream and upstream of road crossings, 2012. 38

Table 10. Number of Creek Chubs marked with RFID tags, planted in the outlet pool, and later detected at the antenna upstream of the crossing structure in 2012. 38

Introduction

Understanding of the importance of movement to stream-resident fishes lagged behind that of migratory species for the better part of the 20th century. The prevailing attitude was that stream-resident fish movements were limited and most species spent their adult lives in short (< 20 m) stream reaches (Gerking 1959). Near the turn of the century a more complete and nuanced picture of the role of movement in sustaining the genetic and demographic integrity of stream fish populations (Gowan et al. 1994; Rodriguez 2002; Smithson and Johnston 1999), as well as an appreciation for impact of in-stream barriers to fish movement (Warren and Pardew 1998), began to emerge. Though our understanding of movement ecology is still growing, particularly for non-game species, it is now widely accepted that fish must move within stream systems to acquire the resources they need for survival and completion of their life-cycles, and that in-stream barriers to fish movement will negatively impact populations and reduce the likelihood of long-term population persistence (Hoffman and Dunham 2007; Nislow et al. 2011; Whiteley et al. 2013).

The use of road-stream crossing structures is as old as road building itself (Chanson 2002) and stream systems contain untold thousands of structures, each with the potential to impede movement (Nislow et al. 2011). Road-stream crossing design takes many factors into consideration, including safety, hydraulic capacity, maintenance, and life cycle cost (USFS 2014), but until recently seldom included consideration for fish movement. As the importance of movement to resident fishes became better understood (Bouska and Paukert 2010; Coffman 2005; Norman et al. 2009), so did the emphasis on considering passage for all species when repairing or replacing road-stream crossings. In the USDA Forest Service, aquatic organism passage and ecological connectivity are now second only to user safety in design consideration (USFS 2014) and National guidance for construction of crossings on silviculture roads prohibits disruption of the "migration or other movement of those species of aquatic life inhabiting the water body"(Activities not Requiring Permits 2011). Many government and non-government organizations are now in the process of inventorying and replacing road-stream crossings to improve aquatic organism passage.

Designing and installing crossings that provide for fish passage can be costly relative to installing traditional crossing structures, though life-cycle maintenance costs may be lower, and there is an understandable desire on the part of funding agencies to confirm that these structures benefit fish populations. Recognizing this need, the USDA Forest Service, San Dimas Technology Center (SDTC), sponsored a series of inter-agency meetings and funded a variety of projects with the goal of developing simple, cost-effective tools for confirming fish passage through road-stream crossings.

The Daniel Boone National Forest (DBNF) has an active aquatic organism passage assessment and improvement program and is home to a diverse fish fauna making it an ideal location for testing passage monitoring methods for small-bodied, non-game fishes. Beginning in 2010, the DBNF partnered with the USDA Forest Service, Southern Research Station, Center for Aquatic Technology Transfer (CATT) and the SDTC to test mark-recapture and radio frequency identification (RFID) approaches for monitoring fish passage at road-stream crossings. In addition, we collected samples for examining genetics and abundance-based approaches. Our objectives were to determine if the methods are effective for detecting fish movement, and can be implemented by a Forest Service District-level sampling crew, or its equivalent. In this report we present results for the mark-recapture and RFID approaches; the results for the genetics and abundance-based approaches will be presented by project partners in separate reports.

Methods

Site selection

Prior to 2010, the CATT partnered with the Daniel Boone National Forest (DBNF) to assess fish passage at over 850 road-stream crossings on National Forest managed lands in Kentucky (CATT 2010; Coffman et al. 2005; Steele et al. 2007). The inventories were based on methods outlined in the National Inventory and Assessment Procedure (Clarkin et al. 2003), and used criteria described in Coffman (2005) to yield ratings of passable, impassable, or indeterminate for each crossing. The results of these surveys provided crossing attribute and passage status information used to select sites. We prioritized sites using the following criteria:

- Number of pipes in crossing structure; single pipe = highest priority
- Stream network location; avoid sites within 400 m of a major confluence
- Site location; cluster sites to the extent possible to minimize drive time between sites
- Site ownership; select crossings on DBNF managed lands

We selected a total of 20 crossing sites and 3 waterfall sites (Figure 1, Table 1), representing a variety of structure types (Table 2) with a range of attributes (Table 3) and passage ratings (Table 4). Waterfall sites were not sampled in 2010. Three crossings (06, 17, and 19) were modified or replaced to improve fish passage between 2010 and 2012 (Table 4). We tested mark-recapture and RFID approaches, and collected samples for genetic and abundance-based approaches at the sites in both 2010 and 2012 (Table 5).

Sample Reach Layout

2010

In 2010, each site consisted of at least 3 reaches: 2 immediately downstream of the culvert outlet (Reaches A and B), and 1 immediately upstream of the culvert inlet (Reach C): Reach A began 400 m downstream of the culvert outlet and ended 200 m downstream of the outlet; Reach B began at the upstream end of reach A and ended at the culvert outlet; Reach C began at the culvert inlet and ended 200 m upstream (Figure2). A fourth reach (Reach D) was added when a crossing was within 400 m of a major confluence (Figure 3, Table 2).

2012

In 2012, each site consisted of at 4 reaches: 2 immediately downstream of the culvert outlet (Reaches 1 and 2), and 2 immediately upstream of the culvert inlet (Reaches 3 and 4): Reach 1 began 400 m downstream of the culvert outlet and ended 200 m downstream of the outlet; Reach 2 began at the upstream end of Reach A and ended at the culvert outlet; Reach 3 began at the culvert inlet and ended 200 m upstream; Reach 4 began 200 m upstream of the culvert inlet and ended 400 m upstream (Figure4). Where the crossing was within 400 m of a major confluence, Reach 1 started in the mainstem river downstream of the crossing (Figure 5, Table 2).

Mark Recapture

We completed mark-recapture sampling at all 20 crossings in 2010 (Table 5). The marking run and subsequent recapture runs consisted of a single pass through the sample reach with backpack electrofishers. We used 1 backpack electrofisher and 2 dipnetters at sites less than 5 m average wetted width and 2 backpack electrofishers with 3 dipnetters at larger sites. We marked fish in March – April starting at the downstream end Reach A and ended at the upstream end of Reach B. Every 50 m we stopped to record the total number of each species collected, mark fish greater than 40 mm total length with a caudal fin clip, and then return fish to the 50 m reach from which they were collected. We completed 1 – 3 recapture samples at each site in May – August. Recapture sampling typically began 3 – 4 weeks after marking and was repeated every 3 – 4 weeks for sites with multiple recapture samples. Recapture samples started at the downstream end of reach A and continued upstream through Reaches B and C. Reach D was sampled at sites where a confluence was within 400 m of the crossing outlet. Every 50 m we stopped to record the total number of each species collected, check all fish greater than 40 mm total length for a caudal fin clip, and return all fish to the 50 m reach where they were collected.

RFID

2010

We collected fish to mark with RFID tags concurrently with mark-recapture sampling at 3 sites (Table 5) in March – April, 2010. All Creek Chubs and Blackside Dace greater than 90 mm total length collected from Reaches A and B were injected with a 12 mm full-duplex tag, allowing them to be detected as they passed by RFID antennas.

We used Allflex RFID reader components to construct and install full-duplex antenna systems at 3 crossings (Table 5). Swim-through antennas were constructed of AWG 14, 8 strand ribbon wire enclosed in a rectangular, watertight, 2 inch PVC housing that encircled the stream channel (Figure 6). Each antenna was connected to an Allflex RFID reader panel powered by a 6V deep cycle marine battery. Tag detections were recorded on a small laptop computer powered by two 12V deep cycle marine batteries. We installed two separate systems at each crossing: a single-antenna system between Reaches A and B, and a double-antenna system at the crossing structure (Figures 2 and 3). This configuration was designed to compare movement through the crossing structure to movement within a natural stream reach. The RFID antennas were in place from April – September, 2010, except for brief periods when antennas were damaged by high flows.

2012

We collected fish to mark with RFID tags by making a single backpack electrofishing pass through Reaches 1 and 2 downstream of the crossing (Figures 4 and 5) in March – April, 2012. All Creek Chubs greater than 90 mm total length were injected with a 12 mm half duplex tag allowing them to be detected at they swam past RFID antennas. At sites where less than 50 fish were marked, we collected additional fish from outside of our sample reaches, tagged them, and placed them in the outlet pool immediately downstream of the crossing. These 'planted' fish were analyzed separately from fish marked in the 400 m reach downstream of the crossing.

We installed half-duplex systems from Oregon RFID at 6 crossings (Table 5). Swim-through antennas were constructed by stringing AWG 10 wire in a rectangular loop around the stream channel (Figure 6). Each antenna was connected to a tuner, which in turn was connected to an Oregon RFID multiple-antenna reader box that recorded tag detections. The entire system was powered by two 12 V deep cycle marine batteries. We placed 1 antenna in the first riffle downstream of the crossing, and 1 antenna in the first riffle upstream of the crossing (Figures 4 and 5) to determine if fish approaching the crossing passed through the structure and into the reach upstream. The RFID antennas were in place from March – November, 2012.

Results

Mark-Recapture

We marked a total of 33 species from the 20 crossing sites in 2010 but the majority of species were neither abundant nor widely distributed among sample sites (Table 6). We selected for analysis 5 species representing a range of swimming and leaping abilities that were relatively abundant and found at the majority of sample sites: Creek Chub (*Semotilus atromaculatus*), the *Chrosomus* species Blackside Dace (*C. cumberlandensis*) and Southern Redbelly Dace (*C. erythrogaster*), Central Stoneroller (*Campostoma anomalum*), and Rainbow Darter (*Etheostoma caeruleum*). Recapture rates varied among sites, with median, overall recapture rates of 11%, 4%, 10%, and 7%, respectively for Creek Chub, *Chrosomus* species, Central Stoneroller, and Rainbow Darter (Figures 7, 8, 9, and 10).

RFID

2010

The RFID systems were in place for between 144 and 154 days from March – September, but over that time period the antennas were damaged or displaced by high flows several times resulting in 16 lost monitoring days per site (Table 7). Batteries were replaced every 7 days on average.

We marked 13 - 74 Creek Chubs and 0 - 8 Blackside Dace per stream reach at sites 17, 18, and 19. Antenna detection rates for Creek Chubs moving between reference reaches (moving from Reach A to Reach B) ranged from 39% to 49% (Table 8). Detection rates for Creek Chubs moving through crossings were 48%, 20%, and 8% for passage difficulty ratings of easy (Site 18), moderate (Site 19), and difficult (Site17), respectively (Figure 11). Site 17 included a mainstem confluence that was not monitored for passage (Figure 3). Too few Blackside Dace were marked to allow for comparisons among reaches or sites but we did detect movement of 5 Blackside Dace through the culvert at the moderately difficult crossing (Site 19, Table 8).

2012

The RFID systems were in place for between 212 and 232 days from March - November with a total of 5 days of monitoring time lost among the 6 sites due to vandalism, equipment failure, or antenna damage during high flows (Table 7). Batteries were replaced every 14 days on average.

We marked 21 – 90 Creek Chubs in the reaches downstream of the crossings and detected between 19% and 37% of the marked fish at the antenna downstream of the crossing (Table 9). Time to first detection at the downstream antenna ranged from 0 to 27 weeks and was similar among all marking reaches, with the bulk of detections occurring within 5 weeks of mark date (Figure 12). Detection rates varied by mark location, with the highest median return rates occurring for fish marked

in Reach 2 (i.e. within 200 m downstream of the crossing) (Figure 13). A higher percentage of the fish at sites rated 'Easy' were detected at the upstream antenna after passing the downstream antenna than at sites rated 'Moderate' or 'Difficult' (Table 9, Figures 14 and 15). The majority of fish made their initial upstream movements before the end of May (Figures 14 and 15).

On April 3, we placed additional Creek Chubs in the outlet pools at Sites 19 and 17. Sixty percent of these fish moved upstream through the crossing at Site 19 and 72% moved through the crossing at Site 17 (Table 10), and the majority of the initial upstream movement through the culverts occurred before the end of May (Figure 16).

Discussion

Comparison of methods

Our objectives were to assess the effectiveness and practicality of two approaches of monitoring fish passage: traditional mark and recapture and continuous monitoring using RFID tags. With mark-recapture we detected movement through several crossings, but were not able to provide any meaningful analysis of the relative degree of passage difficulty at any crossing because of small sample sizes and low recapture rates. Low recapture rates often plague mark-recapture studies (Gowan et al. 1994), limiting the conclusions that can be made from even the most rigorous sampling designs (Albanese et al. 2003; Bouska and Paukert 2010; Norman et al. 2009; Warren and Pardew 1998). In our study, collection of marked fish upstream of a crossing provided direct evidence of fish passage, but low overall recapture rates raised questions about the fate of fish marked but never recaptured (e.g. did they move through the crossing but escape recapture?) and thus limited our appraisal of the mark-recapture approach for monitoring fish passage.

In contrast, our use of RFID antennas to continuously detect any fish implanted with a PIT tag enabled us to determine the number, timing, and distance moved through both the natural stream channel and the crossing. However, RFID monitoring systems required a large investment in both time and money to design, acquire, deploy, and maintain. The systems required frequent maintenance, including changing and charging batteries, downloading data, and repairing antennas damaged by high flows or vandalism. The high cost of equipment and maintenance thus limited the number of sites that could be concurrently maintained. However, RFID technology is rapidly evolving and as more products and vendors enter the market equipment cost, complexity, and power requirements will likely decrease making it a more viable approach in future applications.

Over the course of our study we deployed two basic systems for RFID detection: full and half-duplex. The full-duplex systems were entirely custom-built and required components from several

different vendors; half-duplex systems were purchased as nearly complete systems from a single vendor. In 2010, the smallest commercially available full- and half-duplex RFID tags were 12 mm and 23 mm, respectively. Because we were working with small-bodied non-game fishes the full-duplex systems were our only viable option. By 2012, a 12 mm half-duplex tag was available, providing us with the option to use either system type. The half-duplex systems had several advantages, including ease of design and installation, lower power requirements, and simpler data management. Full duplex antennas required a water-tight PVC housing, whereas half-duplex antenna wires could be laid directly within the wetted stream channel, greatly simplifying design, installation, maintenance, and repair. The full duplex systems required a minimum of 2 12V and 2 6V deep cycle batteries that had to be changed weekly; a similar half-duplex system required only 2 12V batteries, changed every 2 weeks. The full-duplex systems were capable of reading only one tag at a time, and provided a tag reading several times per second, so that a single fish lingering within the range of detection effectively blocked detection of other fish and resulted in thousands of redundant readings of a single tag. The half-duplex systems were capable of recording several tags simultaneously and the resulting datasets consisted of individual records per unique tag detection, greatly simplifying data management and analysis.

The RFID systems worked best at sites where there were abundant fish large enough to tag (>80 mm for a 12 mm tag). At sites in 2012 where we tagged low numbers of fish, we placed additional tagged fish in the outlet pool of the crossing. A relatively large percentage of these fish moved away from the outlet pool within several weeks, suggesting that perhaps planted fish could be used to rapidly assess the passage status of a crossing. Similar observations have been made during passage monitoring studies in western streams (Jason Dunham, USGS, pers. comm.). However, we only planted fish at sites rated as 'Easy', and additional testing is needed to determine if planted fish provide a realistic determination of passage status or if the stress induced by planting large numbers of fish in a small area produces movements that do not accurately reflect the true impact of a crossing on a fish population.

Observations on movements

The characteristics of Creek Chub movements we observed using RFID systems may be useful for planning future monitoring projects. Most fish moved between the months of March and June, shortly after being tagged. Although we do not know if these patterns are reflective of natural movement tendencies or a result of stress caused by tagging, our results demonstrate that monitoring for a relatively short period of time can be effective for confirming fish passage through a crossing.

The probability of detecting tagged fish decreased as distance from the site of tagging to the crossing increased; the greatest proportion of fish detected at a crossing came from fish tagged within

200 m of the crossing . However, use of short reach lengths for marking would have limited our ability to determine the range of movements capable by a species. For example, in the Dog Slaughter Creek drainage we detected a movement between Site 17 (North Fork) and Site 19 (South Fork), a distance of 4 km completed in 5 days (March 29 – April 4, 2012) by a 211 mm Creek Chub. Where resources permit, the placment of multiple, RFID antenna arrays throughout a drainage can help to describe the full range of fish movements (Kanno et al. 2014; Zydlewski et al. 2006).

Additional sampling

We also collected fin clips and recorded fish community information at 20 crossing sites and 3 waterfall sites (Figure 1, Tables 1-4) in both 2010 and 2012. The fin clip samples and fish community datasets have been sent to our project partners at the University of Massachusetts and USDA Forest Service, Northern Research Station for analysis and additional reports assessing both genetic (Dr. Andrew Whitely and Jason Coombs) and abundance-based (Dr. Keith Nislow) approaches for detecting fish passage are forthcoming.

Summary

The benefits and costs of the approaches we tested for assessing fish passage varied widely Mark-recapture methods provided only the coarsest level of passage information and, although changes in sampling design and intensity may improve future results we do not recommend this approach. Continuous monitoring of RFID-tagged fish with strategically placed antennas was highly effective for detecting fish passage and comparing passage at sites with varying levels of passage difficulty, but the initial outlay required significant effort to maintain. These are only two approaches in an ever growing plethora of passage detection techniques, which is rapidly expanding to include not only site-specific passage detection, but also information on population genetic (Neville and Peterson 2014; Whiteley et al. 2014) or demographic characteristics (Nislow et al. 2011), and ultimately for determining the effectiveness of entire fish passage programs (Chelgren and Dunham *In press*). At the present time, no single approach can definitively describe fish movement patterns or resolve all questions about fish passage through barriers, both natural and man-made. As the number of tools in the movement detection toolbox grows managers must select methods and sampling protocols best suited to cost-effectively address their clearly defined project goals and expectations.

Acknowledgements

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Figures

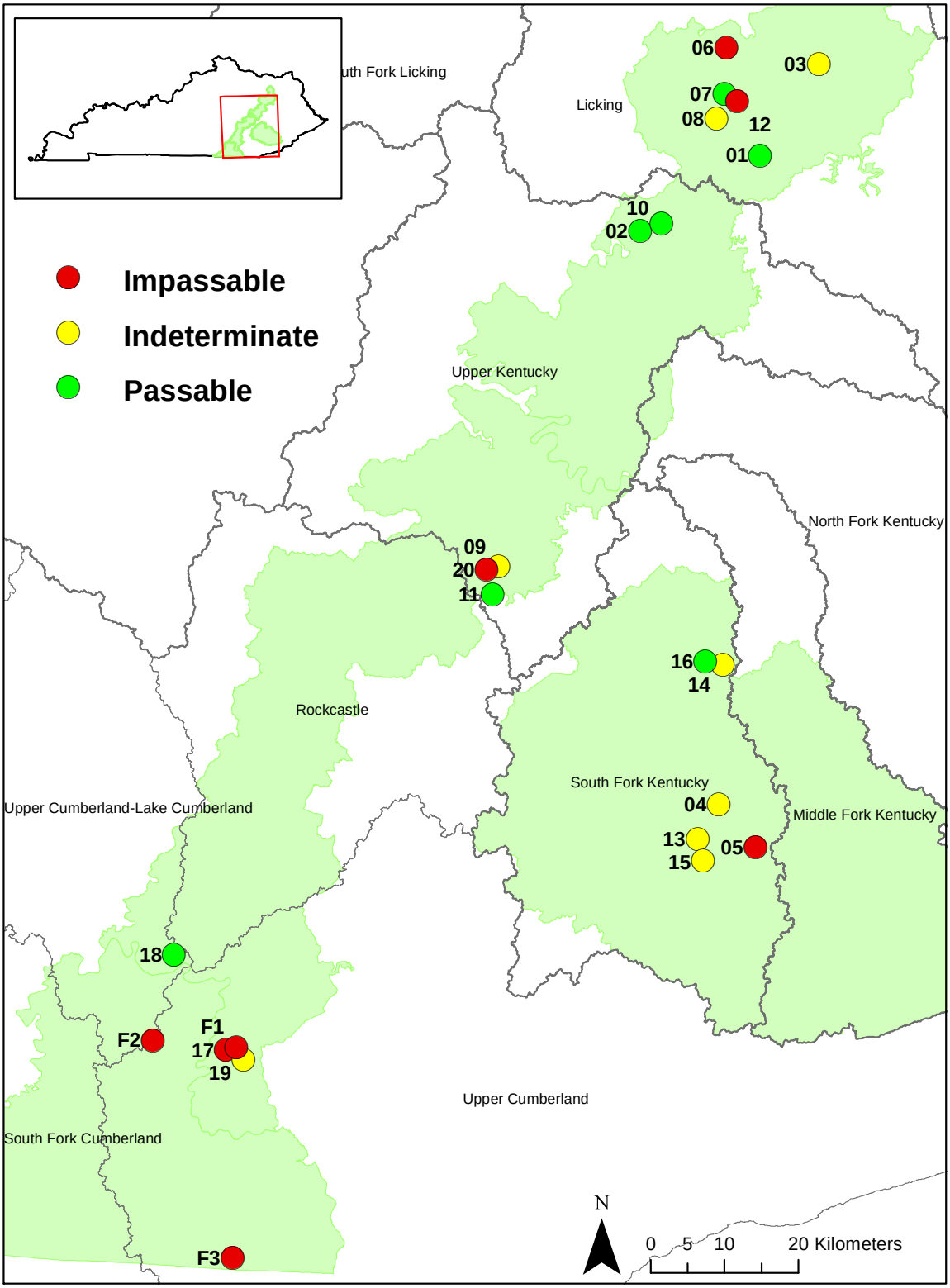


Figure 1. Road-stream crossing and waterfall monitoring sites on the Daniel Boone National Forest (green shading) in 2010 and 2012. See Tables 1 & 2 for location and description. Passage ratings are prior to start of project and are presented for moderately strong swimmers and leapers as described for Filter B in Coffman (2005). Sites 17 and 19 were modified in 2011 to improve fish passage.

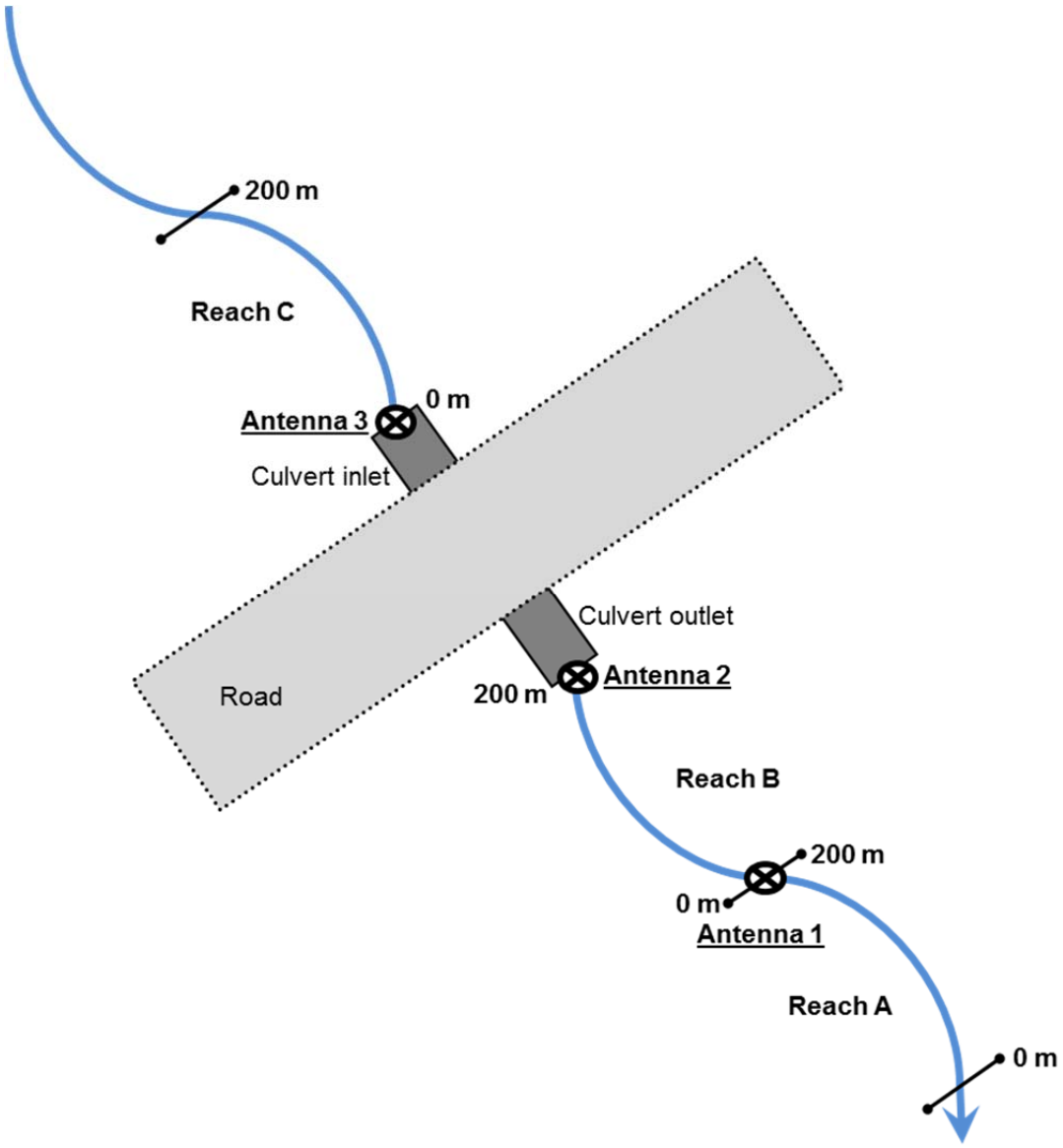


Figure 2. Reach layout and RFID antenna configuration at non-tributary sites in 2010.

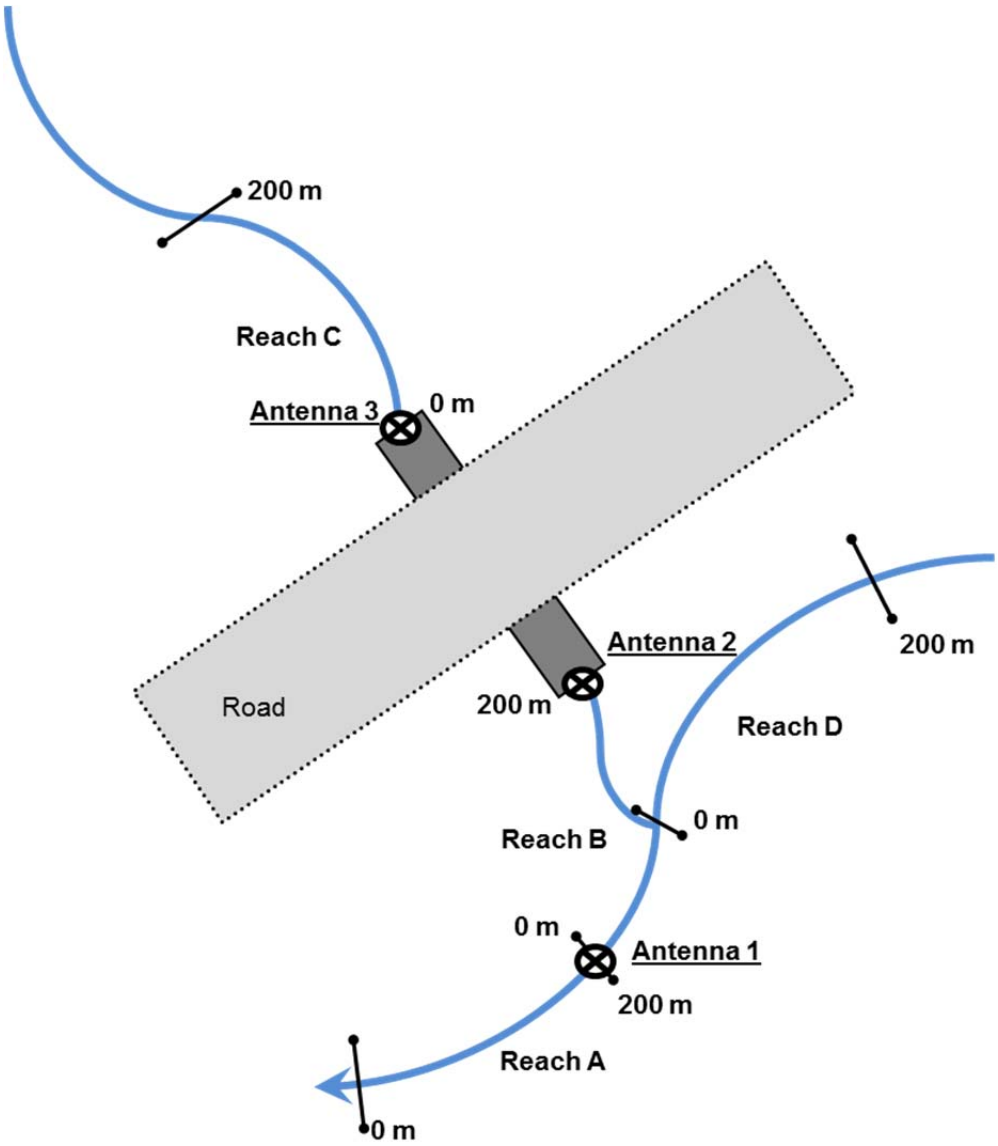


Figure 3. Reach layout and RFID antenna configuration at tributary sites in 2010.

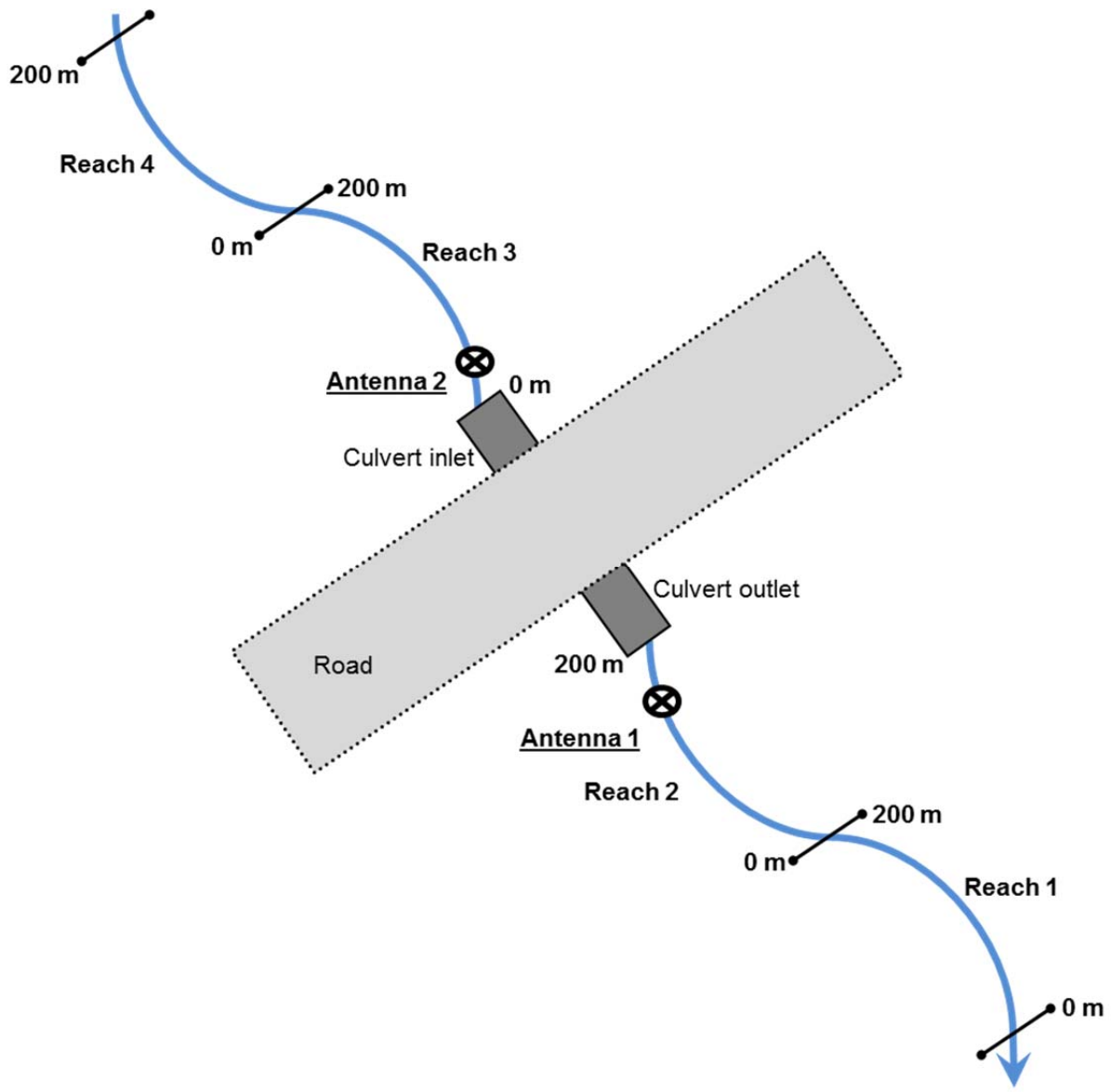


Figure 4. Reach layout and RFID antenna configuration at non-tributary sites in 2012.

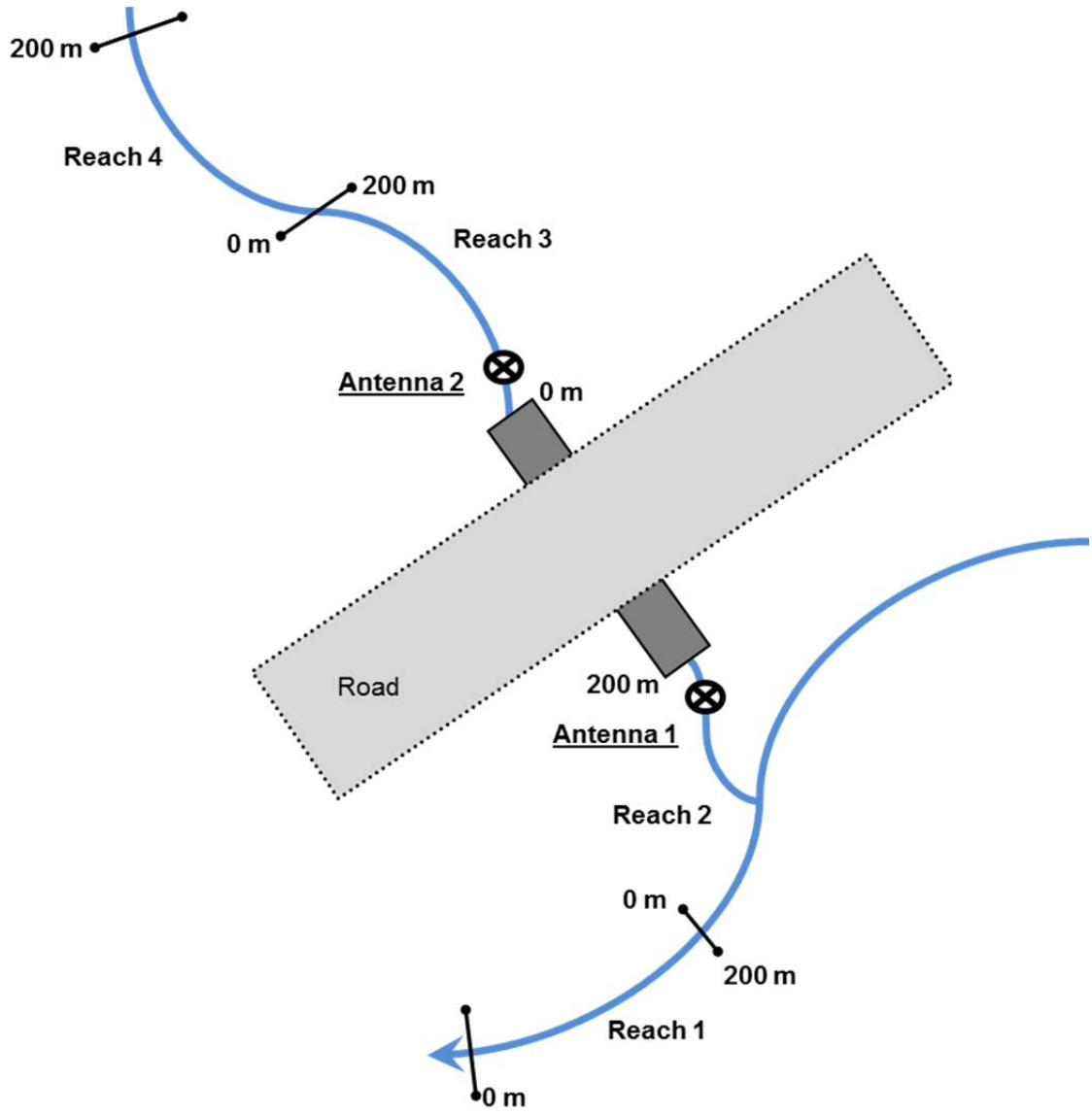


Figure 5. Reach layout and RFID antenna configuration at tributary sites in 2012.

Figure 6. Full-duplex (top) and half-duplex (bottom; antenna marked with orange flagging) swim-through antenna designs. The full-duplex design was used in 2010, the half-duplex in 2012.

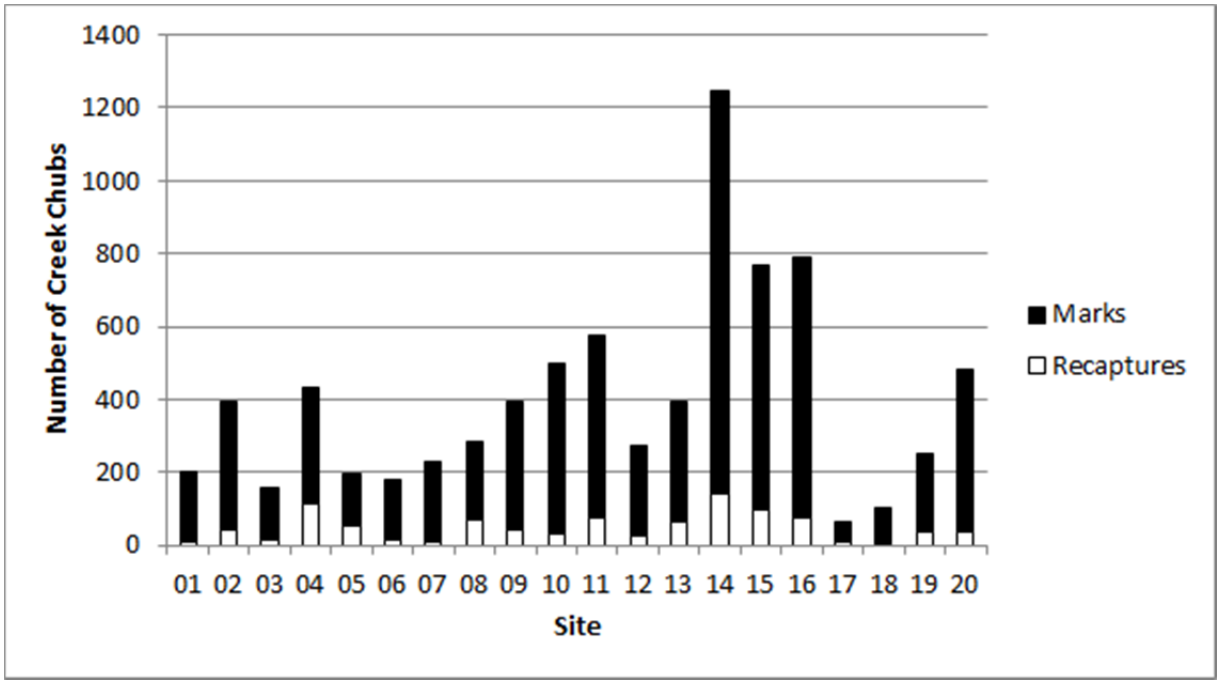


Figure 7. Number of Creek Chubs collected during mark and recapture sampling at 20 road-stream crossings on the Daniel Boone National Forest, 2010. Recaptures includes marked fish collected from downstream and upstream of the crossing.

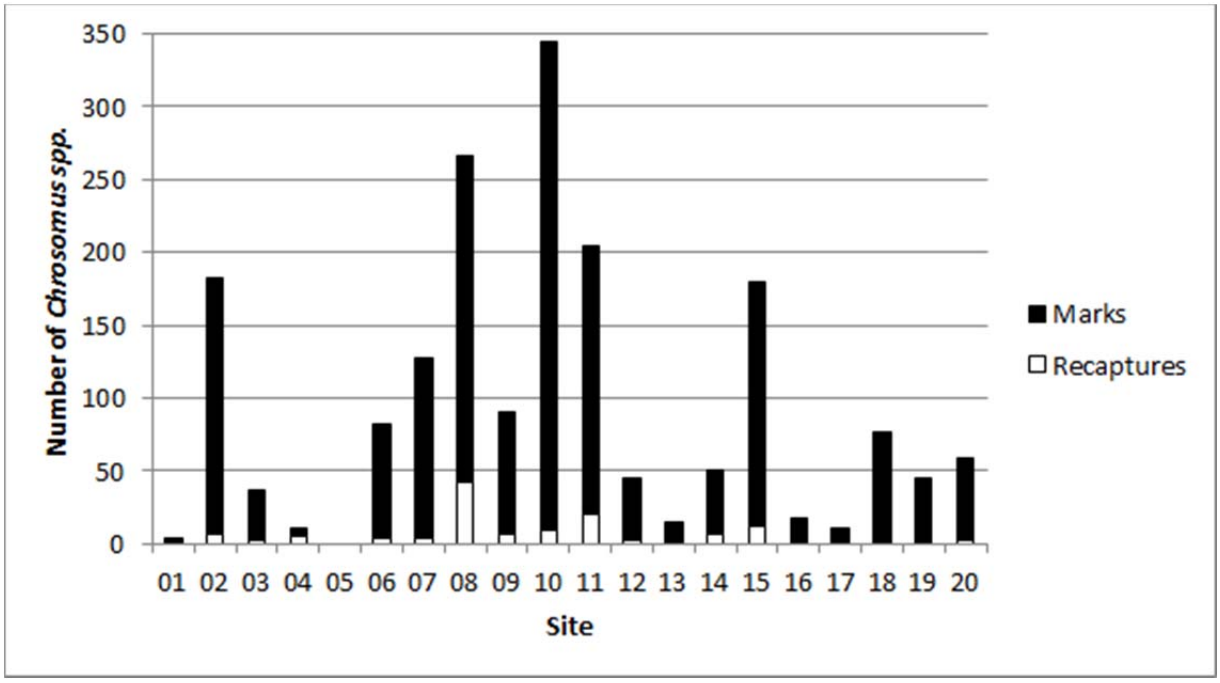


Figure 8. Number of *Chrosomus* species collected during mark and recapture sampling at 20 road-stream crossings on the Daniel Boone National Forest, 2010. *C. cumberlandensis* were collected at sites 17, 18, and 19; *C. erythrogaster* at all other sites. Recaptures includes marked fish collected from downstream and upstream of the crossing.

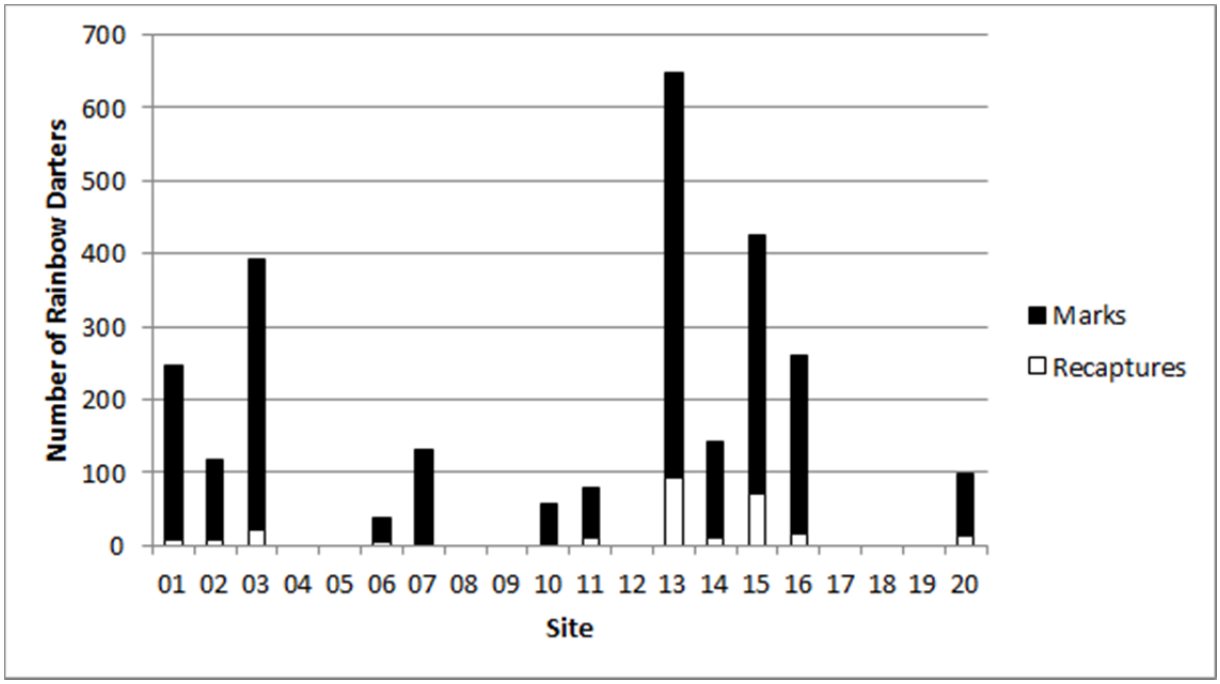


Figure 9. Number of Rainbow Darters collected during mark and recapture sampling at 20 road-stream crossings on the Daniel Boone National Forest, 2010. Recaptures includes marked fish collected from downstream and upstream of the crossing.

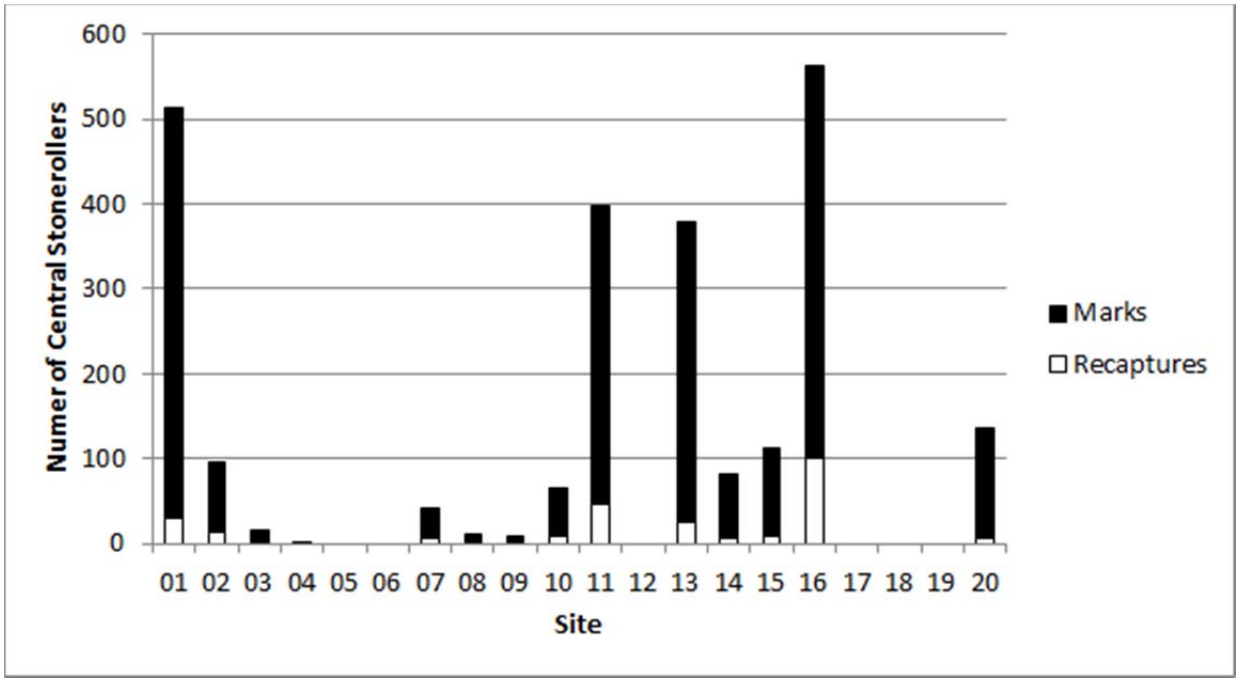


Figure 10. Number of Central Stonerollers collected during mark and recapture sampling at 20 road-stream crossings on the Daniel Boone National Forest, 2010. Recaptures includes marked fish collected from downstream and upstream of the crossing.

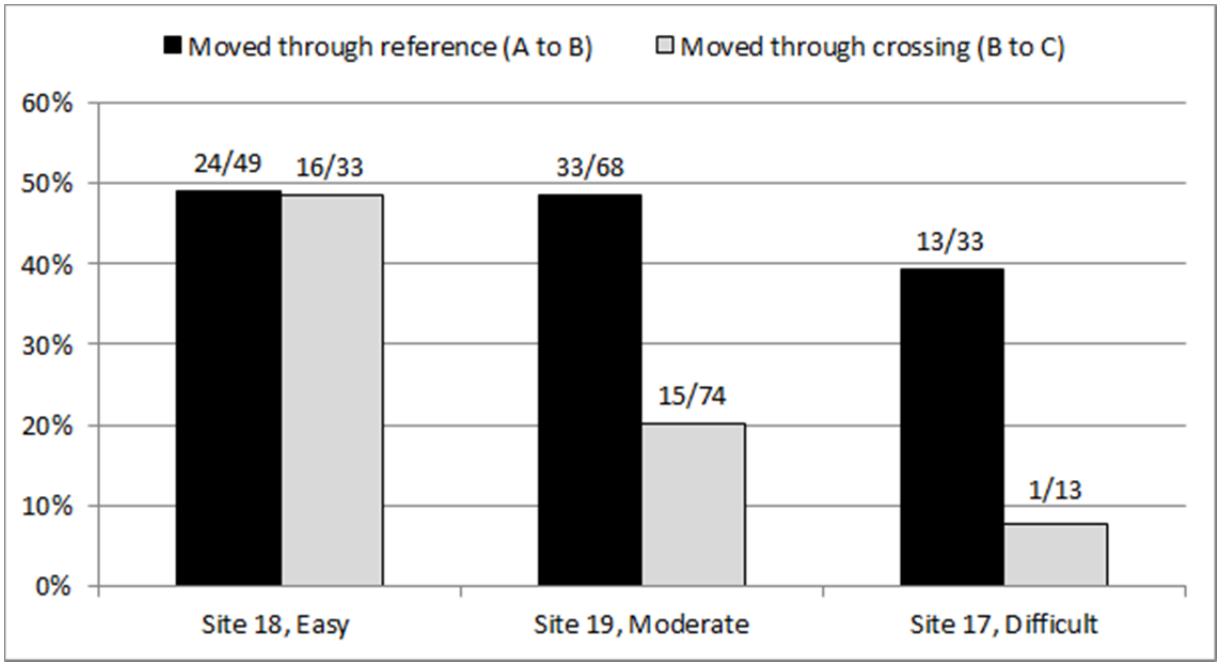


Figure 11. Percentage of Creek Chubs marked with RFID tags detected moving through a reference reach (from Reach A to Reach B) or through crossing structures (from Reach B to Reach C) at three sites on the Daniel Boone National Forest, 2010. Reach layouts are displayed in Figure 2 (Site 18, Site 19) and Figure 3 (Site 17). Site 17 had an unmonitored mainstem confluence near the crossing. Fractions above bars are the number detected over the number marked.

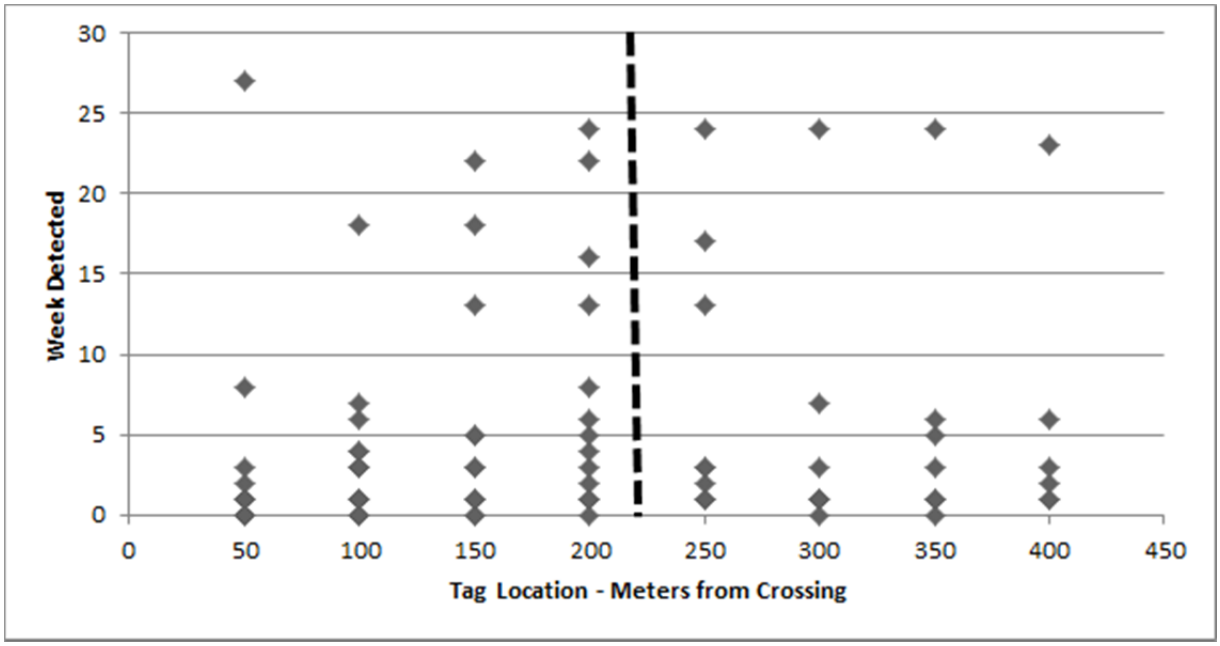


Figure 12. Time to first detection at the downstream antenna for RFID marked Creek Chubs marked at 6 road-stream crossings on the Daniel Boone National Forest, 2012. Vertical dashed line separates fish marked in Reach 1 (meter 400 to meter 200) from Reach 2 (meter 200 to meter 0) downstream of the road crossing (meter 0).

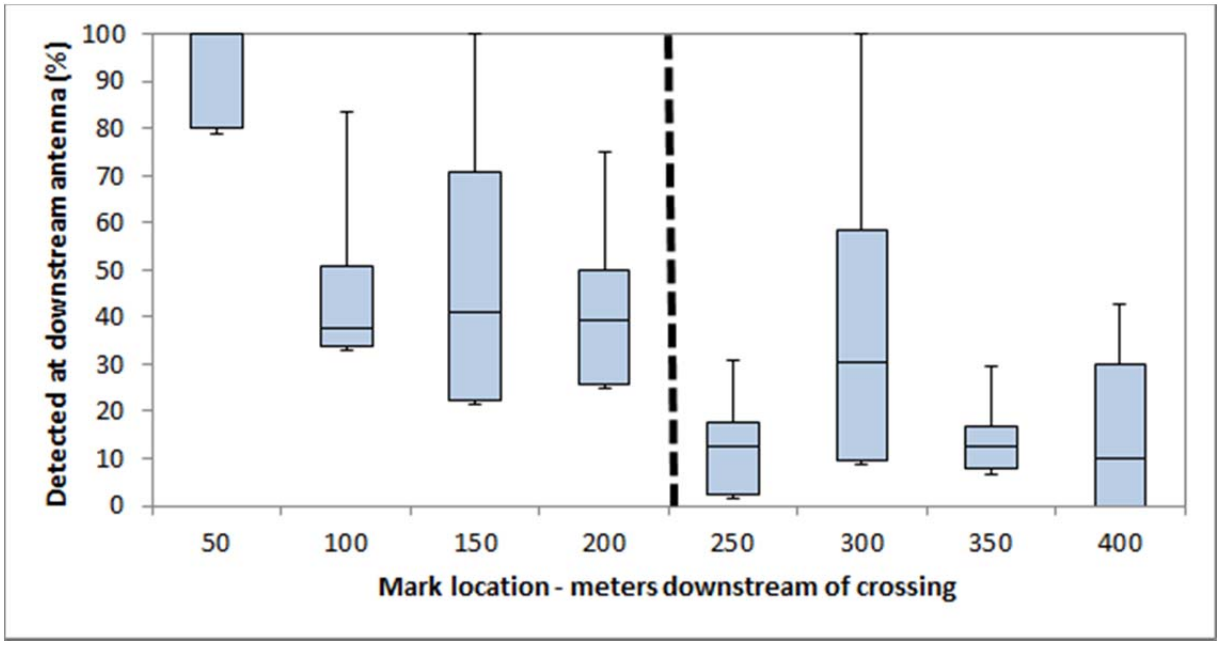
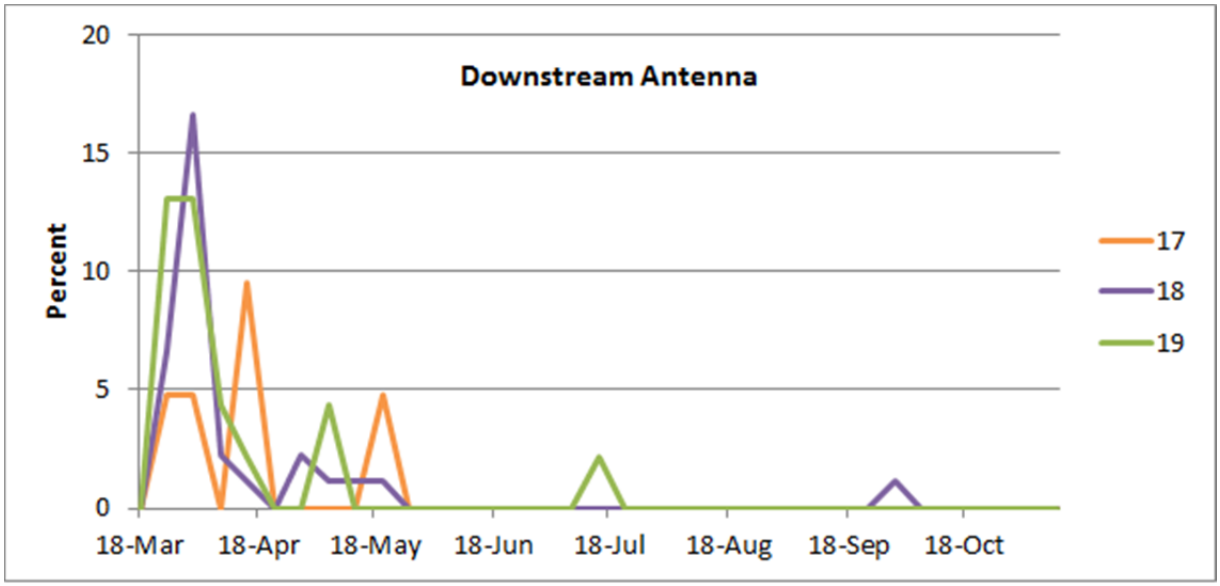


Figure 13. Percentage of Creek Chubs marked with RFID tags that were later detected at the downstream antenna at 6 road-stream crossings on the Daniel Boone National Forest, 2012. Box plot whiskers represent the total range of values; top and bottom of box are 25th and 75th percentiles; middle line is median. N = 6 (6 crossings) for each box plot. Vertical dashed line separates fish marked in Reach 1 (meter 400 to meter 200) from Reach 2 (meter 200 to meter 0) downstream of the road crossing (meter 0).



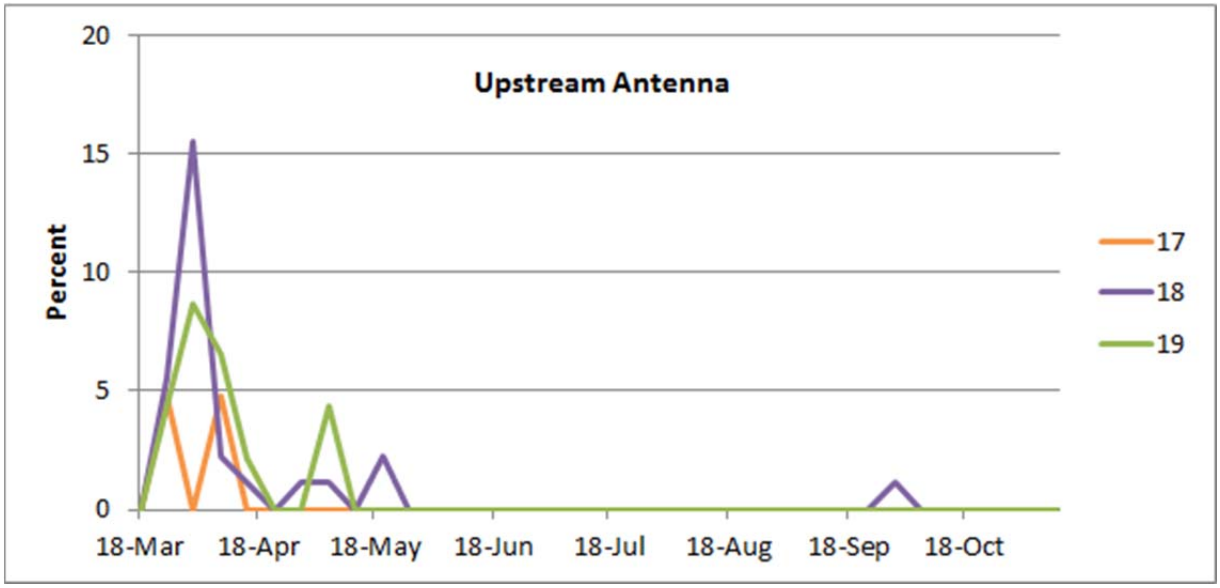
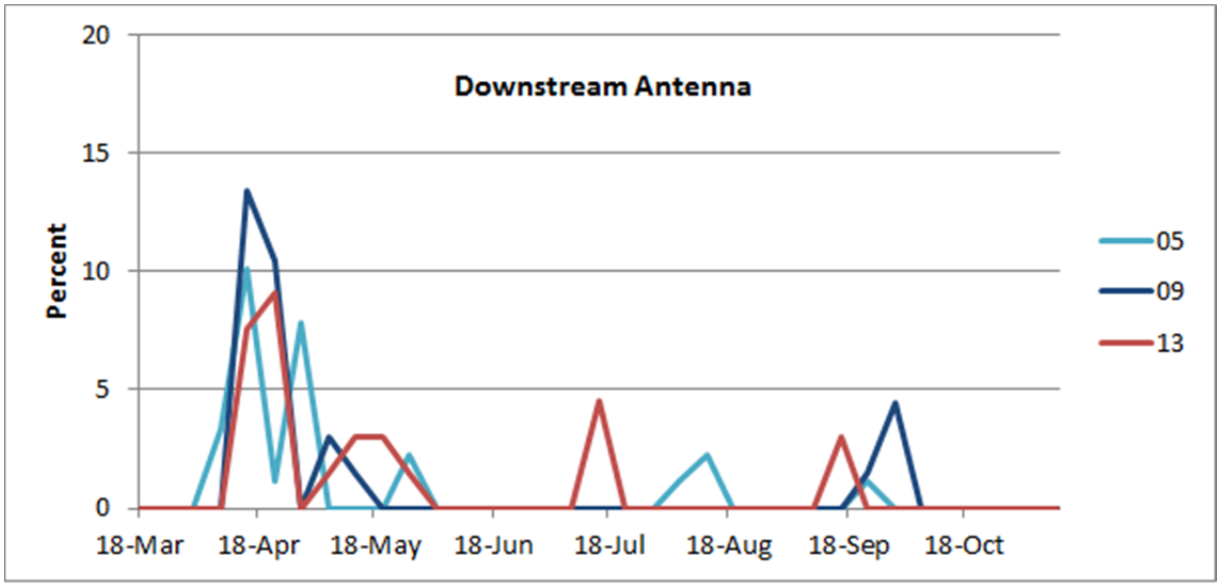


Figure 14. Percent of RFID marked Creek Chubs from Reaches 1 and 2 detected at antennas downstream and upstream of road crossings rated as 'Easy' for fish passage in 2012 (sites 17, 18, and 19). Percent is the number of new (i.e. first-time) detections / total Creek Chubs marked *100 and is reported here by week. For example, the week of April 1, 17% of the total marked fish were detected for the first time at the downstream antenna at Site 18. Reach layouts are displayed in Figure 4 (Site 18, Site 19) and Figure 5 (Site 17). Site 17 had an unmonitored mainstem confluence near the crossing. Fractions above bars are the number detected over the number marked.



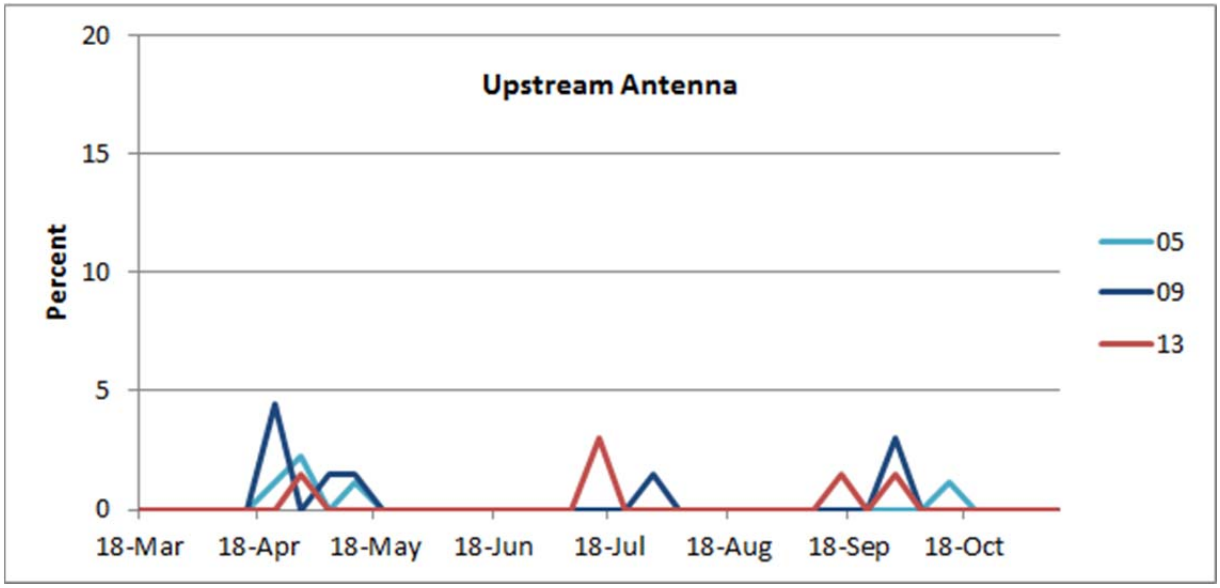


Figure 15. Percent of RFID marked Creek Chubs from Reaches 1 and 2 detected at antennas downstream and upstream of road crossings rated as 'Moderate' or 'Difficult' for fish passage in 2012 (sites 05, 09, and 13). Percent is the number of new (i.e. first-time) detections / total Creek Chubs marked *100 and is reported here by week. For example, the week of April 15, 13% of the total marked fish were detected for the first time at the downstream antenna at Site 09. Reach layout is displayed in Figure 4.

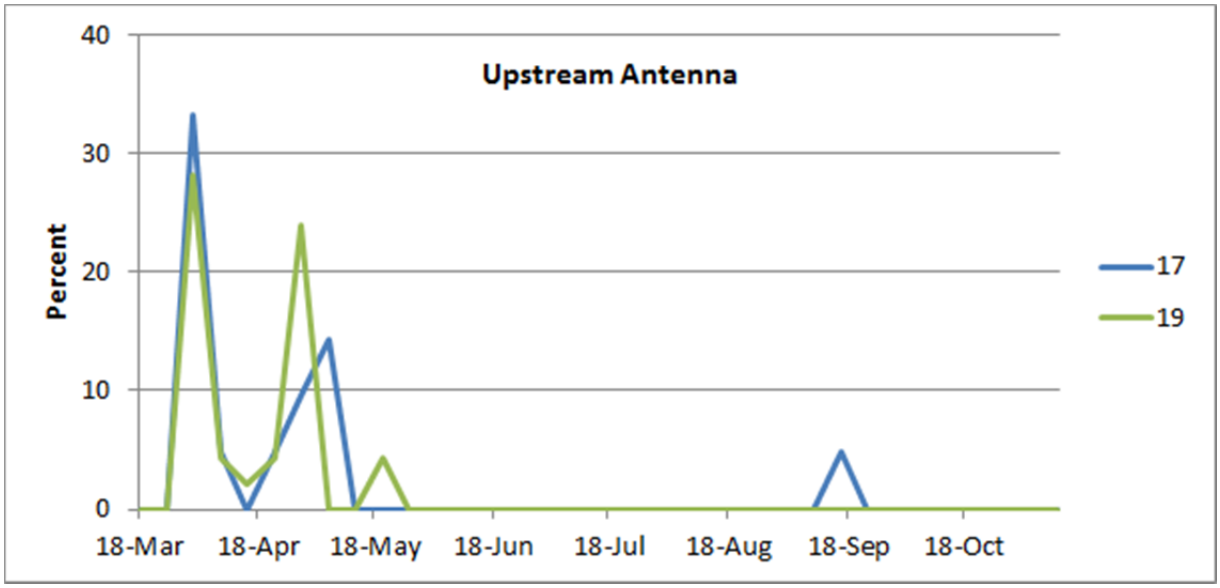


Figure 16. Percent of RFID marked Creek Chubs planted in the outlet pools of sites 17 and 19 that were detected at the antenna upstream of the crossing. Percent is the number of new (i.e. first-time) detections / total Creek Chubs planted *100 and is reported here by week. For example, the week of April 1, 33% of the total planted fish were detected for the first time at the upstream antenna at Site 17.

Tables

Table 1. Location of road-stream crossing and waterfall monitoring sites on the Daniel Boone National Forest (green shading) in 2010 and 2012.

Site	Stream	District	USGS Quad	Road	GPS (NAD83)
01	Meyers Fork	Cumberland	Scranton	1240	N37.96918, W83.526672
02	Big Cordual Branch	Cumberland	Slade	MEN-164	N37.873063, W83.70792
03	Warix Run	Cumberland	Bangor	ROW-1298	N38.082176, W83.440348
04	Grannys Branch	Redbird	Big Creek	1604	N37.176819, W83.562829
05	Sugar Creek	Redbird	Big Creek	1600	N37.126407, W83.505654
06	Caney Creek	Cumberland	Salt Lick	105	N38.098999, W83.58347
07	Clear Creek	Cumberland	Salt Lick	909	N38.042526, W83.584108
08	Clear Creek	Cumberland	Salt Lick	909	N38.012924, W83.595727
09	Hughes Fork	London	McKee	4- Elster	N37.459529, W83.909677
10	Leatherwood Fork	Cumberland	Slade	9A	N37.883192, W83.676041
11	Unnamed	London	McKee	JAC-3112	N37.424743, W83.917656
12	Leatherwood Creek	Cumberland	Salt Lick	BAT-129	N38.034432, W83.564631
13	Little Double Creek	Redbird	Big Creek	1500	N37.134626, W83.594092
14	Cortland Fork	Redbird	Mistletoe	1649	N37.34798, W83.563043
15	Big Double Creek	Redbird	Creekville	1501	N37.107997, W83.584372
16	Laurel Fork	Redbird	Mistletoe	1649	N37.351027, W83.589521
17	NF Dog Slaughter Creek	London	Cumberland Falls	195	N36.859475, W84.299921
18	Big Lick	Somerset	Hail	272	N36.973098, W84.384138
19	SF Dog Slaughter Creek	London	Cumberland Falls	195	N36.848178, W84.272985
20	Warfork	London	McKee	3109	N37.454744, W83.927265
F1	Little Dog Slaughter	London	Cumberland Falls	NA	N36.862944, W84.28444
F2	Eagle Creek	Stearns	Wiborg	NA	N36.868471, W84.411172
F3	Rock Creek	Stearns	Ketchen	NA	N36.60655, W84.279457

Table 2. Description of road-stream crossing and waterfall monitoring sites on the Daniel Boone National Forest prior to initiation of project in 2010. Sites 06, 17, and 19 were modified or replaced to improve fish passage between 2010 and 2012. Material for vented fords refers to vents; all vented fords were composed of concrete. For sites with multiple pipes the width and height are for each individual pipe.

Site	Stream	Tributary	Shape	Material	Pipes	Width (ft)	Height (ft)
01	Meyers Fork	--	Box	Concrete	2	17.8	9.8
02	Big Cordual Branch	Yes	Circular	Concrete	2	5.0	5.0
03	Warix Run	--	Circular	Smooth metal	1	7.3	7.4
04	Grannys Branch	--	Circular	Smooth metal	2	2.3	2.3
05	Sugar Creek	--	Pipe arch	Corrugated metal	1	11.9	7.9
06	Caney Creek	--	Pipe arch	Corrugated metal	1	9.4	6.6
07	Clear Creek	--	Box	Concrete	1	22.3	6.6
08	Clear Creek	--	Circular	Corrugated metal	2	5.4	5.4
09	Hughes Fork	--	Pipe arch	Corrugated metal	1	14.1	8.3
10	Leatherwood Fork	--	Open bottom arch	Corrugated metal	1	21.1	9.2
11	Unnamed	--	Vented ford	Concrete	4	1.7	1.7
12	Leatherwood Creek	--	Pipe arch	Corrugated metal	1	11.9	6.8
13	Little Double Creek	--	Circular	Corrugated metal	2	4.1	4.1
14	Cortland Fork	Yes	Pipe arch	Smooth metal	1	7.7	5.3
15	Big Double Creek	--	Vented ford	Corrugated metal	4	3.5	2.3
16	Laurel Fork	--	Vented ford	Corrugated metal	5	1.7	1.7
17	NF Dog Slaughter Creek	Yes	Pipe arch	Corrugated metal	1	13.3	8.4
18	Big Lick	--	Pipe arch	Corrugated metal	1	12.0	6.7
19	SF Dog Slaughter Creek	--	Pipe arch	Corrugated metal	1	11.6	7.6
20	Warfork	--	Vented ford	Concrete	4	2.0	2.0
F1	Little Dog Slaughter	--	Waterfall	--	--	--	--
F2	Eagle Creek	--	Waterfall	--	--	--	--
F3	Rock Creek	--	Waterfall	--	--	--	--

Table 3. Site attributes used to calculate passage ratings for stream crossings and waterfall monitoring sites on the Daniel Boone National Forest. Site attributes for stream crossings were recorded prior to initiation of the project in 2010. Sites 06, 17, and 19 were modified or replaced to improve fish passage between 2010 and 2012. Substrate: Y = substrate in pipe similar to substrate in stream channel. Backwater: Y = outlet pool tail crest higher in elevation than pipe inlet resulting in pool throughout the pipe. Drop: difference in elevation between pipe outlet and riffle crest of outlet pool. Drop for waterfall sites is largest vertical drop in the series of cascades and waterfalls at the site. Slope is change in elevation between pipe inlet and outlet divided by pipe length. Slope * Length is percent pipe slope multiplied by pipe length.

Site	Stream	Substrate	Backwater	Drop (ft)	Slope (%)	Slope*Length
01	Meyers Fork	Y	Y	0	0	10
02	Big Cordual Branch	N	Y	0	-1	-42
03	Warix Run	N	N	0.73	1	42
04	Grannys Branch	N	N	0.19	3	105
05	Sugar Creek	N	N	1.95	2	138
06	Caney Creek	N	N	1.16	2	196
07	Clear Creek	Y	N	0	1	24
08	Clear Creek	N	N	0.51	2	166
09	Hughes Fork	N	N	0.67	1	71
10	Leatherwood Fork	Y	N	0	1	26
11	Unnamed	N	N	0.33	1	14
12	Leatherwood Creek	N	N	0	7	393
13	Little Double Creek	N	N	0.25	2	35
14	Cortland Fork	N	N	0.29	2	70
15	Big Double Creek	N	N	0.32	3	106
16	Laurel Fork	N	N	0.64	0	6
17	NF Dog Slaughter Creek	N	N	1.41	1	89
18	Big Lick	Y	Y	0	0	-1
19	SF Dog Slaughter Creek	N	N	0.74	1	95
20	Warfork	N	N	1.13	1	29
F1	Little Dog Slaughter	--	--	4.5	--	--
F2	Eagle Creek	--	--	7.5	--	--
F3	Rock Creek	--	--	4.5	--	--

Table 4. Passage ratings of road-stream crossing and waterfall monitoring sites on the Daniel Boone National Forest prior to initiation of project in 2010. Ratings are based on coarse filter models presented in Coffman (2005) for strong, moderate, and weak swimming/leaping fishes; see appendix A for detailed description of coarse filter models. Three crossings were replaced or modified to improve fish passage over the duration of the project.

Site	Stream	A-strong	B-moderate	C-weak	Upgrade
01	Meyers Fork	Easy	Easy	Easy	--
02	Big Cordual Branch	Easy	Easy	Easy	--
03	Warix Run	Easy	Moderate	Difficult	--
04	Grannys Branch	Moderate	Moderate	Moderate	--
05	Sugar Creek	Moderate	Difficult	Difficult	--
06	Caney Creek	Moderate	Difficult	Difficult	2010
07	Clear Creek	Easy	Easy	Easy	--
08	Clear Creek	Moderate	Moderate	Difficult	--
09	Hughes Fork	Moderate	Moderate	Difficult	--
10	Leatherwood Fork	Easy	Easy	Easy	--
11	Unnamed	Easy	Easy	Easy	--
12	Leatherwood Creek	Moderate	Difficult	Difficult	--
13	Little Double Creek	Easy	Moderate	Moderate	--
14	Cortland Fork	Moderate	Moderate	Moderate	--
15	Big Double Creek	Moderate	Moderate	Moderate	--
16	Laurel Fork	Easy	Easy	Difficult	--
17	NF Dog Slaughter Creek	Moderate	Difficult	Difficult	2011
18	Big Lick	Easy	Easy	Easy	--
19	SF Dog Slaughter Creek	Moderate	Moderate	Difficult	2011
20	Warfork	Easy	Difficult	Difficult	--
F1	Little Dog Slaughter	Difficult	Difficult	Difficult	NA
F2	Eagle Creek	Difficult	Difficult	Difficult	NA
F3	Rock Creek	Difficult	Difficult	Difficult	NA

Table 5. Methods tested at road-stream crossing and waterfall monitoring sites on the Daniel Boone National Forest in 2010 and 2012. This report presents results for mark-recapture and RFID results only; abundance and genetics based approaches are being analyzed separately by our project partners at the University of Massachusetts and USDA Forest Service Northern Research Station.

Site	Stream	Mark-Recap	Abundance	Genetics	RFID
01	Meyers Fork	2010	2012	--	--
02	Big Cordual Branch	2010	2012	--	--
03	Warix Run	2010	2012	--	--
04	Grannys Branch	2010	2012	--	--
05	Sugar Creek	2010	--	--	2012
06	Caney Creek	2010	2012	--	--
07	Clear Creek	2010	2012	--	--
08	Clear Creek	2010	2012	--	--
09	Hughes Fork	2010	2012	2010, 2012	2012
10	Leatherwood Fork	2010	2012	2010, 2012	--
11	Unnamed	2010	2012	--	--
12	Leatherwood Creek	2010	2012	--	--
13	Little Double Creek	2010	2012	2012	2012
14	Cortland Fork	2010	2012	--	--
15	Big Double Creek	2010	2012	--	--
16	Laurel Fork	2010	2012	2010, 2012	--
17	NF Dog Slaughter Creek	2010	2012	2010, 2012	2010, 2012
18	Big Lick	2010	2012	2010, 2012	2010, 2012
19	SF Dog Slaughter Creek	2010	2012	2010, 2012	2010, 2012
20	Warfork	2010	2012	2010, 2012	--
F1	Little Dog Slaughter	--	2012	2012	--
F2	Eagle Creek	--	2012	2012	--
F3	Rock Creek	--	2012	2012	--

Table 6. Number of fish marked at each site in 2010. Table continued on next page.

Species	01	02	03	04	05	06	07	08	09	10	11	12
Ambloplites rupestris	1											
Campostoma anomalum	513	95	15	1			41	12	8	65	397	
Catostomus commersoni	21	17					4			9	59	
Clinostomus elongatus	5	24					10	10		40		
Chrosomus cumberlandensis												
Chrosomus erythrogaster	4	183	37	10		82	128	266	91	344	205	45
Cottus bairdi	301	428					452	313	301	286	485	33
Cyprinella spiloptera			12									
Etheostoma baileyi												
Etheostoma blennioides	1	4								5		
Etheostoma caeruleum	247	118	392			37	130			58	78	
Etheostoma flabellare	110	36		86			1		43	78	151	
Etheostoma nigrum	99		57			7	57			12	117	
Etheostoma sagitta spp.					8							
Hypentelium nigricans	58	1									11	
Labidesthes sicculus	1											
Lepomis cyanellus						6					5	
Lepomis macrochirus			6								4	
Lepomis megalotis			43									
Lepomis spp.	759	1	93	13		13	10				28	
Luxilus chrysocephalus	85		3				45			10		
Lythrurus fasciolaris	4											
Micropterus dolomieu												
Micropterus punctulatus	1											
Micropterus salmoides			3									
Notropis buccatus	9											
Notropis volucellus												
Oncorhynchus mykiss												
Percina caprodes	30		100			127						1
Percina maculata										4		
Percina stictogaster		1								1		
Pimephales notatus	71		65			4	1					
Rhinichthys obtusus	33	94	29		2	76	47	290		424		59
Semotilus atromaculatus	203	395	160	434	196	180	230	286	396	498	578	274

Table 6 (*continued*). We did not collect fish at waterfall sites (F1, F2, F3) in 2010.

Species	13	14	15	16	17	18	19	20	F1	F2	F3
Ambloplites rupestris									--	--	--
Campostoma anomalum	378	82	112	562				135	--	--	--
Catostomus commersoni		14	21	19				12	--	--	--
Clinostomus elongatus									--	--	--
Chrosomus cumberlandensis					10	77	45		--	--	--
Chrosomus erythrogaster	15	51	180	18				59	--	--	--
Cottus bairdi								377	--	--	--
Cyprinella spiloptera			2						--	--	--
Etheostoma baileyi				3					--	--	--
Etheostoma blennioides	44	6	19	97					--	--	--
Etheostoma caeruleum	649	142	426	261				98	--	--	--
Etheostoma flabellare	294	293	102	320				144	--	--	--
Etheostoma nigrum	24	18	35	89					--	--	--
Etheostoma sagitta spp.		53	8	92		1			--	--	--
Hypentelium nigricans	2		3	17					--	--	--
Labidesthes sicculus									--	--	--
Lepomis cyanellus	2	39		16					--	--	--
Lepomis macrochirus								1	--	--	--
Lepomis megalotis									--	--	--
Lepomis spp.	6	130		33				3	--	--	--
Luxilus chrysocephalus	121		70	74					--	--	--
Lythrurus fasciolaris	37			2					--	--	--
Micropterus dolomieu				3					--	--	--
Micropterus punctulatus									--	--	--
Micropterus salmoides									--	--	--
Notropis buccatus				6					--	--	--
Notropis volucellus	1								--	--	--
Oncorhynchus mykiss	3		5					3	--	--	--
Percina caprodes									--	--	--
Percina maculata	2		8	5					--	--	--
Percina stictogaster	1		3	2					--	--	--
Pimephales notatus	24		1	4					--	--	--
Rhinichthys obtusus									--	--	--
Semotilus atromaculatus	393	1248	769	792	64	101	250	483	--	--	--

Table 7. Dates RFID antennas monitored for fish movement in 2010 and 2012. We did not install antennas at sites 05, 09, or 13 in 2010. Days Lost are the number of days we not able to monitor for fish movement due to antenna damage or equipment failure.

Site	Year	Start	End	Days	Days Lost	Reason Lost
05	2010	--	--	--	--	--
09	2010	--	--	--	--	--
13	2010	--	--	--	--	--
17	2010	16-Apr	7-Sep	144	16	flood damage
18	2010	25-Mar	26-Aug	154	16	flood damage
19	2010	15-Apr	7-Sep	145	16	flood damage
05	2012	11-Apr	16-Nov	219	0	
09	2012	17-Apr	16-Nov	213	2	flood damage
13	2012	18-Apr	16-Nov	212	0	
17	2012	29-Mar	15-Nov	231	0	
18	2012	29-Mar	15-Nov	231	2	vandalism and equipment failure
19	2012	28-Mar	15-Nov	232	1	vandalism

Table 8. Number of fish marked with RFID tags, and number of fish with RFID tags detected moving past antennas between Reaches A and B and Reaches B and C in 2010. Movement from Reach A to Reach B is movement through a reference reach; movement from Reach B to Reach C is movement through the crossing structure. Reach layouts are displayed in Figure 2 (Site 18, Site 19) and Figure 3 (Site 17).

Species	Site	Passage	Marked A	Detected B	Moved A to B	Marked B	Detected C	Moved B to C
Creek Chub	18	Easy	49	24	49%	33	16	48%
	19	Moderate	68	33	49%	74	15	20%
	17	Difficult	33	13	39%	13	1	8%
Blackside Dace	18	Easy	0	0	NA	0	0	NA
	19	Moderate	2	2	100%	8	5	63%
	17	Difficult	1	1	100%	0	0	NA

Table 9. Number of Creek Chubs marked with RFID tags and later detected at antennas placed downstream and upstream of road crossings, 2012. % Passage is calculated as Upstream / Downstream *100 (i.e. the percentage of fish that approached the crossing that successfully crossed through the structure). Crossing structures at sites 19 and 17 were improved for fish passage in 2011. Reach layouts are displayed in Figure 4 (all sites excluding Site 17) and Figure 5 (Site 17).

Site	2012 Rating	Marked (n)	Downstream (n)	Upstream (n)	% Passage
18	Easy	90	27	24	89
19	Easy	46	17	12	71
17	Easy	21	4	2	50
13	Moderate	66	22	5	23
09	Difficult	67	23	8	35
05	Difficult	89	26	5	19

Table 10. Number of Creek Chubs marked with RFID tags, planted in the outlet pool, and later detected at the antenna upstream of the crossing structure in 2012. Percent Passage is calculated as Upstream / Planted *100. Crossing structures at sites 19 and 17 were improved for fish passage in 2011.

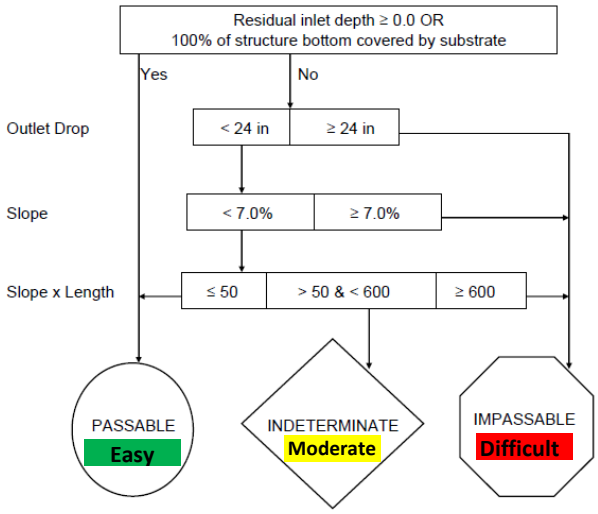
Site	2012 Rating	Planted (n)	Upstream (n)	% Passage
19	Easy	25	15	60
17	Easy	43	31	72

Appendix A – Coarse Filter Models

Filter A

Application: strong swimmers and leapers

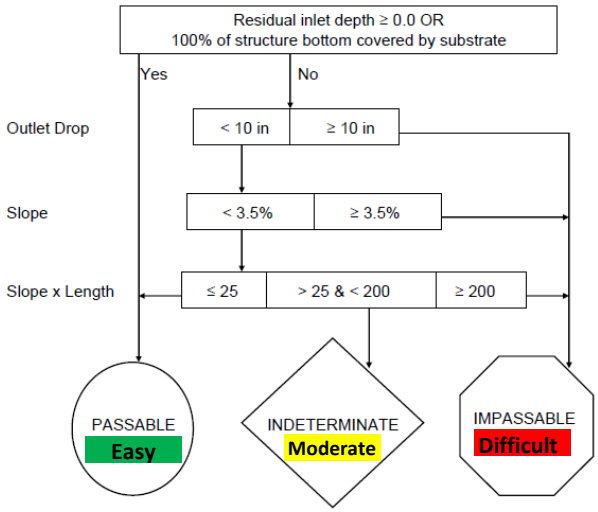
Example: adult brook trout



Filter B

Application: moderate swimmers and leapers

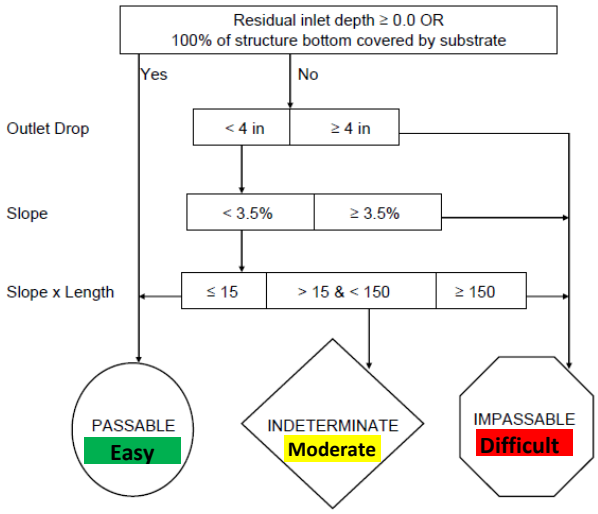
Examples: adult minnows, age-0 brook trout



Filter C

Application: weak swimmers and leapers

Examples: darters, sculpins



Source: Coffman (2005)