Modeling Occupancy of Rare Stream Fish Species in the Upper Cumberland and Kentucky River Basins
Focal species in this study: Cumberland arrow darter (top), blackside dace (middle), Kentucky arrow darter (bottom). Photos by Dr. Matthew Thomas, Kentucky Department of Fish and Wildlife Resources.
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By Nathaniel P. Hitt, Karli M. Rogers, Karmann Kessler, and Hannah Macmillan

Prepared in cooperation with U.S. Fish and Wildlife Service

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## Conversion Factors

International System of Units to U.S. customary units

| Multiply (unit) | By (factor) | To obtain (unit) |
|----------------|-------------|------------------|
| Length         |             |                  |
| centimeter (cm)| 0.3937      | inch (in.)       |
| millimeter (mm)| 0.03937     | inch (in.)       |
| meter (m)      | 3.281       | foot (ft)        |
| kilometer (km) | 0.6214      | mile (mi)        |
| kilometer (km) | 0.5400      | mile, nautical (nmi) |
| meter (m)      | 1.094       | yard (yd)        |
| Area           |             |                  |
| square meter (m²)| 0.0002471 | acre             |
| hectare (ha)   | 2.471       | acre             |
| square hectometer (hm²)| 2.471 | acre             |
| square kilometer (km²)| 247.1 | acre             |
| square centimeter (cm²)| 0.001076 | square foot (ft²) |
| square meter (m²)| 10.76    | square foot (ft²) |
| square centimeter (cm²)| 0.1550 | square inch (in²) |
| square hectometer (hm²)| 0.003861 | section (640 acres or 1 square mile) |
| hectare (ha)   | 0.003861    | square mile (mi²) |
| square kilometer (km²)| 0.3861 | square mile (mi²) |
| Volume         |             |                  |
| cubic meter (m³)| 6.290    | barrel (petroleum, 1 barrel = 42 gal) |
| liter (L)      | 33.81402    | ounce, fluid (fl. oz) |
| liter (L)      | 2.113       | pint (pt)        |
| liter (L)      | 1.057       | quart (qt)       |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows: °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = (°F − 32) / 1.8.

## Datum

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.
Modeling Occupancy of Rare Stream Fish Species in the Upper Cumberland and Kentucky River Basins

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Abstract

Biological conservation often requires an understanding of how environmental conditions affect species occurrence and detection probabilities. We used a hierarchical framework to evaluate these effects for several Appalachian stream fish species of conservation concern: *Chrosomus cumberlandensis* (BSD; blackside dace), *Etheostoma sagitta* (CAD; Cumberland arrow darter), and *Etheostoma spilotum* (KAD; Kentucky arrow darter). *Etheostoma susanae* (Cumberland darter) also is present in the study area but was too rare to model in this analysis. In this study, conducted by the U.S. Geological Survey in cooperation with the U.S. Fish and Wildlife Service, fish and habitat data were collected from 205 randomly selected stream sites in the upper Cumberland and Kentucky River Basins (120 and 85 sites, respectively) of Kentucky and Tennessee. Sites were sampled with 10 spatial replicates (2 meter x 5 meter electrofishing zones) to enable estimation of detection probabilities and environmental effects. The best models (that is, lowest Akaike information criterion scores) showed the effects of agriculture (negative) on occurrence of BSD and stream conductivity (negative) on occurrence of CAD and KAD. These effects were statistically more important than measures of basin area, elevation, and substrate size. Conductivity and agriculture showed nonlinear effects on species occurrence, and effects of conductivity were more precise above 400 microsiemens per centimeter than below this threshold. Models incorporated detection-level effects of electrofishing time (positive), flow velocity (negative), sand substrate (positive), and gravel/cobble substrate (negative). Models accounting for detection of BSD estimated occupancy rates similar to the observed proportion of occupied sites (0.10), but the best-supported models for CAD and KAD increased expected occupancy by about 4 percent for each species (from 0.17 to 0.21 for CAD and from 0.07 to 0.11 for KAD). Results of this study provide new inferences for modeling stream fish occurrence and detection processes and highlight the importance of continued monitoring and assessment of rare fish species in Appalachian headwater streams.

Introduction

Biological conservation often requires an understanding of environmental controls on species occurrence and detection probabilities (MacKenzie and others, 2002). *Chrosomus cumberlandensis* (Blackside dace; BSD), *Etheostoma sagitta* (Cumberland arrow darter; CAD), *Etheostoma susanae* (Cumberland darter; CD), and *Etheostoma spilotum* (Kentucky arrow darter; KAD) (fig. 1) are high-priority species because they involve Endangered Species Act (ESA) conservation planning by the U.S. Fish and Wildlife Service (FWS). The U.S. Geological Survey (USGS) conducted this study in cooperation with the FWS to evaluate environmental predictors of species occurrence while jointly modeling the detection process in a hierarchical framework.

BSD is a headwater fish species endemic to the upper Cumberland River Basin in Tennessee and Kentucky (Starnes and Starnes, 1978; FWS, 1987), with recent expansions into the Kentucky River Basin in Kentucky and the Clinch and Powell River Basins in Virginia (Skelton, 2013). It inhabits small upland streams characterized by low turbidity and fine substrates, and low conductivity levels (Starnes and Starnes, 1981; Eisenhour and Strange, 1998; Black and others, 2013a, 2013b; Hitt and others, 2016). Prior research identified conductivity thresholds associated with reduced BSD abundance at about 240 microsiemens per centimeter (µS/cm) (Black and others, 2013a) and about 340 µS/cm (Hitt and others, 2016). BSD was listed as a threatened species under the ESA in 1987 (FWS, 1987). A recovery plan was developed in 1988 (FWS, 1988), and the FWS continues conservation planning for this species (for example, FWS, 2015a).

CAD and KAD also are endemic to the study area, with CAD restricted to the upper Cumberland River Basin (FWS, 2012) and KAD restricted to the upper Kentucky River Basin (FWS, 2010a). These closely related species are distinguished by genetic and morphological differences (Kuehne and Bailey, 1961). Both species inhabit moderate- to high-gradient headwater streams and are obligate invertivores; adult diets include larval mayflies and other invertebrates (Thomas, 2007, 2008; FWS, 2010a, 2012). Both species also apparently have been extirpated from some locations. Rangewide surveys conducted over the last several decades have not detected CAD in 43 of 128 historically inhabited streams (34 percent) (FWS, 2015b).
and have not detected KAD in 36 of 74 historically inhabited streams (49 percent) (FWS, 2016). In part based on these survey data, the FWS determined CAD did not constitute a threatened species under the ESA (FWS, 2015b), but KAD did (FWS, 2016). Genetic analysis further indicated effects of recent isolation and fragmentation of KAD populations (Blanton and others, 2019) that exacerbates local extirpation risks (Fagan, 2002).

CD is also an endemic species within the upper Cumberland River Basin, but it has a much smaller range than BSD or CAD. Known occurrences are limited to 14 sites within 12 streams (FWS, 2010b). Ecological requirements of the species are not fully understood (FWS, 2019), but the species has been observed in streams with width ranging from 4 to 9 meters (m) and within pools and shallow runs (O’Bara, 1991; Thomas, 2007). Their diet is probably like that of a closely related species (Etheostoma nigrum, Johnny darter) (FWS, 2011) and consists primarily of benthic macroinvertebrate larvae (Etnier and Starnes, 1993). Based on its geographic rarity and threats from degraded water quality and physical habitat, CD was recognized as an endangered species under the ESA in 2011 (FWS, 2011).

This report presents applied hierarchical modeling techniques to estimate environmental effects on species occurrence while modeling their detection probabilities. Imperfect detection of individuals may bias predicted occurrence rates (MacKenzie and others, 2002), and this potential problem is widely recognized for interpretation of species survey data (Bailey and others, 2014), including for the focal species (see FWS, 2016). The objectives of the study were to (1) model species occurrence and detection probabilities from environmental data and (2) estimate the potential importance of the detection process by comparing model predictions that account for detection against the observed proportion of occupied sites.

**Methods**

**Data Collection**

Fish and habitat data collected from 205 stream sites in the upper Cumberland River Basin (CU) and upper Kentucky River Basin (KE) in the southeastern United States were evaluated (fig. 2; appendix table 1.1). The landscape of the study area is characterized by highly dissected forested watersheds of the Cumberland Plateau physiographic region. Land use includes mining, forestry, and agricultural development with some urbanization in lower elevations. The CU study area is upstream from Cumberland Falls, and the KE study area is upstream from a series of locks and dams managed by the U.S. Army Corps of Engineers near Lexington, Ky.

Stream sampling was conducted by State and Federal wildlife biologists led by Mike Compton (Office of Kentucky Nature Preserves, OKNP) and Michael Floyd (FWS) during summer base-flow conditions in 2012, 2013, and 2015. CU sites were sampled in 2012 and 2015 (n = 120), and KE sites were sampled in 2013 (n = 85). Site locations were selected at random to facilitate interpretation of results across the study area. Sampling occurred between June and September each year, and most sites were sampled during August.

Sampling was conducted using spatial replicates (quadrats) to model the detection process (Charbonnel and others, 2014). Within each site, 10 quadrats were sampled using a systematic randomized design to represent available mesohabitat types (pool, riffle, run). Quadrats measured 2 m x 5 m with the long side parallel to stream flow and were separated by a minimum of 5 m. Backpack electrofishing techniques were used to collect all fish within each quadrat (Reynolds and Kolz, 2012) using a Smith-Root LR24 backpack electrofishing unit with dipnets at 200–350 volts, 60 megahertz, and 15–20 percent duty cycle. Blocknets were not used. Captured fish
**Figure 2.** Location of Cumberland and Kentucky River Basins in Virginia and Kentucky with sampling sites. Sampling sites are shown as points and are listed in appendix table 1.1.
were identified to species, counted, and released downstream after each quadrat was sampled. Sampling proceeded in an upstream direction.

Environmental covariates were measured in each quadrat (table 1), including measures of sampling effort (electrofishing time), flow velocity, stream depth, and substrate size. Substrate size categories followed Wentworth (1922) with pebble, gravel, and cobble categories combined. Stream depth and substrate size class were measured at the corners and center of each quadrat (five samples). Flow velocity was visually estimated and scored on a scale of 1 (no flow) to 4 (fast flow), following Albanese and others (2007). A total of 2,050 quadrats was sampled in the study area, including 1,200 samples in the CU area (120 sites) and 850 samples in the KE area (85 sites).

Site-level covariates include measures of water quality, stream volume, and land use (table 2). Conductivity was measured with a calibrated YSI Professional Plus multiparameter meter prior to fish sampling. We calculated elevation, upstream basin size, and stream gradient from 30-m digital elevation models with a geographic information system (ESRI Arc Hydro tools). Land cover was expressed as the percent of upstream watershed area classified as forest, agriculture, barren land, or developed land as defined by the 2016 version of the National Land Cover Database (see Wickham and others, 2014).

**Occupancy Modelling**

The R package “unmarked” version 0.13-2 (Fiske and Chandler, 2011) was used to model species detection and occurrence probabilities in a hierarchical framework as

\[
\begin{align*}
  z_i &\sim \text{Bernoulli}(\Psi_i) \\
  y_{ij} &\sim \text{Bernoulli}(z_ip_{ij})
\end{align*}
\]

where

- \( z_i \) is the state variable defining the presence or absence of BSD, CAD, or KAD within site \( i \),
- \( \Psi_i \) is the probability of species presence within site \( i \),
- \( p_{ij} \) is the probability of species detection in quadrat \( j \) within site \( i \), and
- \( y_{ij} \) is the observed presence or absence of the target species in quadrat \( j \) within site \( i \).

Model (1) represents the process of species occurrence among sites, and model (2) represents the process of detection within a quadrat when a species is present in a given site. Within each site, the sequence of observed presence and absence records across quadrats represents a detection history with a likelihood contingent on true presence or absence (\( z \)). Percent variables and continuous variables with arcsine square-root and ln-transformations, respectively, were

| Covariate                  | Code | Unit | Basin | Mean | SD | Range |
|----------------------------|------|------|-------|------|----|-------|
| Electrofishing time        | dET  | Second | CU    | 66   | 22 | 6–182  |
|                            |      |       | KE    | 66   | 20 | 18–171 |
| Stream depth               | dSD  | Meter | CU    | 0.15 | 0.13 | 0.01–1.00 |
|                            |      |       | KE    | 0.10 | 0.11 | 0.01–0.84 |
| Flow velocity              | dFV  | Index | CU    | 1.9  | 0.6 | 1.0–4.0 |
|                            |      |       | KE    | 2.1  | 0.5 | 1.0–4.0 |
| Fine substrates            | dFI  | Percent | CU    | 9    | 18 | 0–100 |
|                            |      |       | KE    | 4    | 11 | 0–100 |
| Sand substrates            | dSA  | Percent | CU    | 16   | 22 | 0–100 |
|                            |      |       | KE    | 14   | 21 | 0–100 |
| Gravel/cobble substrates   | dGC  | Percent | CU    | 61   | 32 | 0–100 |
|                            |      |       | KE    | 58   | 33 | 0–100 |
| Boulder substrates         | dBO  | Percent | CU    | 7    | 14 | 0–80 |
|                            |      |       | KE    | 6    | 12 | 0–80 |
| Bedrock substrates         | dBE  | Percent | CU    | 8    | 20 | 0–100 |
|                            |      |       | KE    | 19   | 32 | 0–100 |

Table 1. Environmental covariates for modeling species detection probability in the upper Cumberland River Basin and upper Kentucky River Basin. Samples were observed at the quadrat level (that is, 10 quadrats per site).

[CU, Cumberland River Basin, n=1,200; KE, Kentucky River Basin, n=850. Codes are indexed with “d” to indicate detection-level covariates in subsequent tables and figures. SD, standard deviation]
transformed, and all covariates were scaled to a mean of 0 and standard deviation of 1. Logit link functions were used to relate covariates to $\psi$ and $p$ on a 0–1 probability scale.

This modeling structure provides a hierarchical framework because the observed data ($y$) are modeled jointly with a detection process and a higher-level occupancy process. The underlying Bernoulli probability distributions assume three conditions: (1) there are only two possible outcomes (species presence or absence and species detection or non-detection), (2) species occurrence or detection in one sample unit does not affect occurrence or detection in others, and (3) the true occurrence state ($z$) does not change during the period of data collection (Bailey and others, 2014). The rapid collection of quadrat-level data in the current study (that is, sampled within a single day) gives high confidence for satisfying the latter condition. We assumed that electrofishing did not affect the spatial distribution of fish among quadrats (see “Discussion” section).

The dataset was split by basin for modeling species occupancy, yielding 120 sites (1,200 quadrats) for analysis of BSD and CAD, and 85 sites (850 quadrats) for analysis of KAD. First-order combinations of all covariates at the detection and occurrence levels were evaluated using Akaike Information Criterion scores (AIC) scores to identify the best performing models for each species (117 models per species). Model goodness-of-fit was evaluated using bootstrapped chi-squared statistics with 1,000 samples; all possible combinations of covariates were not evaluated because higher-order models generally lacked sufficient goodness-of-fit for interpretation. The expected probability of detection and occurrence ($p$ and $\psi$) was evaluated for top-performing models with covariates effects held at mean-effect levels.

Table 2. Site covariates for modeling species occurrence probability in the upper Cumberland River Basin and upper Kentucky River Basin.

[Covariates were observed at the site level. CU: Cumberland River Basin, n=120; KE: Kentucky River Basin, n=85. Codes are indexed with “o” to indicate occurrence-level covariates in subsequent tables and figures. $\mu$S/cm, microsiemens per centimeter; <, less than; SD, standard deviation]

| Covariate                  | Code | Units     | Basin | Mean | SD  | Range   |
|----------------------------|------|-----------|-------|------|-----|---------|
| Conductivity               | oCO  | $\mu$S/cm | CU    | 401  | 360 | 15–2,171|
|                           |      |           | KE    | 473  | 484 | 29–2,175|
| Basin area                 | oBA  | Hectare   | CU    | 3007 | 6756| 103–37,907|
|                           |      |           | KE    | 1471 | 2789| 189–14,617|
| Elevation above sea-level  | oEL  | Meter     | CU    | 391  | 91  | 282–769 |
|                           |      |           | KE    | 308  | 54  | 219–488 |
| Barren land cover          | oBR  | Percent   | CU    | < 1  | 1   | 0–6     |
|                           |      |           | KE    | 1    | 3   | 0–15    |
| Forest land cover          | oFO  | Percent   | CU    | 83   | 16  | 26–100  |
|                           |      |           | KE    | 82   | 17  | 13–100  |
| Agricultural land cover    | oAG  | Percent   | CU    | 2    | 5   | 0–31    |
|                           |      |           | KE    | 3    | 7   | 0–44    |
| Developed land cover       | oDE  | Percent   | CU    | 3    | 4   | 0–29    |
|                           |      |           | KE    | 5    | 3   | 0–18    |
| Fine substrates            | oFI  | Percent   | CU    | 9    | 13  | 0–75    |
|                           |      |           | KE    | 4    | 5   | 0–22    |
| Sand substrates            | oSA  | Percent   | CU    | 16   | 16  | 0–94    |
|                           |      |           | KE    | 14   | 15  | 0–65    |
| Gravel/cobble substrates   | oGC  | Percent   | CU    | 61   | 23  | 2–98    |
|                           |      |           | KE    | 58   | 23  | 6–98    |
| Boulder substrates         | oBO  | Percent   | CU    | 7    | 8   | 0–42    |
|                           |      |           | KE    | 6    | 7   | 0–37    |
| Bedrock substrates         | oBE  | Percent   | CU    | 8    | 14  | 0–64    |
|                           |      |           | KE    | 19   | 26  | 0–90    |
Results

The fish dataset includes 16,717 individuals, of which the focal species constituted a small fraction. A total of 96 individual BSD were observed within 23 quadrats across 12 sites in the CU study area (naive occupancy = 0.10). In sites where BSD were observed, they were detected on average in 1.9 quadrats (19 percent) with a maximum observed presence within 5 quadrats in one site (DOW02036606 in table 1.1). Conductivity was positively related to the percent gravel/cobble and negatively related to the percent sand within CU sites but not KE sites (fig. 4). Conductivity increased with the percent fine substrates in KE but not in CU (fig. 4).

Upstream basin areas range from 103 hectares (ha) to nearly 38,000 ha (table 2) and were larger on average in CU than in KE (t = 2.3, p = 0.02). Site elevations ranged from 282 m to 769 m (table 2) and were higher on average in CU than in KE (t = 8.1, p < 0.001). Forest dominated land cover in both study areas (83 percent and 82 percent in CU and KE, respectively), whereas agriculture and developed areas constituted less than 5 percent of land cover in all cases (table 2). Barren land was rare in the land-cover dataset, accounting for 1 percent of the KE basins on average and less than 1 percent of the CU basins on average (table 2).

Basin area and elevation generally showed stronger correlations with land use and substrate size among CU sites than among KE sites (fig. 4). Percent agriculture and developed areas were positively associated, and each showed negative associations with percent forest cover. The percent barren land was positively associated with developed land in CU but not in KE (fig. 4). Elevation showed a positive correlation with percent bedrock in CU but a negative correlation in KE (fig. 4). Percent agriculture showed a positive association with percent fine substrate in CU but not in KE (fig. 4).

Bootstrapped chi-squared statistics indicated sufficient goodness-of-fit for the top three models for each species (appendix table 1.2). The top three models (that is, lowest AIC scores) for BSD (table 3) show a negative effect of agriculture on occurrence probability and detection-level effects of electrofishing time (positive), flow velocity (negative), and gravel/cobble substrate (negative) (table 4; fig. 5). Uncertainty of the predicted effect of agriculture generally decreased with increasing agricultural land cover (that is, decreasing confidence intervals with increasing covariate values; fig. 5). Conductivity exhibited a negative relation with BSD occurrence but was not included in the top three models.

A single model best described CAD occupancy given the observed data (that is, AIC cumulative weight = 1 for the top model; table 3). This model showed a negative effect for stream conductivity on occurrence probability and simulated the detection process with a positive effect for electrofishing time (table 4; fig. 6). The predicted (negative) effect of conductivity on CAD occurrence probability was more precise at greater than mean values than less than mean values in the CU study area (about 400 µS/cm threshold; table 2). In contrast, predicted effects of barren land cover (negative) and forest cover (positive) on CAD occurrence probability showed decreasing precision at low and high covariate values (fig. 6).

The top three models for KAD (table 3) included negative effects of conductivity and barren land cover on occurrence probability (table 4; fig. 7). Covariates on KAD detection probability included effects of sand substrate (positive) and electrofishing time (positive). As with CAD, uncertainty in the predicted (negative) effect of conductivity on KAD occurrence diminished with increasing conductivity values. In contrast,
**Figure 3.** Correlation matrix for detection-level covariates in the upper Cumberland River Basin and the upper Kentucky River Basin. Cumberland River Basin, n=1,200 quadrats; Kentucky River Basin, n=850 quadrats. Lower diagonal cells give Spearman correlation coefficients, and upper diagonal cells represent correlation direction (color) and magnitude (circle size). Codes are given in table 1, and study sites are shown in figure 2.
Figure 4. Correlation matrix for occurrence-level covariates in the upper Cumberland River Basin, $n = 120$, and upper Kentucky River Basin, $n = 85$. Lower diagonal cells give Spearman correlation coefficients, and upper diagonal cells represent correlation direction (color) and magnitude (circle size). Codes are given in table 2, and study sites are shown in figure 2.
the predicted effect of barren land cover on KAD occurrence became less precise at high values, indicating that conductivity is a more important predictor in this regard (fig. 7).

Estimated occurrence probabilities for BSD in the top three models were similar to the naive occupancy rate (0.10), and estimated detection probabilities ranged from 0.123 to 0.170 (table 5). Estimated occurrence probability for CAD was 0.209 in the top model, an increase of 4.2 percent from the naive occupancy rate of 0.167 (table 5), and detection probability was 0.057 in the top model for this species. Estimated occurrence probabilities for KAD ranged from 0.029 to 0.112 in the top three models, and detection probabilities ranged from 0.035 to 0.071 in the top three models (table 5). Greater detection probabilities were estimated for BSD than CAD or KAD in the top three models for each species: the maximum estimated detection probabilities for CAD (0.062) and KAD (0.071) were less than the minimum detection probability for BSD (0.123) (table 5).

| Model | βp | βpsi | nP | ΔAIC | AICw | AICwc |
|-------|----|------|----|------|------|-------|
|       | dET | oAG  | 4  | 0.00 | 0.10 | 0.10  |
|       | dFV | oAG  | 4  | 0.77 | 0.07 | 0.18  |
|       | dGC | oAG  | 4  | 1.44 | 0.05 | 0.23  |

Table 3. Description of the top three occupancy models for blackside dace, Cumberland arrow darter, and Kentucky arrow darter.

| Level          | Covariate | Estimate | SE  | z    | p     |
|----------------|-----------|----------|-----|------|-------|
| Occurrence     | Intercept | -2.16    | 0.45| -4.79| < 0.001|
|                | oAG       | -1.15    | 0.72| -1.61| 0.108 |
| Detection      | Intercept | -1.97    | 0.34| -5.88| < 0.001|
|                | dET       | 0.76     | 0.30| 2.53 | 0.011 |

Table 4. Top model coefficients for blackside dace, Cumberland arrow darter, and Kentucky arrow darter.

| Level          | Covariate | Estimate | SE  | z    | p     |
|----------------|-----------|----------|-----|------|-------|
| Occurrence     | Intercept | -1.33    | 0.44| -3.05| 0.002 |
|                | oCO       | -2.21    | 0.70| -3.14| 0.002 |
| Detection      | Intercept | -2.81    | 0.31| -9.16| < 0.001|
|                | dET       | 1.41     | 0.28| 4.96 | < 0.001|

| Level          | Covariate | Estimate | SE  | z    | p     |
|----------------|-----------|----------|-----|------|-------|
| Occurrence     | Intercept | -2.07    | 0.99| -2.10| 0.036 |
|                | oCO       | -2.59    | 1.91| -1.36| 0.175 |
| Detection      | Intercept | -3.32    | 0.67| -4.94| < 0.001|
|                | dSA       | 0.74     | 0.28| 2.68 | 0.007 |
Discussion

Our analysis provides several inferences for monitoring and assessment of rare stream fishes in Appalachia. We showed that (1) quadrat-based spatial replicates can provide a useful framework for modeling stream fish occupancy; (2) sampling effort, flow velocity, and substrate size can affect species detection probabilities; (3) agriculture decreased occurrence probability for BSD, and conductivity decreased occurrence probabilities for CAD and KAD; (4) predicted effects of conductivity and agriculture became more precise as their values increased; and (5) maximum potential occupancy rates (that is, accounting for imperfect detection) were relatively low in all cases, highlighting the importance of continued monitoring and assessment of these rare stream fish species.

The best-performing models for CAD and KAD included negative effects of conductivity on species occurrence (table 4), and similar effects have been observed from independent datasets in the study area (Black and others, 2013b; Hitt and others, 2016) and elsewhere in Appalachia (Palmer and others, 2010; Hitt and Chambers, 2014; Merovich and others, in press). Conductivity was clearly the most important covariate to model CAD occurrence (that is, AIC cumulative weight = 1.0; table 3). Conductivity was also included in the best model for KAD, but other variables were closer in their performance for KAD than for CAD (table 3). However, the next-best models for KAD included barren land cover (table 3, fig. 7), which is correlated with stream conductivity (fig. 3) and therefore may represent the same underlying mechanisms. Even though stream volume and temperature are primary determinants of stream fish distributions (Burton and Odum, 1945; Sheldon, 1968; Vannote and others, 1980), our indices of stream volume (basin area) and stream temperature (elevation) were unimportant in occurrence models relative to the overriding effect of conductivity.

Analysis contributed a new inference on conductivity: the predicted effects became more precise as observed conductivity values increased (fig. 6 and fig. 7). Specifically, predicted effects on CAD occurrence were more precise at greater than the mean observed value within the CU area (about 400 µS/cm) than below this threshold. This pattern is consistent with the wedge-shaped relation between abundance and conductivity reported previously for KAD (Hitt and others, 2016), implying a limiting effect of water quality at high conductivity values and other limiting effects at low conductivity values (see Schmidt and others, 2012). Moreover, conductivity showed nonlinear relations to CAD and KAD occurrence such that models predicted more change at less than mean conductivity values than at greater than mean conductivity (fig. 6 and fig. 7). For instance, the steepest changes in predicted occurrence were near the conductivity benchmark established by the U.S. Environmental Protection Agency (EPA) for protection of aquatic life downstream from mining operations in Appalachia (300 µS/cm; EPA, 2011). Predicted effects of conductivity on CAD and KAD were consistent with the hypothesis that conductivity affects growth and survival of invertivorous fishes by altering the benthic macroinvertebrate prey base available for consumption (see Hitt and others, 2016). Moreover, we attribute observed conductivity effects to sulfates from mining activity rather than chlorides from road salts (Cormier and others, 2013) because conductivity was weakly related to developed land but strongly related to “barren” land associated with surface mining (fig. 4).

Agriculture was more important than conductivity for modeling BSD occurrence in this analysis (table 3, table 4) even though their occurrence was limited to low conductivity sites. Because agriculture is more prevalent in lower elevation sites (fig. 4), unmeasured effects of water temperature or other conditions that vary by elevation may influence the observed effect of agriculture in these models. Nonetheless, agriculture was associated with increasing fine substrates and decreasing
Figure 6. Cumberland arrow darter predicted occurrence and detection probabilities (black lines) and 95-percent confidence intervals (grey lines) for covariates in the top three models. Top three models are described in table 3. Covariates for occurrence (“o”) and detection (“d”) probabilities are defined in table 1 and table 2.

For example, Pteronotropis welaka (bluenose shiner) detection rates ranged from 0.03 to 0.08 (Albanese and others, 2007), and the detection rate for Percina auriohynchos (goldline darter) was 0.20 (Albanese and others, 2013) using seine hauls as spatial replicates. Electrofishing and snorkeling surveys also revealed low detection rates for Erimystax insigins (blotched chub) in southern Appalachian streams (0.11 and 0.09, respectively; Albanese and others, 2011). In contrast, common stream fish species in this region can show detection rates of nearly 90 percent (for example, Albanese and others, 2007).

Higher detection probabilities were found for BSD than KAD or CAD (table 5); this may be due to differences in local abundance. BSD showed greater mean abundance than CAD or KAD at the site level (8.0, 2.6, and 2.2 fish per occupied site, respectively), consistent with prior research (Black and others, 2013a; Hitt and others, 2016). Likewise, BSD showed greater densities at the quadrat level than CAD or KAD (4.2, 1.4, and 1.3 fish per occupied quadrat, respectively), and fish density therefore may be related to the detection process (see Royle and Nichols, 2003). Future studies on the focal species therefore may benefit by limiting quadrat samples to targeted microhabitats rather than sampling all available habitats as implemented in this study.

We found that sampling effort (that is, electrofishing time) increased detection rates for all species (table 3), as expected. However, the precision of the predicted effects was greater for CAD than KAD (that is, confidence intervals for DET in fig. 6 and fig. 7), whereas BSD showed an intermediate response (fig. 5). The results therefore underscore the importance of sampling effort for rare species detection, as shown previously (Green and Young, 1993). We further note that the effect of electrofishing effort was not simply a function of observed density because BSD was most abundant but exhibited an intermediate response to electrofishing effort (fig. 5). Instead, the observed effect of electrofishing time in our study may indicate that more effort was expended after the first individual of a target species was observed within a quadrat (M. Compton, OKNP, oral commun.). Future studies with blocknetted quadrats or repeat samples are needed to evaluate this effect empirically.

Flow velocity affects fish detection rates in many lotic ecosystem types (Gwinn and others, 2016), and our results showed this. However, flow velocity was found to be more important for BSD than CAD or KAD (table 3); this may be due to variation in mesohabitat use and body morphology between species. Specifically, pelagic stream fishes such as BSD typically exhibit laterally compressed body shapes that
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are expected to be more sensitive to changes in flow velocity than dorsally compressed benthic fishes such as CAD and KAD (Sagnes and Statzner, 2009). Similarly, Albanese and others (2007) report negative effects of flow velocity for detection of another rare, pelagic stream fish species in Appalachia (bluenose shiner). We also found that smaller substrates (that is, sand) increased detection probability for BSD and KAD (table 3), as reported by Albanese and others (2011).

Our inferences on conductivity were constrained by the sampling design. High conductivity levels can affect electrofishing efficiency (Hill and Willis, 1994; Hense and others, 2010; Dean and others, 2019), but we could not directly evaluate this effect because conductivity was measured at the site level (that is, invariant at the quadrat level). Incorporation of temporal replicates would be necessary to quantify this effect (for example, Hayer and Irwin, 2008), but we are not confident that seasonal differences in conductivity downstream from mining operations in Appalachia (see Lindberg and others, 2011) would provide enough variation to permit modeling. Nonetheless, observed conductivity thresholds for electrofishing efficiency (Dean and others, 2019) exceed threshold effects of conductivity on stream fish populations and assemblages (Black and others, 2013b; Hitt and Chambers, 2014; Hitt and others, 2016); therefore, conductivity is expected to be more important for the occurrence process than the detection process for the focal species studied here.

This study was constrained by the spatial-replicate sampling design within sites. We assumed that the sampling process was independent among quadrats within a site, as required for statistical analysis. However, fish escapement from electrofishing may exceed the minimum quadrat spacing distance in this study (5 m), particularly within pool environ-

Table 5. Estimated detection probability and occurrence probability for top three occupancy models for blackside dace, Cumberland arrow darter, and Kentucky arrow darter.

| BSD | CAD | KAD |
|-----|-----|-----|
| Model | p | psi | p | psi | p | psi |
| Naive | — | 0.100 | — | 0.167 | — | 0.071 |
| 1 | 0.123 | 0.103 | 0.057 | 0.209 | 0.035 | 0.112 |
| 2 | 0.142 | 0.100 | 0.059 | 0.278 | 0.051 | 0.029 |
| 3 | 0.170 | 0.094 | 0.062 | 0.271 | 0.071 | 0.075 |

[Models hold covariates at mean-effect levels and are listed in table 3. BSD, blackside dace; CAD, Cumberland arrow darter; KAD, Kentucky arrow darter; —, no data; p, detection probability; psi, occurrence probability]
spatial replicates (Srivathsaa and others, 2018) by reallocating sampling effort with single site visits rather than requiring multiple site visits.

We found that imperfect detection is unlikely to explain the observed rarity of the focal species. Models accounting for detection of estimated BSD occupancy rates are similar to the observed proportion of occupied sites (0.10), and the best-supported models for CAD and KAD increased expected occupancy by about 4 percent for each species (from 0.17 to 0.21 for CAD and from 0.07 to 0.11 for KAD). Our results therefore support prior research demonstrating the rarity of the focal species (Thomas, 2007, 2008; FWS, 2010a, 2015a, 2010b) and highlight the importance of their continued monitoring and assessment. A strength of this study is that sites were selected at random; therefore, results can inform expectations for species occupancy and detection across the study area.

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Appendix 1
Table 1.1. Sampling sites in the upper Cumberland River Basin and upper Kentucky River Basin.  

[Site coordinates are given in decimal degrees. CU, Cumberland River Basin, n=120; KE, Kentucky River Basin, n=85. Fish and habitat sampling were coordinated by M. Compton (Office of Kentucky Nature Preserves) and M. Floyd (U.S. Fish and Wildlife Service)]

| Station    | Latitude  | Longitude  | Stream                  | Date    |
|------------|-----------|------------|-------------------------|---------|
| DOW02036601| 36.90598  | -83.72948  | BRICES CREEK            | 7/17/2012|
| DOW02036601| 36.65717  | -84.16132  | WOLF CREEK              | 6/28/2012|
| DOW02037603| 36.66455  | -83.64608  | CRANES CREEK            | 7/27/2012|
| DOW02041601| 36.70291  | -83.52935  | BROWNIES CREEK          | 7/27/2012|
| DOW02044601| 36.88399  | -83.02526  | CLOVER FORK CUMBERLAND  | 7/26/2012|
| DOW02044603| 36.8753   | -82.93544  | CLOVER FORK CUMBERLAND  | 7/26/2012|
| DOW02044602| 36.85611  | -83.26593  | CLOVER FORK CUMBERLAND  | 7/26/2012|
| DOW02041617| 36.68467  | -83.59329  | HANCES CREEK            | 7/25/2012|
| DOW02041605| 36.7805   | -83.52426  | PUCKETT CREEK           | 7/25/2012|
| DOW02044604| 36.92651  | -83.04314  | LEFT FORK FUGITT        | 7/24/2012|
| DOW02041607| 36.72028  | -83.56627  | ELK BRANCH              | 7/24/2012|
| DOW02042602| 36.82159  | -83.36319  | EWING CREEK             | 7/23/2012|
| DOW02041603| 36.69983  | -83.42879  | BROWNIES CREEK          | 7/18/2012|
| DOW02036605| 36.96339  | -83.73792  | MILLS CREEK             | 7/17/2012|
| DOW02041606| 36.75569  | -83.46034  | PUCKETT CREEK           | 7/18/2012|
| DOW02041602| 36.69646  | -83.45905  | BROWNIES CREEK          | 8/1/2012 |
| DOW02040601| 36.73694  | -83.71306  | CLEAR CREEK             | 8/1/2012 |
| DOW02032606| 36.90901  | -83.94677  | POPULAR BRANCH          | 8/31/2012|
| DOW02040604| 36.73206  | -83.69544  | UT-196                  | 7/30/2012|
| DOW02042603| 36.80444  | -83.41106  | CAMP BRANCH             | 7/30/2012|
| DOW02043604| 36.79032  | -83.15156  | CRANKS CREEK            | 7/31/2012|
| DOW02043603| 36.76968  | -83.16811  | GRANT BRANCH            | 7/31/2012|
| DOW02040602| 36.67733  | -83.82357  | CANEY CREEK             | 8/1/2012 |
| DOW02032601| 36.99611  | -83.8814   | RICHLAND CREEK          | 8/30/2012|
| DOW02035602| 36.63828  | -83.94102  | PINE CREEK              | 9/14/2012|
| DOW02031603| 36.77212  | -83.91212  | SUGAR TREE BRANCH       | 9/14/2012|
| DOW02032602| 36.87435  | -83.90479  | RICHLAND CREEK          | 9/10/2012|
| DOW02043602| 36.77945  | -83.2153   | LONG BRANCH             | 9/11/2012|
| DOW02040603| 36.65038  | -83.79216  | LITTLE CLEAR CREEK      | 9/11/2012|
| DOW02039605| 36.89312  | -83.57455  | CAMP BRANCH             | 9/13/2012|
| DOW02039603| 36.82549  | -83.63101  | LEFT FORK STRAIGHT CREEK| 9/13/2012|
| DOW02031601| 36.78969  | -83.94464  | LITTLE POPLAR CREEK     | 9/12/2012|
| DOW02031602| 36.77274  | -83.91222  | HUBBS CREEK             | 9/12/2012|
| DOW02034602| 36.73361  | -83.80891  | CENTER'S BRANCH         | 9/12/2012|
| DOW02037601| 36.69687  | -83.68401  | CANNON CREEK            | 9/12/2012|
| DOW02046601| 37.05023  | -82.79206  | FRANKS CREEK            | 9/17/2012|
| DOW02044606| 36.88248  | -83.19489  | UT-67                   | 8/23/2012|
| DOW02015602| 36.68263  | -84.22676  | PAINT CREEK             | 8/17/2012|
| DOW02031604| 36.81115  | -84.04119  | MEADOW CREEK            | 8/17/2012|
| DOW02013601| 36.82457  | -84.3847   | LAUREL FORK             | 8/16/2012|
| DOW02018602| 36.79557  | -84.24338  | MIDDLE FORK SANDERS     | 8/16/2012|
Table 1.1. Sampling sites in the upper Cumberland River Basin and upper Kentucky River Basin. —Continued

[Site coordinates are given in decimal degrees. CU, Cumberland River Basin, \(n=120\); KE, Kentucky River Basin, \(n=85\). Fish and habitat sampling were coordinated by M. Compton (Office of Kentucky Nature Preserves) and M. Floyd (U.S. Fish and Wildlife Service)]

| Station     | Latitude   | Longitude  | Stream               | Date       |
|-------------|------------|------------|----------------------|------------|
| DOW02018601 | 36.76049   | -84.28849  | ARCHERS CREEK        | 8/16/2012  |
| DOW02017601 | 36.81052   | -84.10201  | JACKS FORK           | 8/15/2012  |
| DOW02034603 | 36.79533   | -83.85919  | LITTLE BRUSH CREEK   | 8/21/2012  |
| DOW02031606 | 36.68153   | -83.92248  | POPULAR CREEK        | 8/21/2012  |
| DOW02034601 | 36.72989   | -83.80033  | GREASY CREEK         | 8/21/2012  |
| DOW02044605 | 36.90649   | -83.06894  | BEAR BRANCH          | 8/23/2012  |
| DOW02042601 | 36.8301    | -83.36998  | EWING CREEK          | 8/22/2012  |
| DOW02043606 | 36.77204   | -83.24889  | LICK BRANCH          | 8/23/2012  |
| DOW02042604 | 36.82518   | -83.41264  | TERRY FORK           | 8/23/2012  |
| DOW02031608 | 36.88628   | -83.97385  | DEMPS HOLLOW         | 8/27/2012  |
| DOW02031607 | 36.81023   | -84.06365  | UT-60                | 8/28/2012  |
| DOW02031605 | 36.82652   | -84.04601  | MEADOW CREEK         | 8/28/2012  |
| DOW02030602 | 36.65313   | -84.157    | LITTLE WOLF CREEK    | 6/28/2012  |
| DOW02037602 | 36.66847   | -83.66283  | YELLOW CREEK         | 8/20/2012  |
| DOW02039602 | 36.80714   | -83.64741  | LEFT FORK STRAIGHT CREEK | 8/24/2012 |
| DOW02045601 | 36.87145   | -83.31072  | POOR FORK CUMBERLAND RIVER | 8/22/2012 |
| DOW02045602 | 36.88417   | -83.28529  | POOR FORK CUMBERLAND RIVER | 8/22/2012 |
| DOW02043601 | 36.77607   | -83.24201  | MARTINS FORK CUMBERLAND RIVER | 7/31/2012 |
| DOW02013602 | 36.81386   | -84.46021  | COGUR FORK           | 7/23/2012  |
| DOW02014604 | 36.65868   | -84.40472  | CAT CREEK            | 8/29/2012  |
| DOW02014603 | 36.66594   | -84.36974  | CLEAR CREEK          | 8/29/2012  |
| DOW02015604 | 36.60236   | -84.31311  | ROCK CREEK           | 8/15/2012  |
| DOW02015603 | 36.63893   | -84.31179  | UT-RYANS CREEK       | 8/24/2012  |
| DOW02036602 | 36.90945   | -83.60419  | ALEX CREEK           | 8/16/2012  |
| DOW02039604 | 36.89095   | -83.3674   | STRAIGHT CREEK       | 8/16/2012  |
| DOW02037604 | 36.64438   | -83.65958  | SUGAR RUN            | 7/24/2012  |
| DOW02036603 | 36.84575   | -83.70913  | LEFT FORK MOORE CREEK | 8/2/2012   |
| DOW02039601 | 36.83207   | -83.67007  | RIGHT FORK CANEY CREEK | 9/12/2012 |
| DOW02037605 | 36.64899   | -83.57877  | SHILLALAH CREEK      | 9/21/2012  |
| DOW02036604 | 36.90733   | -83.75924  | HALE FORK            | 8/2/2012   |
| DOW02043605 | 36.68058   | -83.46429  | MARTINS FORK CUMBERLAND RIVER | 9/20/2012 |
| DOW02014602 | 36.76416   | -84.37695  | HENS NEST CREEK      | 7/3/2012   |
| DOW02032605 | 37.03444   | -83.8686   | RICHLAND CREEK       | 8/16/2012  |
| DOW02036606 | 36.93514   | -83.6008   | PAINT GAP BRANCH     | 8/28/2012  |
| DOW02045603 | 37.06947   | -82.74626  | POOR FORK CUMBERLAND RIVER | 7/5/2012   |
| DOW02015605 | 36.62646   | -84.24312  | CRISCILLIS BRANCH    | 9/11/2012  |
| DOW02014605 | 36.65385   | -84.42559  | PERKINS CREEK        | 9/20/2012  |
| DOW02041604 | 36.70994   | -83.54005  | COAL STONE BRANCH    | 9/20/2012  |
| DOW02035601 | 36.65200   | -83.87141  | LAUREL FORK          | 9/19/2012  |
| DOW02015601 | 36.68715   | -84.27884  | JELLICO CREEK        | 8/28/2012  |
| DOW02014601 | 36.78823   | -84.35911  | MARSH CREEK          | 8/30/2012  |
| Primary 1   | 36.56581   | -83.81561  | SUGAN CREEK          | 8/1/2015   |
Table 1.1. Sampling sites in the upper Cumberland River Basin and upper Kentucky River Basin. —Continued

| Station   | Latitude   | Longitude   | Stream                  | Date     |
|-----------|------------|-------------|-------------------------|----------|
| Primary   |            |             |                         |          |
| 2         | 36.57804   | -84.34507   | MIKE BRANCH             | 8/19/2015|
| 3         | 36.52047   | -84.30369   | BEAR BRANCH             | 8/25/2015|
| 5         | 36.56393   | -84.37943   | UT GUM FORK             | 8/19/2015|
| 12        | 36.45307   | -84.30542   | COONTAIL BRANCH         | 8/26/2015|
| 13        | 36.56353   | -84.04906   | UT CLEAR FORK           | 8/6/2015  |
| 14        | 36.57555   | -84.22761   | TRAMMEL BRANCH          | 8/20/2015|
| 15        | 36.53909   | -84.38879   | UT JELLICO CREEK        | 8/21/2015|
| 16        | 36.43894   | -84.30947   | ELK CREEK               | 8/26/2015|
| 17        | 36.48133   | -84.11278   | ROCK CREEK              | 8/6/2015  |
| 20        | 36.49043   | -83.97393   | LITTLE TACKETT CR.      | 8/10/2015|
| 21        | 36.54494   | -84.30111   | TRAMMEL BRANCH          | 8/18/2015|
| 23        | 36.54988   | -83.86082   | VALLEY CREEK            | 8/2/2015  |
| 24a       | 36.52085   | -84.21069   | LITTLE ELK CREEK        | 8/27/2015|
| 25        | 36.57605   | -84.23817   | HATFIELD CREEK          | 8/19/2015|
| 26        | 36.46268   | -84.05355   | DAVIS CREEK             | 8/10/2015|
| 27        | 36.49928   | -83.9553    | LITTLE TACKETT          | 8/11/2015|
| 28        | 36.52367   | -84.39598   | JELLICO CREEK           | 8/20/2015|
| 29        | 36.57056   | -83.80809   | BURRELL CREEK           | 8/1/2015  |
| 31        | 36.47584   | -84.01652   | DAVIS CREEK             | 8/10/2015|
| 32        | 36.44670   | -84.29517   | ELK CREEK               | 8/26/2015|
| 33        | 36.53685   | -83.90038   | STRAIGHT CREEK          | 8/2/2015  |
| 35        | 36.46874   | -84.14506   | JIM BRANCH              | 8/6/2015  |
| 36        | 36.57643   | -84.2695    | CAPUCHIN CREEK          | 8/25/2015|
| 37        | 36.49582   | -84.06539   | DAVIS CREEK             | 8/5/2015  |
| 38a       | 36.57146   | -83.91659   | CLEARFORK               | 8/27/2015|
| 39        | 36.50621   | -84.13808   | STINKING CREEK          | 8/5/2015  |
| 40        | 36.50000   | -84.13157   | STINKING CREEK          | 8/5/2015  |
| 41        | 36.55595   | -83.9659    | CLEARFORK               | 8/2/2015  |
| 42        | 36.56521   | -84.00356   | TACKETT CREEK           | 8/3/2015  |
| 1         | 36.55688   | -83.98358   | ROSE CREEK              | 8/3/2012  |
| 2         | 36.52740   | -83.93635   | ROCK CREEK              | 8/2/2015  |
| 5         | 36.54557   | -84.09405   | UT LAUREL               | 8/11/2015|
| 7         | 36.47255   | -84.19511   | UT STINKING CK.         | 8/6/2015  |
| 8         | 36.47799   | -84.29189   | LICK FORK               | 8/26/2015|
| 9         | 36.51407   | -84.23458   | BARLEY BRANCH           | 8/26/2015|
| 10        | 36.57671   | -84.36054   | CHILDERS BRANCH         | 8/20/2015|
| 11        | 36.54827   | -84.2631    | BAIRD CREEK             | 8/20/2015|

Kentucky River Basin

| Station   | Latitude   | Longitude   | Stream                  | Date     |
|-----------|------------|-------------|-------------------------|----------|
| DOW04038401 | 37.49732   | -83.83042   | GRANNY DISMAL CREEK     | 6/20/2013|
| DOW04038402 | 37.41188   | -83.8299    | UT STURGEON CREEK (ROCK SPRINGS) | 6/26/2013|
| DOW04038403 | 37.50179   | -83.8511    | GRANNY DISMAL CREEK     | 8/2/2013  |
| DOW04038404 | 37.43681   | -83.84544   | STURGEON CREEK          | 9/10/2013|
Table 1.1. Sampling sites in the upper Cumberland River Basin and upper Kentucky River Basin. —Continued

[Site coordinates are given in decimal degrees. CU, Cumberland River Basin, n=120; KE, Kentucky River Basin, n=85. Fish and habitat sampling were coordinated by M. Compton (Office of Kentucky Nature Preserves) and M. Floyd (U.S. Fish and Wildlife Service)]

| Station    | Latitude  | Longitude  | Stream                          | Date      |
|------------|-----------|------------|---------------------------------|-----------|
| DOW04039401| 37.54149  | -83.72368  | LONG BRANCH                     | 6/19/2013 |
| DOW04039402| 37.58561  | -83.71268  | SILVER CREEK                    | 6/20/2013 |
| DOW04039403| 37.61643  | -83.74454  | RIGHT FORK CONTRARY CREEK       | 7/16/2013 |
| DOW04044401| 37.44506  | -83.64023  | BEAR RUN                        | 6/20/2013 |
| DOW04044402| 37.41258  | -83.68385  | WHITE OAK CREEK                 | 7/17/2013 |
| DOW04044404| 37.28516  | -83.85613  | OPOSSUM TROT BRANCH             | 8/22/2013 |
| DOW04044405| 37.29567  | -83.75351  | CRADLEBOW BRANCH                | 8/22/2013 |
| DOW04044406| 37.30911  | -83.73415  | UPPER FORK COOL SPRING BRANCH   | 8/22/2013 |
| DOW04044407| 37.29664  | -83.70576  | LOWER TEGES CREEK               | 8/22/2013 |
| DOW04044408| 37.36016  | -83.58179  | LUCKY FORK                      | 8/25/2013 |
| DOW04044409| 37.40905  | -83.67178  | WHITE OAK CREEK                 | 7/17/2013 |
| DOW04044410| 37.41268  | -83.69508  | WHITE OAK CREEK                 | 9/11/2013 |
| DOW04044411| 37.41041  | -83.70264  | WHITE OAK CREEK                 | 9/11/2013 |
| DOW04044412| 37.40899  | -83.7147   | WHITE OAK CREEK                 | 8/25/2013 |
| DOW04045401| 37.32835  | -83.50723  | SQUABBLE CREEK                  | 8/28/2013 |
| DOW04046401| 37.26333  | -83.50521  | LEATHERWOOD CREEK               | 8/28/2013 |
| DOW04046402| 37.26028  | -83.50119  | NEWBERRY FORK                   | 8/20/2013 |
| DOW04046403| 37.22697  | -83.43024  | HELL FOR CERTAIN CREEK          | 8/27/2013 |
| DOW04047401| 37.67855  | -83.46541  | MANDY HOLLAND FORK              | 7/18/2013 |
| DOW04047402| 37.66894  | -83.41686  | HURST FORK                      | 7/18/2013 |
| DOW04047403| 37.63549  | -83.38718  | LOWER NEGRO BRANCH              | 7/18/2013 |
| DOW04047404| 37.60892  | -83.55217  | BRUSH CREEK                     | 7/18/2013 |
| DOW04047405| 37.57276  | -83.68169  | BLAINES BRANCH                  | 7/16/2013 |
| DOW04047406| 37.67855  | -83.65406  | WALKER CREEK                    | 8/30/2013 |
| DOW04048401| 37.31157  | -83.20725  | FIRST CREEK                     | 6/7/2013  |
| DOW04048403| 37.39196  | -83.32555  | CANEY CREEK                     | 8/27/2013 |
| DOW04049401| 37.59481  | -83.22408  | HUNTING CREEK                   | 9/6/2013  |
| DOW04049402| 37.57578  | -83.09102  | HAWES FORK                      | 8/28/2013 |
| DOW04049403| 37.54995  | -83.23978  | SULPHUR SPRINGS FORK            | 9/6/2013  |
| DOW04049404| 37.52342  | -83.02912  | PRATER BRANCH                   | 8/28/2013 |
| DOW04049405| 37.52876  | -83.25871  | SOUTH FORK QUICKSAND CREEK      | 9/6/2013  |
| DOW04049406| 37.51577  | -82.97854  | SPRING FORK QUICKSAND CREEK     | 8/21/2013 |
| DOW04050401| 37.40995  | -82.96258  | MILL BRANCH                     | 7/16/2013 |
| DOW04050402| 37.46055  | -83.23601  | FUGATE FORK                     | 7/18/2013 |
| DOW04050403| 37.34294  | -83.16306  | PIGEONROOST BRANCH              | 7/16/2013 |
| DOW04050404| 37.30779  | -82.94965  | TRACE FORK                      | 7/16/2013 |
| DOW04050405| 37.30609  | -82.92903  | TROUBLESOME CREEK               | 7/15/2013 |
| DOW04050406| 37.3083   | -83.07702  | CLEAR CREEK                     | 7/15/2013 |
| DOW04050407| 37.33969  | -82.93541  | MILL CREEK                      | 7/18/2013 |
| DOW04050408| 37.45782  | -83.32144  | MILL BRANCH                     | 8/27/2013 |
| DOW04051401| 37.20612  | -83.74454  | JACKS BRANCH                    | 7/3/2013  |
| DOW04051402| 37.19313  | -83.8833   | UT TANYARD BRANCH               | 7/3/2013  |
Table 1.1. Sampling sites in the upper Cumberland River Basin and upper Kentucky River Basin. —Continued

| Station       | Latitude   | Longitude | Stream                              | Date     |
|---------------|------------|-----------|-------------------------------------|----------|
| DOW04051403   | 36.99118   | -83.79731 | HORN BRANCH                         | 7/2/2013 |
| DOW04051404   | 36.97298   | -83.78805 | SPRUCE PINE BRANCH                 | 7/2/2013 |
| DOW04051405   | 37.10643   | -83.84928 | EAST FORK PIGEON ROOST BRANCH      | 7/3/2013 |
| DOW04051406   | 37.08695   | -83.70726 | SEVIER BRANCH                       | 7/25/2013|
| DOW04051407   | 37.02646   | -83.84806 | BULL CREEK                          | 8/6/2013 |
| DOW04051408   | 37.0677    | -83.79964 | COLLINS FORK                        | 8/6/2013 |
| DOW04051409   | 37.10643   | -83.84928 | WEST FORK PIGEON ROOST BRANCH      | 9/5/2013 |
| DOW04051410   | 37.07975   | -83.73809 | SAPLINGS FORK                      | 9/5/2013 |
| DOW04051411   | 37.12211   | -83.78849 | HORSE CREEK                         | 9/5/2013 |
| DOW04052401   | 37.03937   | -83.47185 | BOWEN CREEK                         | 8/29/2013|
| DOW04052402   | 37.07147   | -83.56499 | FLAT CREEK                          | 8/29/2013|
| DOW04052403   | 37.1669    | -83.5146  | BOBS FORK                           | 8/29/2013|
| DOW04052404   | 37.18257   | -83.49213 | BOBS FORK                           | 8/29/2013|
| DOW04053401   | 37.16959   | -83.33263 | FLACKEY BRANCH                     | 9/5/2013 |
| DOW04054401   | 37.13542   | -83.33733 | HURRICANE CREEK                     | 7/25/2013|
| DOW04054402   | 37.13655   | -83.39836 | SHORT CREEK                         | 7/25/2013|
| DOW04054403   | 37.13503   | -83.41166 | SHORT CREEK                         | 7/25/2013|
| DOW04054404   | 36.93154   | -83.30248 | RIGHT FORK BILL BRANCH             | 8/1/2013 |
| DOW04054405   | 36.95212   | -83.4084  | BIG BRANCH                          | 8/1/2013 |
| DOW04054406   | 37.11005   | -83.38237 | MUNCY CREEK                         | 8/1/2013 |
| DOW04054407   | 37.12391   | -83.38228 | MUNCY CREEK                         | 8/1/2013 |
| DOW04054408   | 37.03643   | -83.41328 | MIDDLE FORK KENTUCKY RIVER          | 8/6/2013 |
| DOW04054409   | 36.97415   | -83.40526 | BEECH FORK                          | 8/6/2013 |
| DOW04054410   | 37.05801   | -83.42224 | TRACE BRANCH                        | 9/4/2013 |
| DOW04054411   | 37.00126   | -83.33668 | BRITTON BRANCH                      | 9/4/2013 |
| DOW04055401   | 37.09106   | -82.99763 | LINE FORK                           | 9/9/2013 |
| DOW04055402   | 37.28816   | -83.15596 | LOTTES CREEK                        | 9/3/2013 |
| DOW04055405   | 37.09267   | -82.98618 | WHITAKER BRANCH                     | 9/4/2013 |
| DOW04055406   | 37.06433   | -82.96947 | BIG BRANCH                          | 9/4/2013 |
| DOW04055407   | 37.21628   | -83.18648 | BUFFALO CREEK                       | 8/28/2013|
| DOW04055408   | 37.22045   | -83.17941 | BUFFALO CREEK                       | 8/28/2013|
| DOW04057401   | 37.22125   | -82.98826 | SMITH BRANCH                        | 6/27/2013|
| DOW04057402   | 37.27342   | -82.84293 | MEADOW BRANCH                       | 7/18/2013|
| DOW04057403   | 37.24020   | -82.92062 | LITTLE CARR FORK                    | 9/9/2013 |
| DOW04059401   | 37.16956   | -82.90687 | BLAIR BRANCH                        | 6/27/2013|
| DOW04059402   | 37.11942   | -82.79408 | CRAFTS COLLY CREEK                  | 6/26/2013|
| DOW04059403   | 37.05655   | -82.91555 | KINGS CREEK                         | 6/26/2013|
| DOW04059404   | 37.14162   | -82.96789 | ROCKHOUSE CREEK                     | 6/27/2013|
| DOW04059405   | 37.21926   | -82.66298 | WRIGHT FORK                         | 6/26/2013|
Table 1.2. Goodness-of-fit of the three best occupancy models for blackside dace, Cumberland arrow darter, and Kentucky arrow darter.

[BSD, blackside dace; CAD, Cumberland arrow darter; KAD, Kentucky arrow darter. Cells show the type-1 error rates from bootstrapped chi-squared tests (1,000 replicates). Small error rate values indicate inadequate model fit in this context. See table 3 for model summaries]

| Model | BSD  | CAD  | KAD  |
|-------|------|------|------|
| 1     | 0.106| 0.637| 0.533|
| 2     | 0.782| 0.263| 0.401|
| 3     | 0.681| 0.470| 0.347|
