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

Modeling Occupancy of Rare Stream Fish Species in the Upper Cumberland and Kentucky River Basins

Open-File Report 2020–1100

U.S. Department of the Interior
U.S. Geological Survey

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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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	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 (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (ft^2)
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	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.

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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)

Figure 1. Focal species included in this analysis: blackside dace (top left), Cumberland arrow darter (top right), Kentucky arrow darter (bottom left), and Cumberland darter (bottom right). Photos by Dr. Matthew Thomas, Kentucky Department of Fish and Wildlife Resources.

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

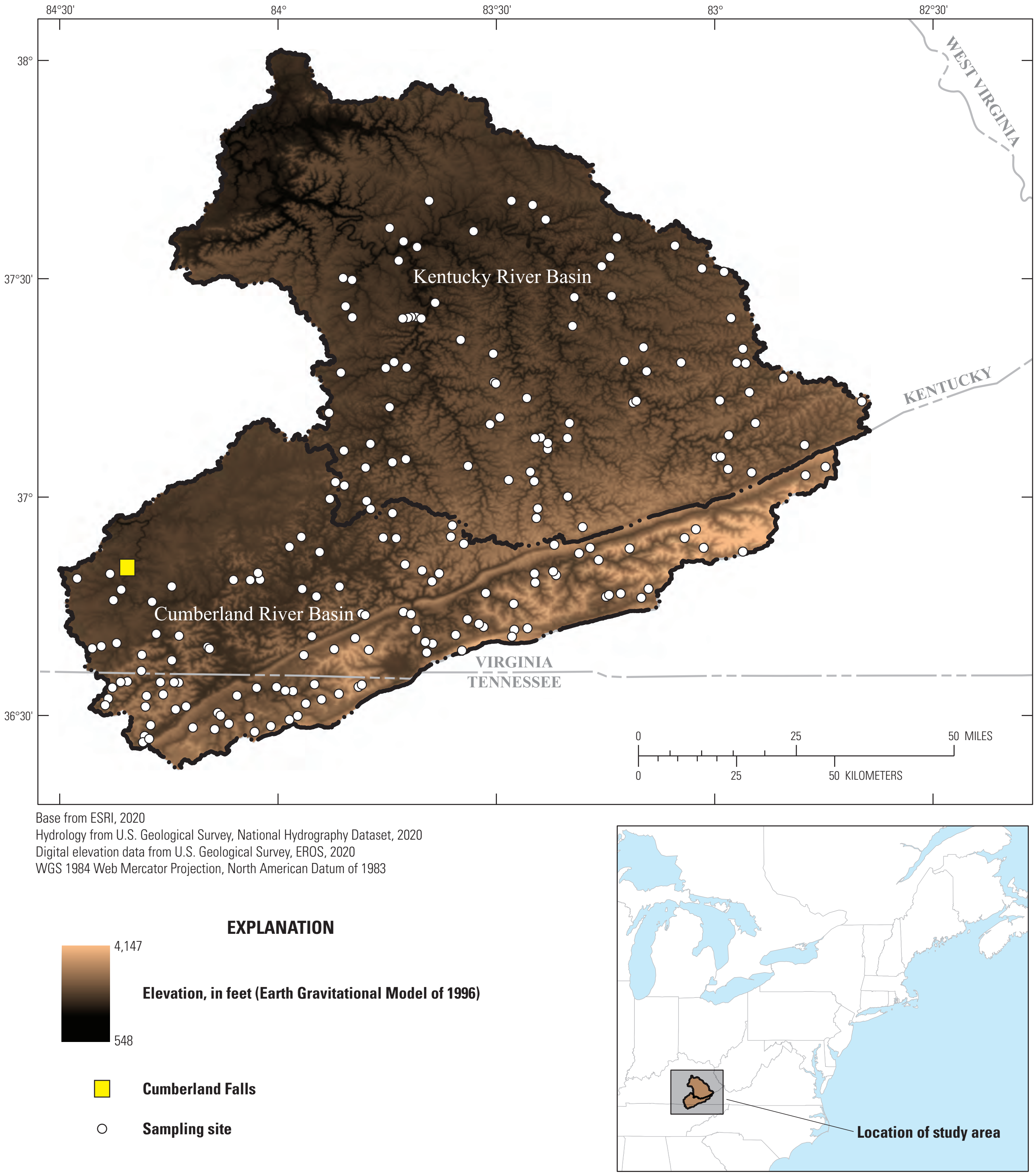

Figure 2. Location of Cumberland and Kentucky River Basins in Virginia and Kentucky with sampling sites. Sampling sites are shown as points and are listed in appendix table 1.1.

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 estimated visually 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

$$z_i \sim Bernoulli(\Psi_i) \quad (1)$$

$$y_{ij} z_i \sim Bernoulli(z_i p_{ij}) \quad (2)$$

where

z_i is the state variable defining the presence or absence of BSD, CAD, or KAD within site *i*,

Ψ_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

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]

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 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. µS/cm, microsiemens per centimenter; <, less than; SD, standard deviation]

Covariate	Code	Units	Basin	Mean	SD	Range
Conductivity	oCO	µS/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

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.

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). A total of 52 individual CAD were observed within 37 quadrats across 20 sites in the CU study area (naive occupancy = 0.17). As with BSD, CAD were observed on average in 1.9 quadrats (19 percent) within sites where they were detected, and the maximum observed presence was 5 quadrats in one site (DOW02013601 in table 1.1). Thirteen KAD were observed within 10 quadrats across six sites within the KE study area (naive occupancy = 0.07). In sites where KAD were observed, they were detected on average in 1.7 quadrats (17 percent) with a maximum observed presence within 3 quadrats in one site (DOW04052401 in table 1.1). CD was observed in only one site (13 individuals within 5 quadrats); therefore, it was excluded from further analysis because it lacked enough observations for modeling.

Environmental covariates measured at the quadrat level exhibited substantial variation (table 1) and similar patterns of correlation within the CU and KE study areas (fig. 3). Sampling effort as indexed by electrofishing time (dET in table 1) ranged from 6 to 182 seconds per quadrat, and mean values were equivalent across study areas (66 seconds; table 1). Quadrat depths ranged from 0.01 m to 1.00 m (table 1) with a grand mean of 0.13 m. Substrates in both study areas were primarily gravel/cobble (61 percent and 58 percent in CU and KE, respectively; table 1) and secondarily sand (16 percent and 14 percent in CU and KE, respectively; table 1). Bedrock was more abundant in KE sites than in CU sites (19 percent and 8 percent, respectively; table 1).

Electrofishing time increased with quadrat depth (fig. 3). Flow velocity was inversely related to the percent fine substrates and positively related to percent gravel/cobble substrates within quadrats (fig. 3). Percent sand and gravel/cobble substrates were inversely related, and gravel/cobble substrates were inversely related to the percent bedrock (fig. 3). Detection covariates showed similar correlations in both study areas, but flow velocity generally showed stronger relations to substrate size in CU than in KE, and bedrock showed stronger relations within KE than CU (fig. 3).

Site-level covariates included measures of water quality, stream volume, land use, and substrate size (table 2). Stream conductivity ranged from 15 to 2,175 µS/cm, and mean values were not different between study areas ($t = -1.2$, $p = 0.25$). Conductivity decreased with forest cover and increased with barren land cover in both study areas (fig. 4). By comparison, developed land cover showed relatively weak correlations with conductivity (fig. 4), indicating the importance of sulfates from surface mine runoff rather than chlorides from road salts (Cormier and others, 2013). 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,

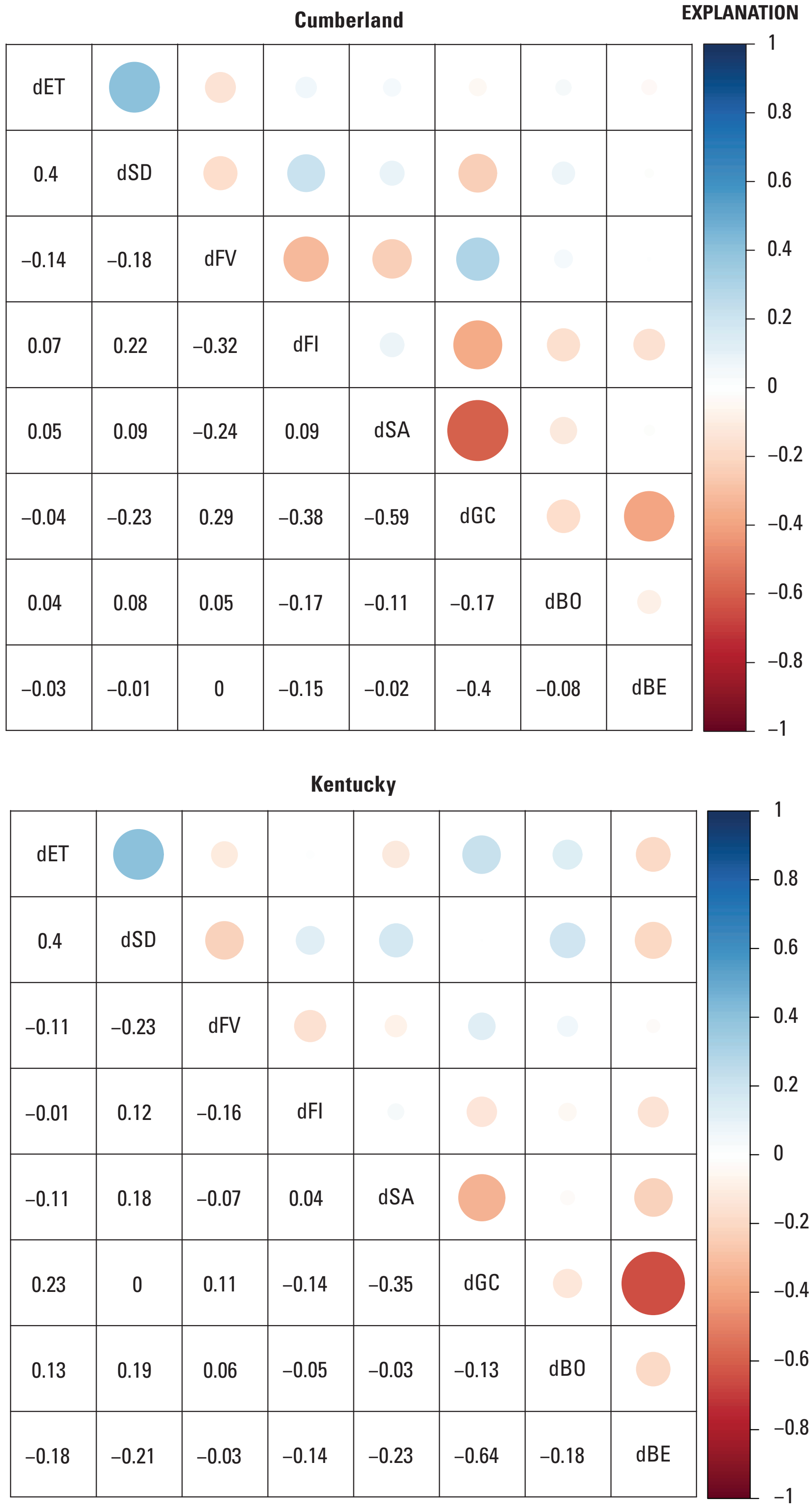

Figure 3. Correlation matrix for detection-level covariates in the upper Cumberland River Basin and the upper Kentucky River Basin. Cumberland River Basin, n=1,200 quadrats; Kentucky River Basin, n=850 quadrats. Lower diagonal cells give Spearman correlation coefficients, and upper diagonal cells represent correlation direction (color) and magnitude (circle size). Codes are given in table 1, and study sites are shown in figure 2.

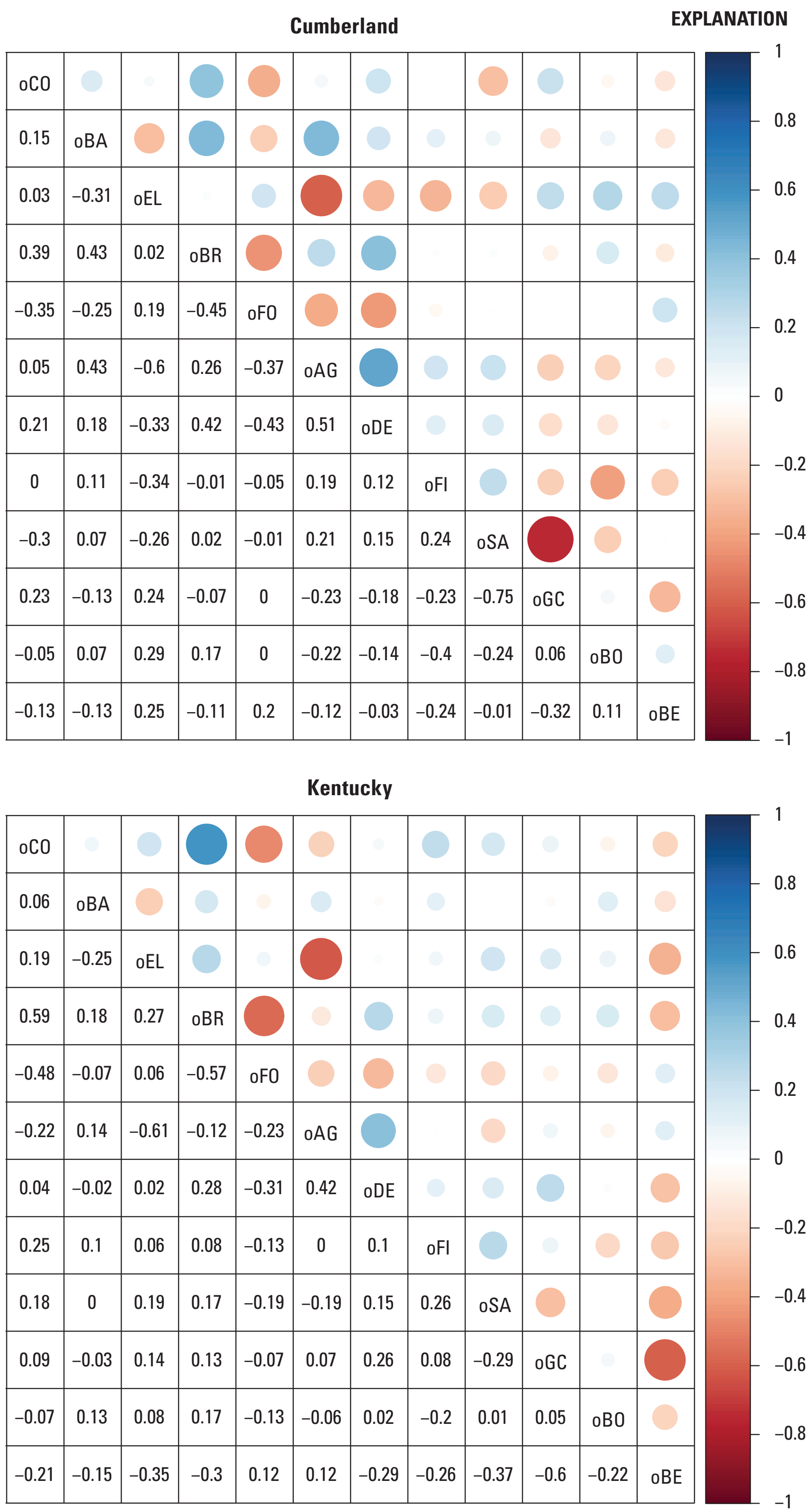

Figure 4. Correlation matrix for occurrence-level covariates in the upper Cumberland River Basin, n = 120, and upper Kentucky River Basin, n = 85. Lower diagonal cells give Spearman correlation coefficients, and upper diagonal cells represent correlation direction (color) and magnitude (circle size). Codes are given in table 2, and study sites are shown in figure 2.

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

[Covariates for detection probability (*βp*) and occurrence probability (*βpsi*) are defined in table 1 and table 2**.** The relative difference in Akaike Information Criterion scores (ΔAIC), AIC weights (AICw), cumulative AIC weights (AICwc), and number of parameters (nP) are given for each model]

Model	*βp*	*βpsi*	nP	ΔAIC	AICw	AICwc
			Blackside dace			
1	dET	oAG	4	0.00	0.10	0.10
2	dFV	oAG	4	0.77	0.07	0.18
3	dGC	oAG	4	1.44	0.05	0.23
			Cumberland arrow darter			
1	dET	oCO	4	0.00	1.00	1.00
2	dET	oBR	4	17.94	0.00	1.00
3	dET	oFO	4	18.48	0.00	1.00
			Kentucky arrow darter			
1	dSA	oCO	4	0.00	0.20	0.20
2	dSA	oBR	4	2.01	0.07	0.27
3	dET	oCO	4	3.06	0.04	0.31

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

[Coefficients are identified in table 3. Cells show standard errors (SE) and type-1 error rates (p) from standardized z-scores. <, less than]

Level	Covariate	Estimate	SE	*z*	*p*
		Blackside dace			
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
		Cumberland arrow darter			
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
		Kentucky arrow darter			
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

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).

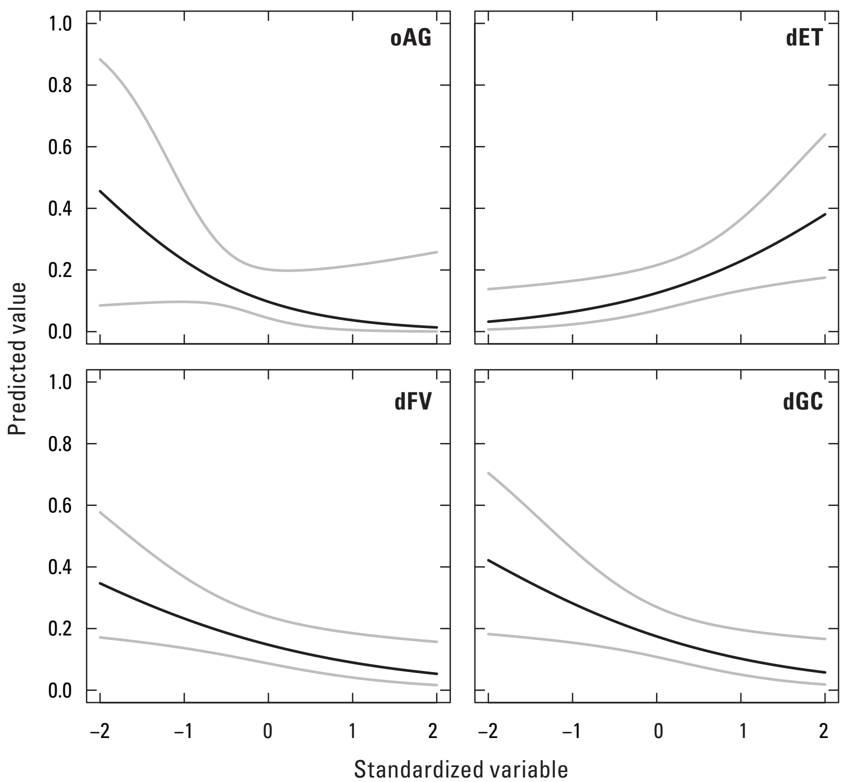

Figure 5. Blackside dace predicted occurrence and detection probabilities (black lines) and 95-percent confidence intervals (grey lines) for covariates in the top three models. Top three models are described in table 3. Covariates for occurrence (“o”) and detection (“d”) probabilities are defined in tables 1 and 2.

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

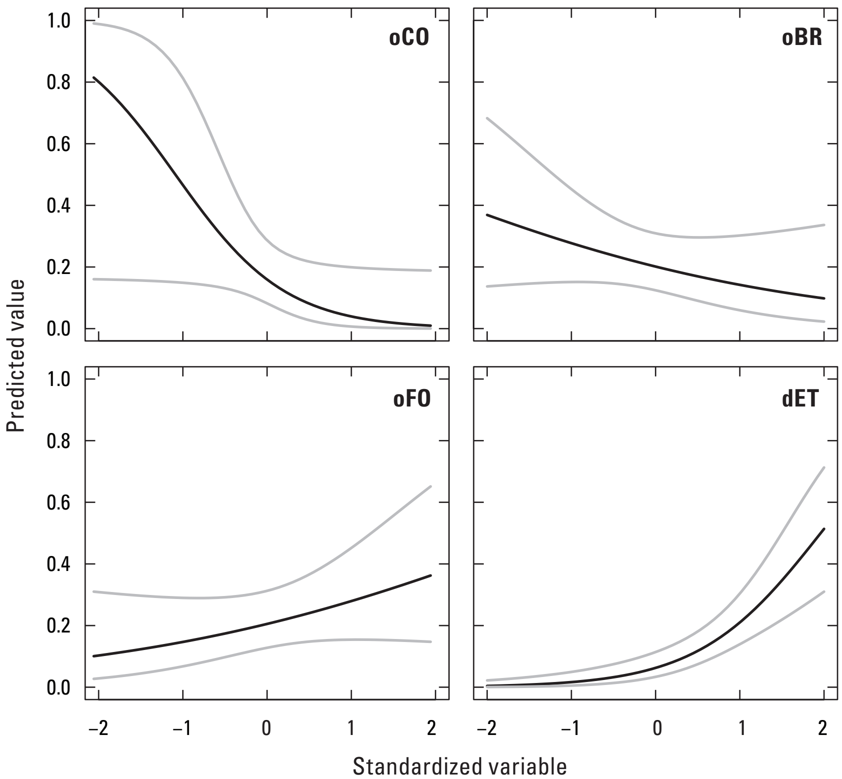

Figure 6. Cumberland arrow darter predicted occurrence and detection probabilities (black lines) and 95-percent confidence intervals (grey lines) for covariates in the top three models. Top three models are described in table 3. Covariates for occurrence ("o") and detection ("d") probabilities are defined in table 1 and table 2.

gravel/cobble substrates in the CU study area (fig. 4), and the negative effects of turbidity and siltation on BSD populations are well known (FWS, 1987). Similar agricultural effects were reported for *Percina oxyrhynchus* (sharpnose darter) in the upper Kentucky River Basin (Hopkins and Roush, 2013). BSD spawning is often associated with spawning mounds constructed by *Semotilus atromaculatus* (creek chub) (Mattingly and Black, 2013), and such nest associations can enable long-term persistence of fish species in agriculturally affected streams (Hitt and Roberts, 2012), which indicates the presence of other mechanistic effects of land use besides siltation and egg mortality. Although agriculture was not included in the top three models for CAD or KAD (table 3), it was included for models ranked 12 of 117 for CAD (top 10 percent) and 42 of 117 for KAD (top 36 percent) (results not shown). All potentially interactive effects were not evaluated (owing to higher-order models lacking sufficient goodness-of-fit), but we expect combined effects of land use as shown for benthic macroinvertebrate communities (Merriam and others, 2011) and a BSD congener in Virginia (*Chrosomus* sp. cf. *saylori,* Clinch dace) (Moore and others, 2017).

Our estimated detection probabilities ranged from 0.035 (KAD) to 0.170 (BSD) (table 5); these values are comparable to other rare stream fishes in the southeastern United States. 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 aurolineata* (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 insignis* (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

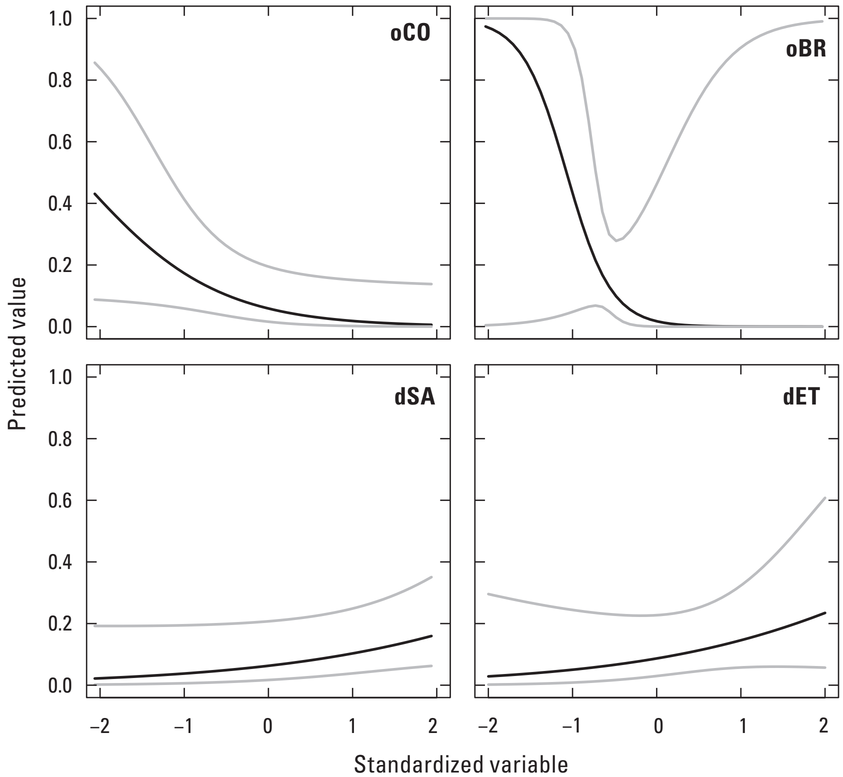

Figure 7. Kentucky arrow darter predicted occurrence and detection probabilities (black lines) and 95-percent confidence intervals (grey lines) for covariates in the top three models. Top three models are described in table 3. Covariates for occurrence (“o”) and detection (“d”) probabilities are defined in tables 1 and 2.

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 environments (for example, Hitt and others, in press). Kendall and White (2009) report that such non-independence in spatial replicates can bias species occupancy estimates. They further demonstrate that sampling quadrats with replacement can overcome this potential bias (Kendall and White, 2009). In our analysis this would require a randomization process to select spatial quadrats within study sites from which all spatial units could be selected in each sampling iteration (that is, sampling with replacement). Future research may benefit from this approach, as this could maintain the logistical benefits of

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

[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]

	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

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 spatial replicates (Srivathsa 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
		Cumberland River Basin		
DOW02036601	36.90598	-83.72948	BRICES CREEK	7/17/2012
DOW02030601	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	POPLAR 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	POPLAR 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

[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
Primary 2	36.57804	-84.34507	MIKE BRANCH	8/19/2015
Primary 3	36.52047	-84.30369	BEAR BRANCH	8/25/2015
Primary 5	36.56393	-84.37943	UT GUM FORK	8/19/2015
Primary 12	36.45307	-84.30542	COONTAIL BRANCH	8/26/2015
Primary 13	36.56353	-84.04906	UT CLEAR FORK	8/6/2015
Primary 14	36.57555	-84.22761	TRAMMEL BRANCH	8/20/2015
Primary 15	36.53909	-84.38879	UT JELLICO CREEK	8/21/2015
Primary 16	36.43894	-84.30947	ELK CREEK	8/26/2015
Primary 17	36.48133	-84.11278	ROCK CREEK	8/6/2015
Primary 20	36.49043	-83.97393	LITTLE TACKETT CR.	8/10/2015
Primary 21	36.54494	-84.30111	TRAMMEL BRANCH	8/18/2015
Primary 23	36.54988	-83.86082	VALLEY CREEK	8/2/2015
Secondary 24a	36.52085	-84.21069	LITTLE ELK CREEK	8/27/2015
Primary 25	36.57605	-84.23817	HATFIELD CREEK	8/19/2015
Primary 26	36.46268	-84.05355	DAVIS CREEK	8/10/2015
Primary 27	36.49928	-83.9553	LITTLE TACKETT	8/11/2015
Primary 28	36.52367	-84.39598	JELLICO CREEK	8/20/2015
Primary 29	36.57056	-83.80809	BURRELL CREEK	8/1/2015
Primary 31	36.47584	-84.01652	DAVIS CREEK	8/10/2015
Primary 32	36.44670	-84.29517	ELK CREEK	8/26/2015
Primary 33	36.53685	-83.90038	STRAIGHT CREEK	8/2/2015
Primary 35	36.46874	-84.14506	JIM BRANCH	8/6/2015
Primary 36	36.57643	-84.2695	CAPUCHIN CREEK	8/25/2015
Primary 37	36.49582	-84.06539	DAVIS CREEK	8/5/2015
Secondary 38a	36.57146	-83.91659	CLEAR FORK	8/27/2015
Primary 39	36.50621	-84.13808	STINKING CREEK	8/5/2015
Primary 40	36.50000	-84.13157	STINKING CREEK	8/5/2015
Primary 41	36.55595	-83.9659	CLEARFORK	8/2/2015
Primary 42	36.56521	-84.00356	TACKETT CREEK	8/3/2015
Secondary 1	36.55688	-83.98358	ROSE CREEK	8/3/2012
Secondary 2	36.52740	-83.93635	ROCK CREEK	8/2/2015
Secondary 5	36.54557	-84.09405	UT LAUREL	8/11/2015
Secondary 7	36.47255	-84.19511	UT STINKING CK.	8/6/2015
Secondary 8	36.47799	-84.29189	LICK FORK	8/26/2015
Secondary 9	36.51407	-84.23458	BARLEY BRANCH	8/26/2015
Secondary 10	36.57671	-84.36054	CHILDERS BRANCH	8/20/2015
Secondary 11	36.54827	-84.2631	BAIRD CREEK	8/20/2015
			Kentucky River Basin	
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	8/8/2013
DOW04046402	37.26028	-83.50119	NEWBERRY FORK	8/8/2013
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

[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
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	LOTTS 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

For additional information, contact:

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Kearneysville, WV 25430

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