3.A Exploratory data analysis of the Arkansas River basin.

The original data pull suggested 982 sampling occasions but this data set included repeated data, missing catch information, capture-mark-recapture studies, headwater sites, trapping data, and surveys conducted by USGS that followed a different protocol. In the cleaned data, there were a total of 405 passes on 201 sampling occasions of 141 unique sites; some sites were sampled in multiple years. Of the 201 sampling occasions, 117 of them included more than one pass. Because only thirteen dip net passes occurred, the dip net passes are excluded from all tables and analyses.

Table A1: The stream types sampled each year. CONNECT means the stream segment was less than 2000 m from the perennial stream network, and UNCONNECT means the stream segment was more than 2000 m from the perennial stream network. Altogether, 109 of the sites were CONNECT and 32 or the sites were UNCONNECT.

	CONNECT	UNCONNECT
2008	33	15
2009	14	3
2010	17	2
2011	21	9
2012	41	5
2013	11	2
2014	12	1
2015	13	2
Total	162	39

Table A2: Stream sizes that were sampled each year. A stream that is size 1 is an intermittent stream while a stream of size 4 is the main stem of the Arkanas River, below the Pueblo reservoir. The stream sizes follow the Strahler stream order rules, but were based on the sampling frame used in this design. When broken out as the unique sites that were sampled, 68 of the unique sites were stream order 1, 23 were order 2, 34 were order 3, and 16 were order 4. See Fig. A3 for a visual break-down of the stream sizes throughout the basin.

	1	2	3	4
2008	24	13	9	2
2009	7	0	7	3
2010	8	5	4	2
2011	10	8	11	1
2012	10	0	30*	6
2013	8	0	3	2
2014	7	0	3	3
2015	9	1	0	5
Total	83	27	67	24

*In 2012, seven sites were each surveyed multiple times within the year. Because the sampling was associated with different dates, these sites appear as 30 separate sampling occasions.

Table A3: Locations of sampling occasions each year, broken down by whether the site would drain into the Pueblo reservoir (abovePueblo), below Pueblo but above John Martin reservoir (between), or below John Martin reservoir (belowJM). Altogether, 7 of the sites were above Pueblo reservoir, 106 were between the reservoirs, and 28 were below John Martin.

	abovePueblo	between	belowJM
2008	0	33	15
2009	1	13	3
2010	3	15	1
2011	0	30	0
2012	3	40	3
2013	0	6	7
2014	1	11	1
2015	5	7	3
Total	13	155	33

Table A4: Locations of sampling occasions each year, broken down by whether the site was located in Fountain Creek or not. NO means the site was not on Fountain Creek and YES means the site was on Fountain Creek or drained into Fountain Creek. Altogether, 31 of the sites were on Fountain Creek or drained into it, and 110 sites were not on Fountain Creek.

	NO	YES
2008	32	16
2009	16	1
2010	16	3
2011	27	3
2012	27	19
2013	13	0
2014	6	7
2015	15	0
Total	152	49

Table A5: Locations of sampling occasions each year, broken down by whether the site was located in the Purgatoire River or not. NO means the site was not in the Purgatoire River and YES means the site was in the Purgatoire River or drained into it. Altogether, 8 of the sites were on the Purgatoire River or drained into it, and 133 sites were not on the Purgatoire River.

	NO	YES
2008	48	0
2009	15	2
2010	18	1
2011	28	2
2012	46	0
2013	10	3
2014	13	0
2015	15	0
Total	193	8

Table A6: Locations of sampling occasions each year, broken down by whether the site was located on the main stem of the Arkansas River or not. NO means the site was not on the main stem of the Arkansas River and YES means the site was on the main stem of the Arkansas River. Altogether, 23 sites were on the main stem of the Arkansas River or drained into it, and 118 sites were not on the main stem of the Arkansas River.

	NO	YES
2008	46	2
2009	11	6
2010	15	4
2011	29	1
2012	28	18
2013	10	3
2014	9	4
2015	10	5
Total	158	43

Table A7: The number of *passes* in which each native fish species was detected, broken down by whether the survey occurred on a connected (CONNECT) or unconnected (UNCONNECT) stream. There were 331 passes in the connected, perrenial stream network and 74 passes in the unconnected streams.

Species	CONNECT	UNCONNECT
ARD	29	11
BBH	49	17
CCF	70	0
FHC	128	6
FMW	164	39
LND	113	7
OSF	5	2
PKF	112	21
PMW	25	0
RDS	149	10
SAH	143	0
SMM	53	0
SNF	84	32
SRD	3	0
STR	140	14
WHS	136	17

Figure A1: Our study area within the Arkansas River basin. The study area includes the connected, perennial streams of the basin and some of the intermittent streams. The stars represent the sampled sites where more than one pass was completed and the points represent the sampled sites where only one pass was completed. The black edging is the southeast corner of the Colorado state boundary. The light gray polygon identifies the entire Arkansas River basin and and the darker gray polygon identifies the portion of the Arkansas River basin that is below 1980 m (6,496 feet).

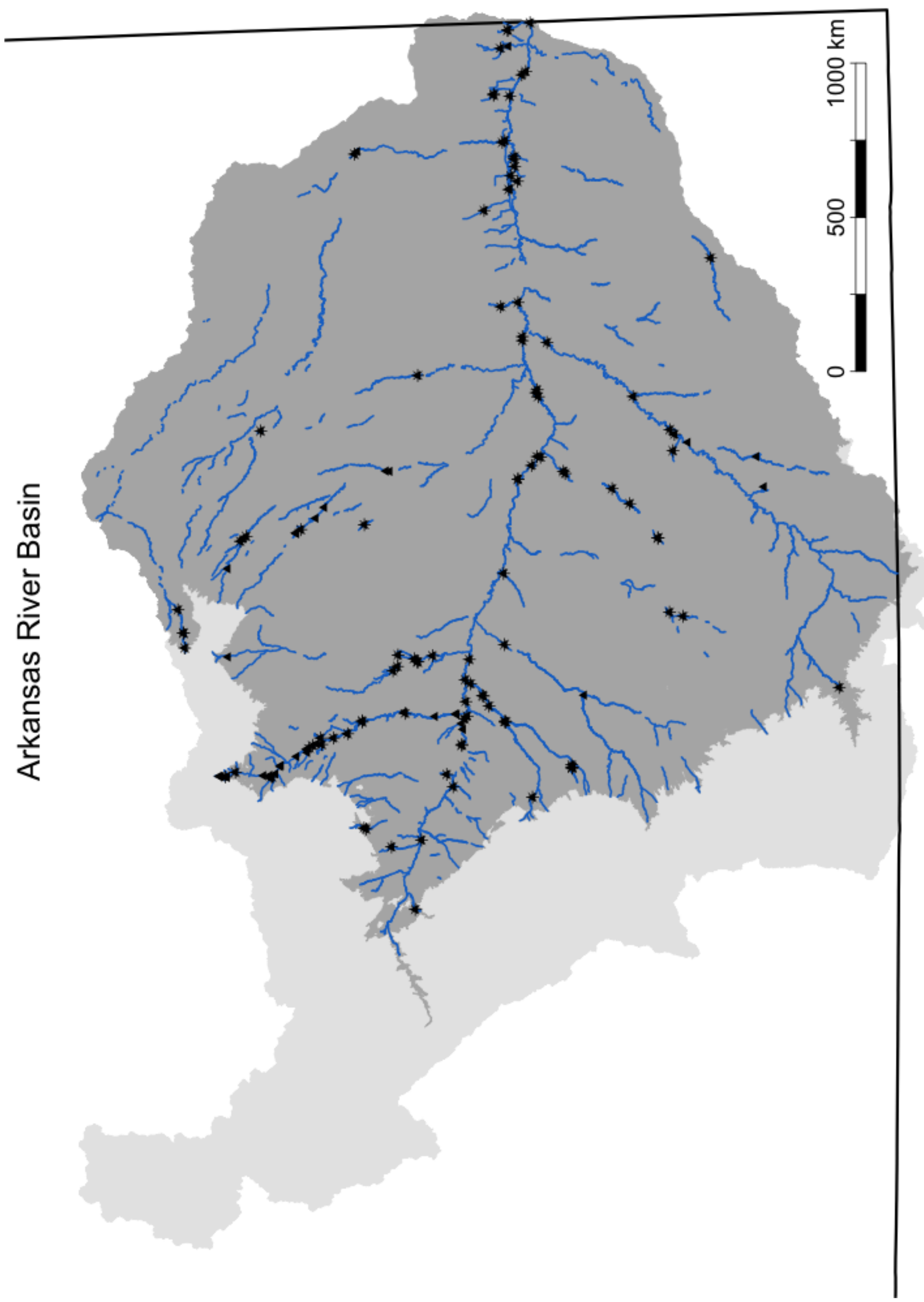


Figure A2: The elevations of the sampling frame. The portion of the basin that is below 1980 m (6,496 ft) is outlined.

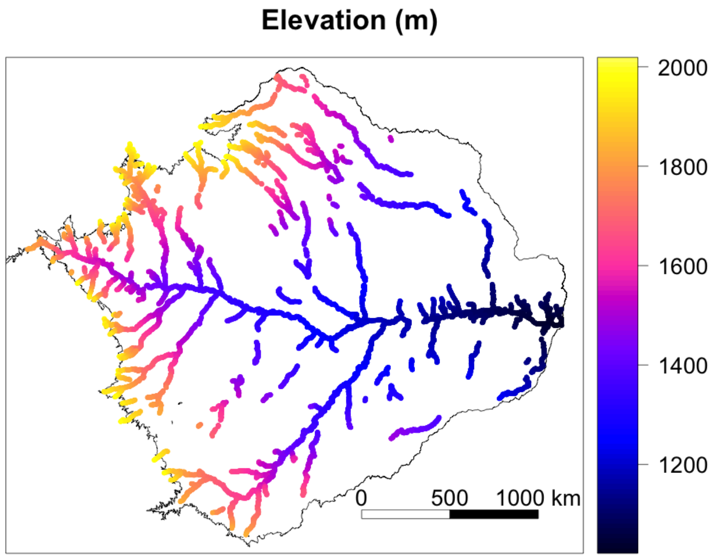


Figure A3: The stream sizes associated with each stream segment. The sizes were calculated from Strahler stream order principles, but were adapted to only be based on the streams in the sampling frame. Streams of size 1 were not gauged. Streams of higher order were wider and generally had larger flows.

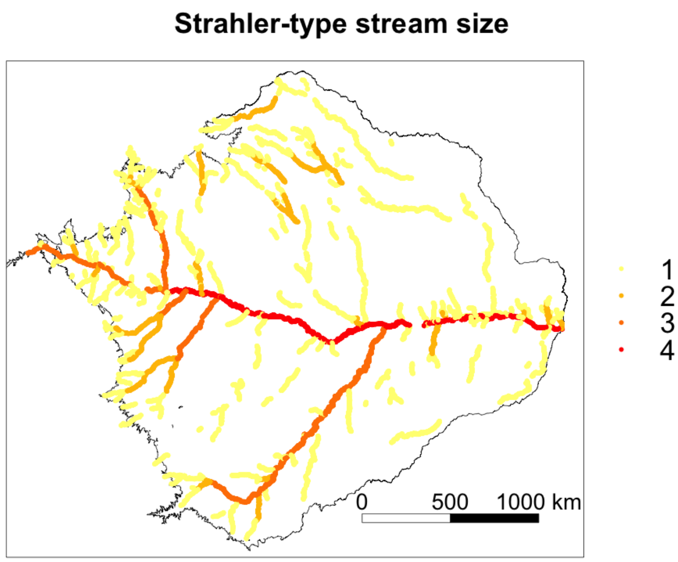


Figure A4: The proportion of the 2000-meter buffer around each site that is cropland. For the stream network, the variable ranges from 0-0.95 with a mean of 0.090; for the sampled sites, it ranges from 0-0.88 with a mean of 0.076.

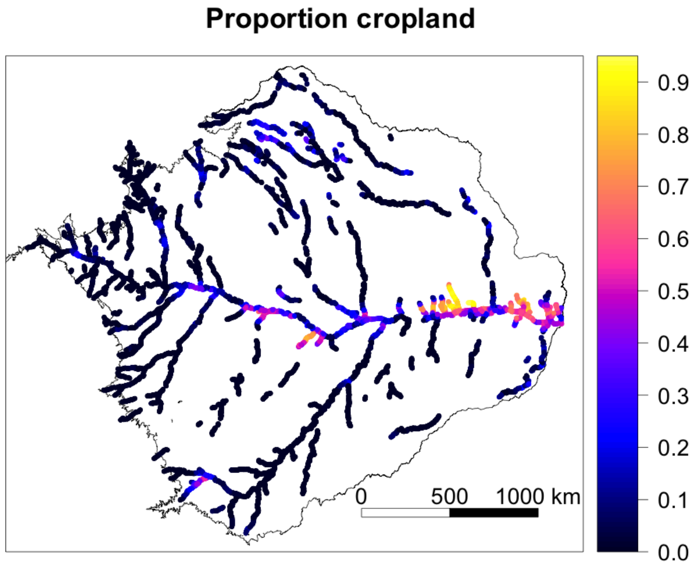


Figure A5: The proportion of the 1000-meter buffer around each site that is developed. For the stream network, the variable ranges from 0–0.99 with a mean of 0.036; for the sampled sites, it ranges from 0-0.98 with a mean of 0.21.

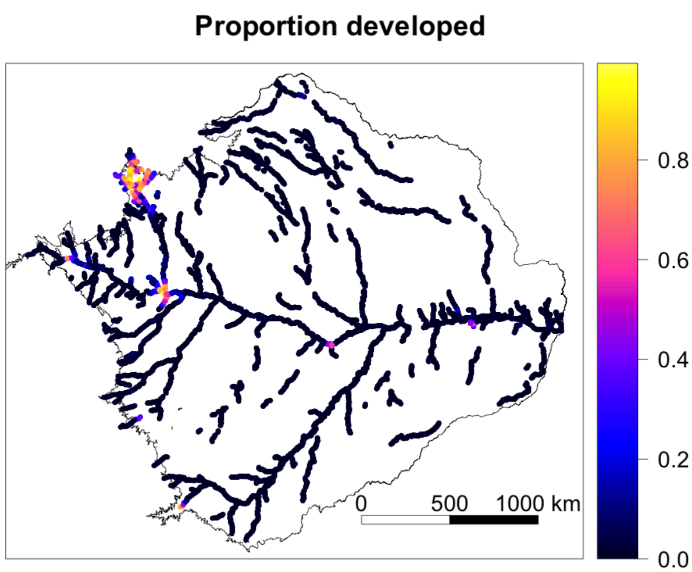


Figure A6: The proportion of the 1000-meter buffer around each site that is wetlands. For the stream network, the variable ranges from 0-0.97 with a mean of 0.063; for the sampled sites, it ranges from 0-0.45 with a mean of 0.11.

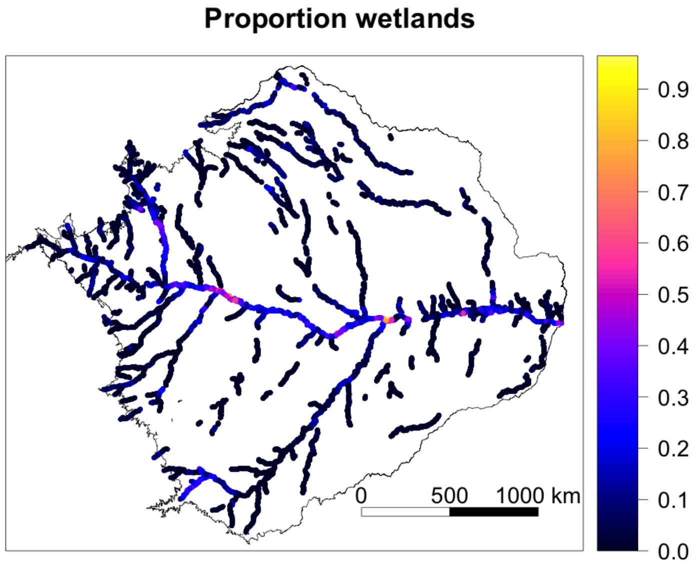


Figure A7: The streams that are considered connected and unconnected to the main, perennial stream netowrk in the sampling design. If the distance between a stream segment and the perennial network was greater than 2000 meters, than the stream segment was considered unconnected. If the distance was less, than the segment was considered to be part of the perennial, connected network.

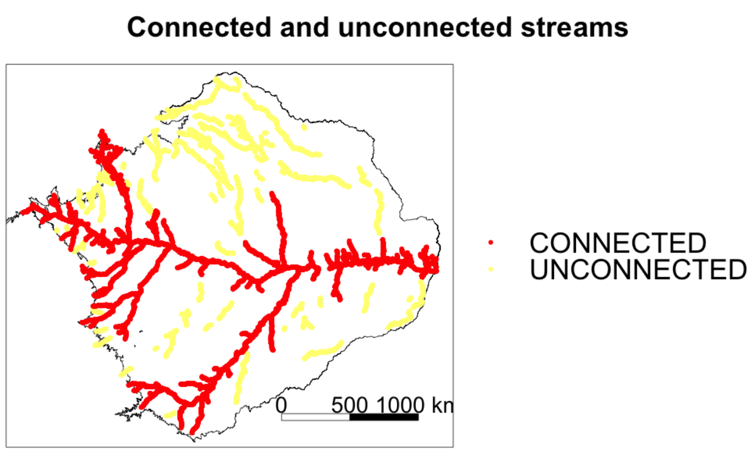


Figure A8: The fish distributions of Fountain Creek may be unique. Therefore whether a site was located on the Fountain Creek, or drained into the Fountain Creek, was considered as a covariate. The red (darker gray) stream segments highlight the streams associated with Fountain Creek.

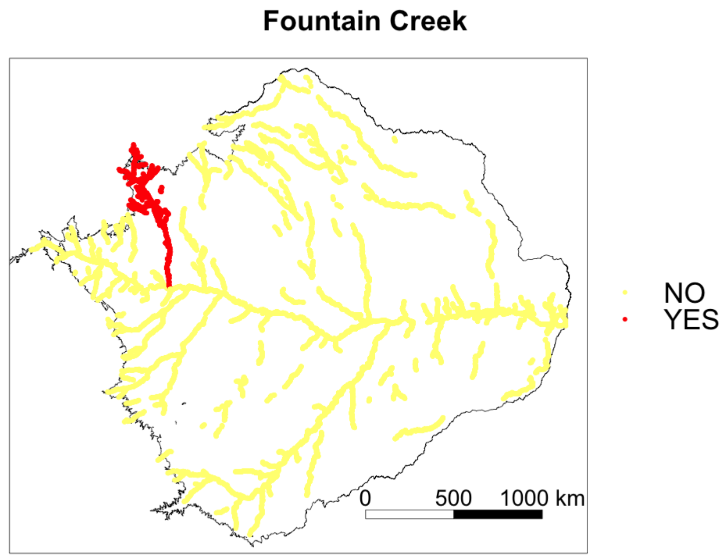


Figure A9: The fish distributions of the Purgatoire River may be unique. Therefore whether a site was located on the Purgatoire River, or drained into the Purgatoire River, was considered as a covariate. The red (darker gray) stream segments highlight the streams associated with the Purgatoire River.

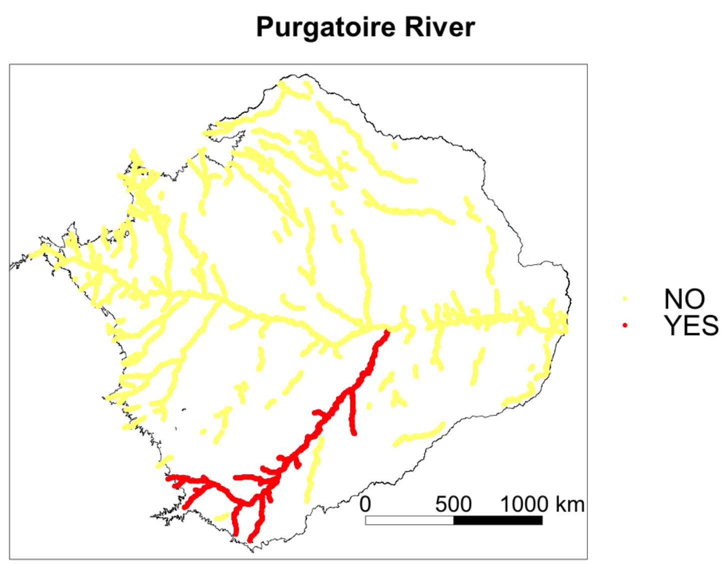


Figure A10: The fish distributions of the main stem of the Arkansas River be unique. herefore whether or not a site was located on the Arkansas River was considered as a covariate. The red (darker gray) stream segments highlight the streams associated with the main stem.

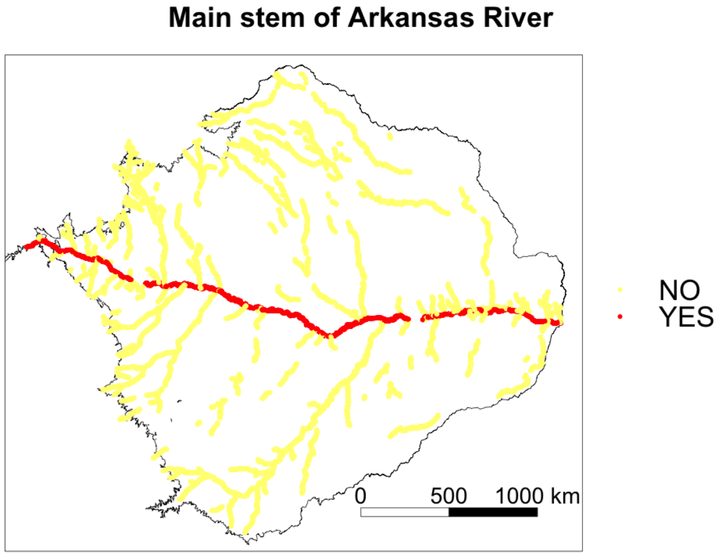


Figure A11: There are two major reservoirs on the Arkansas River in Colorado, the Pueblo reservoir near the upper Arkansas River and the John Martin reservoir, which is closer to the Nebraska border. Because these reservoirs are likely to block fish passages, the assemblages between them may vary and a site's drainage in relation to the reservoirs was considered as a covariate.

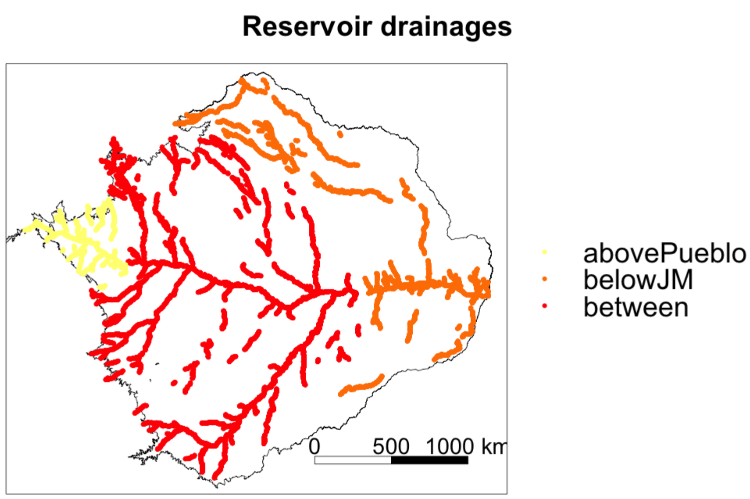


Figure A12: An overview of the day-of-year on which sampling occurred. Most sampling occurred in September and October.

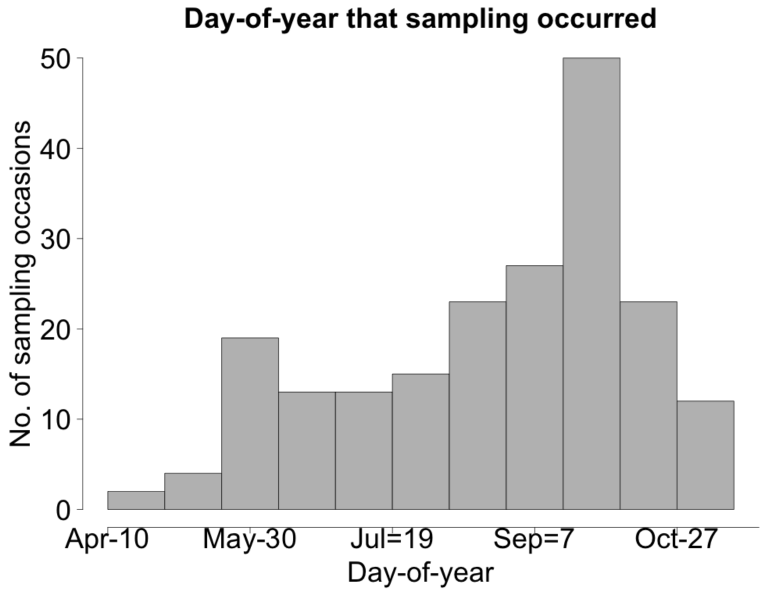


Figure A13: For each survey, all fish were enumerated. On one sampling occasion, no fish were detected. On the remaining sampling occasions, 1-3,264 fish were counted, with median count of 188.5 fish.

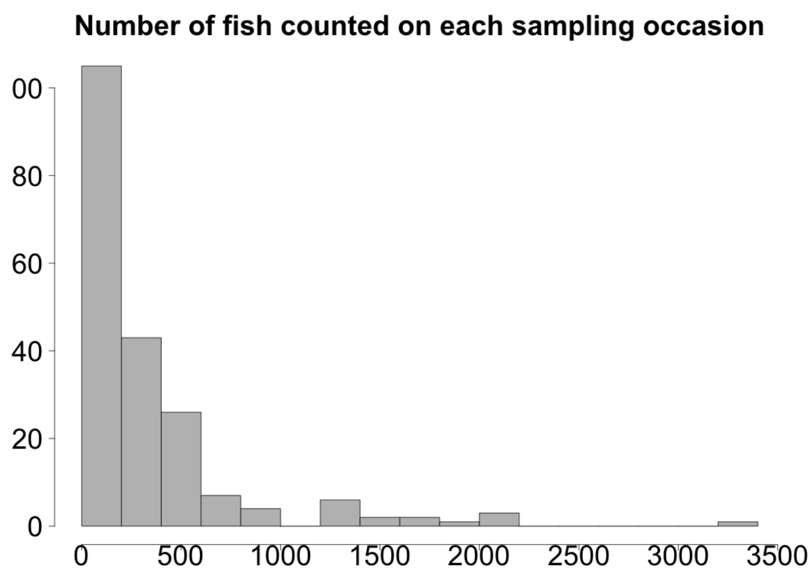


Figure A14: The number of species detected on each sampling occasion. On one sampling occasion, no fish were detected. On 32 sampling occasions, only one species was detected. A maximum of seventeen species were detected on one sampling occasion. The median number of species detected was five.

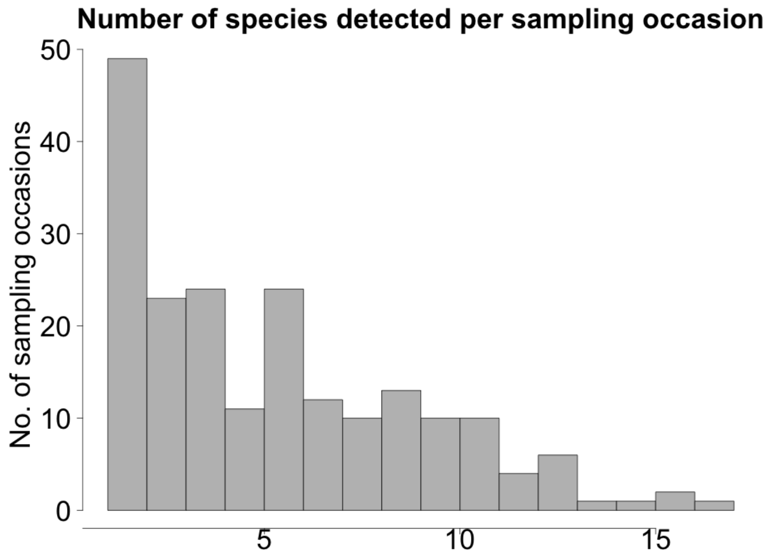


Figure A15: The number of passes associated with each sampling occasion. On 84 of the sampling occasions, only one pass was completed, leaving 117 sampling occasions with multiple passes.

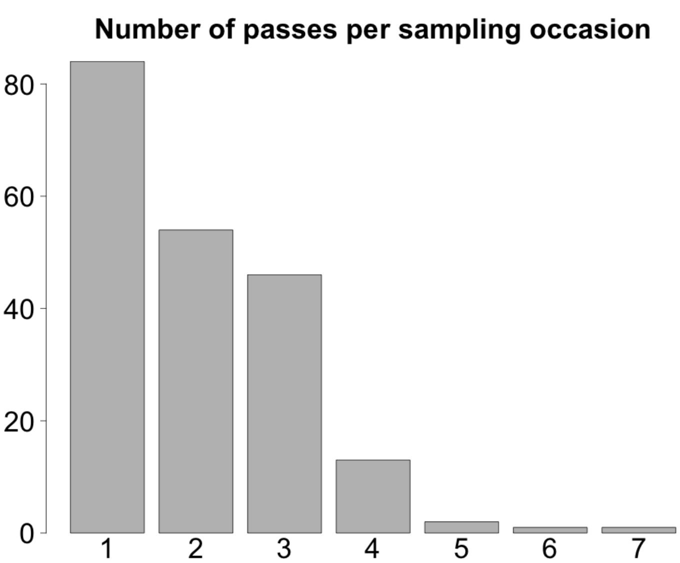
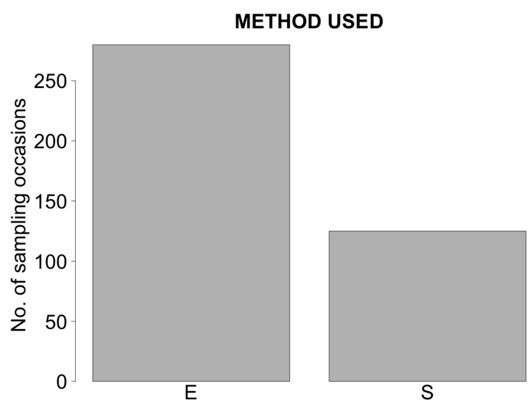


Figure A16: The survey method used on each pass included in the data set. Electrofishing passes are represented by "E"; and seining passes are represented by "S". There were thirteen dipnet passes (excluded from chart), 280 electrofishing passes, and 125 seine passes.



3.A.1 Fish detections in the Arkansas River Basin

Table A8: Fishes detected in the Arkansas River Basin, separated by whether the species is native or nonnative. The last column lists the number of sites at which the species was detected out of a total of 141 unique sites.

Common name (*Scientific name*)	Abbr.	Number of Sites
No fish detected	NULL	1
Native fishes		
Arkansas Darter (*Etheostoma cragini*)	ARD	22
Arkansas River Shiner (*Notropis girardi*)*		0
Black Bullhead (*Ameiurus melas*)	BBH	40
Central Stoneroller (*Campostoma anomalum*)	STR	65
Channel Catfish (*Ictalurus punctatus*)	CCF	30
Cutthroat Trout (*Oncorhynchus clarkii*)**		0
Fathead Minnow (*Pimephales promelas*)	FMW	95
Flathead Chub (*Platygobio gracilus*)	FHC	51
Green Sunfish (*Lepomis cyanellus*)	SNF	56
Longnose Dace (*Rhinichthys cataractae*)	LND	64
Orangespotted Sunfish (*Lepomis humilis*)	OSF	4
Plains Killifish (*Fundulus kansae*)	PKF	59
Plains Minnow (*Hybognathus placitus*)	PMW	8
Red Shiner (*Cyprinella lutrensis*)	RDS	54
River carpsucker (*Carpiodes carpio*)	RCS	0
Sand Shiner (*Notropis stramineus*)	SAH	53
Southern Redbelly Dace (*Phoxinus erythrogaster*)	SRD	1
Speckled Chub (*Macrhybopsis aestivalis*)*		0
Suckermouth Minnow (*Phenacobius mirabilis*)	SMM	24
White Sucker (*Catostomus commersonii*)	WHS	76
Nonnative fishes		
Black Crappie (*Pomoxis nigromaculatus*)	BCR	3
Bluegill (*Lepomis macrochirus*)	BGL	3
Brook Stickleback (*Culaea inconstans*)	BST	7
Brook Trout (*Salvelinus fontinalis*)	BRK	1
Brown Trout (*Salmo trutta*)	LOC	14
Common Carp (*Cyprinus carpio*)	CPP	34
Creek Chub (*Semotilus atromaculatus*)	CRC	23
Cutbow (*Oncorhynchus clarki x mykiss*)	RXN	2
Freshwater Drum (*Aplodinotus grunniens*)	DRM	2
Gizzard Shad (*Dorosoma cepedianum*)	GSD	17
Iowa Darter (*Etheostoma exile*)	SSH	1

Table A8: Fishes detected in the Arkansas River Basin, separated by whether the species is native or nonnative. The last column lists the number of sites at which the species was detected out of a total of 141 unique sites.

Common name (*Scientific name*)	Abbr.	Number of Sites
Largemouth Bass (*Micropterus salmoides*)	LMB	26
Longnose Sucker (*Catostomus catostomus*)	LGS	30
Northern Pike (*Esox lucius*)	NPK	1
Pumpkinseed Sunfish (*Lepomis gibbosus*)	PKS	1
Rainbow Trout (*Oncorhynchus mykiss*)	RBT	9
River Shiner (*Notropis blennius*)	RSH	2
Saugeye (*Sander vitreus x canadensis*)	SAG	4
Smallmouth Bass (*Micropterus dolomieu*)	SMB	9
Spotted Bass (*Micropterus punctulatus*)	SPB	2
Walleye (*Sander vitreus*)	WAL	3
Western Mosquitofish (*Gambusia affinis*)	MSQ	34
Yellow Perch (*Perca flavescens*)	YPE	4
Other		
Rainbow trout hybrid	HXC	1
Generic Minnows	MNW	4
Other Warmwater Species	OTS	11
Generic Sunfish	SUF	2
Generic Trout	TRT	2
Unknown	UNK	1

* Species is extirpated.

** Cutthroat trout were excluded from the analyses because they are a cold-water species whose natural range is higher elevations than our sampling frame.

3.A.2 Number and type of passes associated with each sampling occasion and site.

Table A9: Water name, date, and passes associated with each sampling occasion.

Water Name	Date	Types of passes
ADOBE CREEK	19-Oct-09	E1, E2, S1
APISHAPA RIVER	22-Oct-08	E1, E2, E3
APISHAPA RIVER	23-Oct-08	E1, E2, S1
ARKANSAS R #1	2-Jun-09	E1
ARKANSAS R #1	10-Sep-09	S1, S2, S3
ARKANSAS R #2A	7-Oct-08	E1, S1
ARKANSAS R #2A	7-Oct-08	E1, S1, S2
ARKANSAS R #2A	6-Oct-09	E1, E2
ARKANSAS R #2A	7-Oct-09	E1, E2, E3, S1
ARKANSAS R #2A	21-Jul-10	E1, E2, E3, S1
ARKANSAS R #2A	19-Jul-12	E1, E2
ARKANSAS R #2A	23-Jul-12	E1, E2, S1
ARKANSAS R #2A	24-Jul-12	E1, S1, S2
ARKANSAS R #2A	9-Aug-12	E1, S1, S2, S3
ARKANSAS R #2A	10-Aug-12	E1, E2, S1, S2
ARKANSAS R #2A	21-Aug-12	E1, S1, S2
ARKANSAS R #2A	17-Oct-13	E1, S1, S2, S3, S4
ARKANSAS R #2A	22-Oct-13	S1, S2
ARKANSAS R #3A	15-Sep-10	E1, E2, E3
ARKANSAS R #3A	10-May-11	E1, E2
ARKANSAS R #3B	21-Apr-09	E1
ARKANSAS R #3B	22-Apr-09	E1
ARKANSAS R #3B	8-Oct-09	E1, E2, S1
ARKANSAS R #3B	15-May-12	E1
ARKANSAS R #3B	15-May-12	E1
ARKANSAS R #3B	25-May-12	E1
ARKANSAS R #3B	25-May-12	E1
ARKANSAS R #3B	5-Jun-12	E1
ARKANSAS R #3B	6-Jun-12	E1, E2
ARKANSAS R #3B	21-Jun-12	E1
ARKANSAS R #3B	21-Jun-12	E1
ARKANSAS R #3B	5-Jul-12	E1
ARKANSAS R #3B	5-Jul-12	E1
ARKANSAS R #3B	18-Jul-12	E1
ARKANSAS R #3B	18-Jul-12	E1
ARKANSAS R #3B	13-Jun-13	E1

Table A9: Water name, date, and passes associated with each sampling occasion.

Water Name	Date	Types of passes
ARKANSAS R #3B	9-Jun-14	E1
ARKANSAS R #4	17-Jun-10	E1
ARKANSAS R #4	21-Jun-10	E1, E2, E3, S1
Arkansas River	24-Sep-15	E1, E2, S1
Arkansas River	1-Oct-15	E1, S1, S2
Arkansas River	14-Oct-15	E1, E2, E3, S1
Arkansas River	23-Oct-15	E1, E2, S1
Arkansas River	29-Oct-15	E1, E2, S1
Arkansas River	3-Nov-15	E1, E2, S1
Arkansas River #2A	14-Aug-14	E1, E2, S1
Arkansas River #2A	3-Sep-14	E1, E2, S1
Arkansas River #2A	9-Sep-14	E1, E2, S1
BEAVER CREEK	26-Sep-12	E1, E2
BEAVER CREEK	26-Sep-12	E1, E2
BEAVER CREEK	15-Oct-15	E1, E2
BEAVER CREEK	15-Oct-15	E1, E2
BIG SANDY CREEK	20-Aug-08	E1, E2
BIG SANDY CREEK	17-Sep-08	E1, S1, S2, S3
BIG SANDY CREEK	13-Nov-09	E1, S1, S2, S3
BIG SANDY CREEK	2-Oct-12	E1
BIG SANDY CREEK	2-Nov-12	E1, S1
Big Sandy Creek	23-Oct-13	E1, S1
BIG SANDY CREEK	19-Sep-14	S1
BIG SANDY CREEK #1	12-Aug-08	S1, S2
BIG SANDY CREEK #1	12-Aug-08	S1
BIG SANDY CREEK #1	29-Sep-08	E1, E2, S1
BIG SANDY CREEK #1	24-May-10	E1, E2, S1
BLACK SQUIRREL CREEK	1-Sep-11	E1
BLACK SQUIRREL CREEK	27-Sep-12	E1, S1
BLACK SQUIRREL CREEK	9-Oct-12	E1
Black Squirrell Creek	6-Oct-15	E1
Black Squirrell Creek	12-Oct-15	E1, E2
BRACKETT CREEK	16-Sep-08	E1
BUFFALO CREEK	4-Sep-08	E1, E2, S1
BUFFALO CREEK	19-Sep-13	E1
BUFFALO CREEK	19-Sep-13	E1, S1, S2
CHACUACO CREEK	11-Jun-10	S1
CHEYENNE CREEK	1-Oct-08	E1, E2, S1, S2
CHICO CREEK	9-Sep-08	E1, E2, S1

Table A9: Water name, date, and passes associated with each sampling occasion.

Water Name	Date	Types of passes
CHICO CREEK	9-Sep-08	E1, E2, S1
CHICO CREEK	9-Sep-08	E1, E2, E3
CHICO CREEK	24-Jun-10	E1, E2
CHICO CREEK	2-Sep-11	E1
CHICO CREEK	2-Sep-11	E1, S1
CHICO CREEK	18-Oct-11	E1, S1
CHICOSA CREEK	22-Sep-09	E1, E2, S1, S2
CRAMER CREEK	13-Oct-09	E1, E2
CUCHARAS RIVER #1	29-Jul-10	E1
EIGHTMILE CREEK	17-Sep-09	E1, S1, S2
FOUNTAIN CREEK #1	24-Sep-08	E1
FOUNTAIN CREEK #2	10-Sep-08	E1
FOUNTAIN CREEK #2	11-Sep-08	E1
FOUNTAIN CREEK #2	22-Sep-08	E1
FOUNTAIN CREEK #2	24-Sep-08	E1
FOUNTAIN CREEK #2	24-Sep-08	E1
FOUNTAIN CREEK #2	23-Sep-09	E1, E2, S1
FOUNTAIN CREEK #2	12-Jul-12	E1
FOUNTAIN CREEK #2	12-Jul-12	E1
FOUNTAIN CREEK #2	24-Jul-12	E1
FOUNTAIN CREEK #2	25-Jul-12	E1
FOUNTAIN CREEK #2	26-Jul-12	E1
FOUNTAIN CREEK #2	7-Aug-12	S1
FOUNTAIN CREEK #2	8-Aug-12	E1
FOUNTAIN CREEK #2	10-Aug-12	E1
FOUNTAIN CREEK #2	24-Aug-12	E1
FOUNTAIN CREEK #2	24-Aug-12	E1
FOUNTAIN CREEK #2	24-Aug-12	E1
FOUNTAIN CREEK #2	7-Sep-12	E1
FOUNTAIN CREEK #2	7-Sep-12	E1
FOUNTAIN CREEK #2	21-Sep-12	E1
FOUNTAIN CREEK #2	21-Sep-12	E1
FOUNTAIN CREEK #2	21-Sep-12	E1
FOUNTAIN CREEK #2	5-Oct-12	E1
FOUNTAIN CREEK #2	5-Oct-12	E1
FOUNTAIN CREEK #2	10-Jun-14	E1
FOUNTAIN CREEK #3	23-Sep-08	E1
FOUNTAIN CREEK #3	24-Sep-08	E1
FOUNTAIN CREEK #3	24-Sep-08	E1

Table A9: Water name, date, and passes associated with each sampling occasion.

Water Name	Date	Types of passes
FOUNTAIN CREEK #3	24-Sep-08	E1
FOUNTAIN CREEK #3	18-Jun-10	E1, E2, E3
FOUNTAIN CREEK #3	29-Jun-11	E1, E2
FOUNTAIN CREEK #3	1-Jul-11	E1, E2
FOUNTAIN CREEK #3	9-Jun-14	E1
FOUNTAIN CREEK #4	23-Sep-08	E1
GAGEBY CREEK	25-May-10	E1, E2, E3, S1
GRAPE CREEK #1A	19-May-10	E1, E2
GRAPE CREEK #1A	21-Sep-12	E1, E2
GRAPE CREEK #1A	10-Sep-14	E1, E2
GRAPE CREEK #1A	9-Sep-15	E1, E2
Greenhorn Creek	20-Aug-15	E1, S1, S2
Greenhorn Creek	20-Aug-15	E1, S1
GREENHORN CREEK #1	28-Jun-10	E1, E2, S1
GREENHORN CREEK #1	28-Jun-10	E1, E2, S1
GREENHORN CREEK #1	25-May-11	E1, E2
HORSE CR, LIT, STEELS FK	14-Oct-09	E1, E2, E3
HORSE CR, LIT, STEELS FK	22-Jul-11	E1
HORSE CR, LIT, STEELS FK	22-Jul-11	E1
HORSE CR, LIT, STEELS FK	22-Jul-11	E1
HORSE CR, LIT, STEELS FK	22-Jul-11	E1
HORSE CREEK	18-Jul-08	E1, E2
HORSE CREEK	14-Aug-08	S1
HORSE CREEK	14-Aug-08	S1
HORSE CREEK	8-Sep-08	E1
HORSE CREEK	18-Sep-08	E1
HORSE CREEK	20-Oct-08	S1
Horse Creek	17-Jul-10	E1
HUERFANO R #1	9-Oct-08	E1, E2, E3, E4, S1
JIMMY CAMP CREEK	22-Sep-08	E1, E2, S1
MONUMENT CREEK #1	23-Sep-08	E1
MONUMENT CREEK #1	23-Sep-08	E1
MONUMENT CREEK #2	15-Sep-08	E1, E2, S1
MONUMENT CREEK #2	23-Sep-08	E1
MONUMENT CREEK #2	19-Sep-11	E1
MONUMENT CREEK #2	13-Aug-14	E1
MONUMENT CREEK #2	13-Aug-14	E1
MONUMENT CREEK #2	13-Aug-14	E1
MONUMENT CREEK #2	13-Aug-14	E1

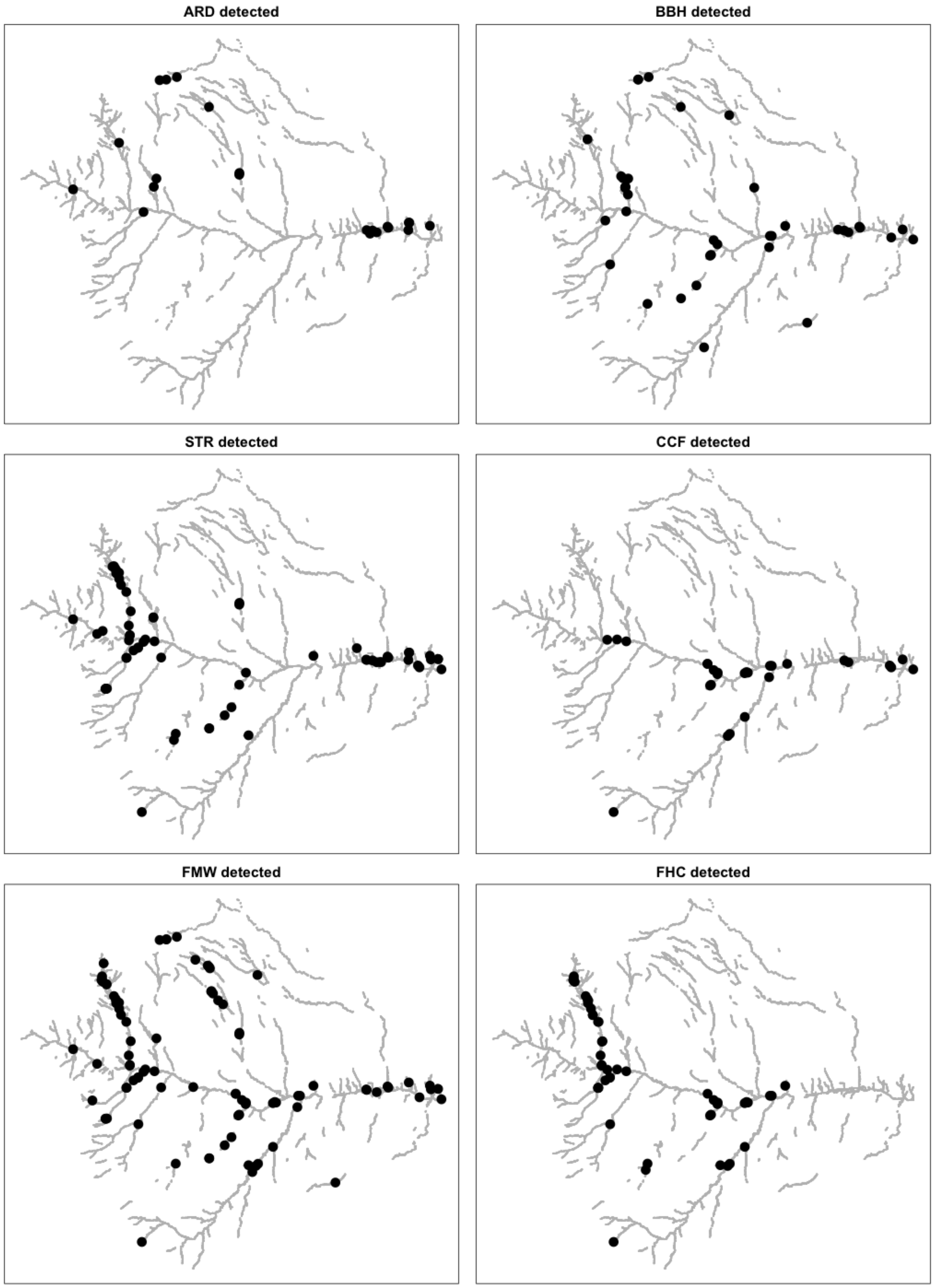
Table A9: Water name, date, and passes associated with each sampling occasion.

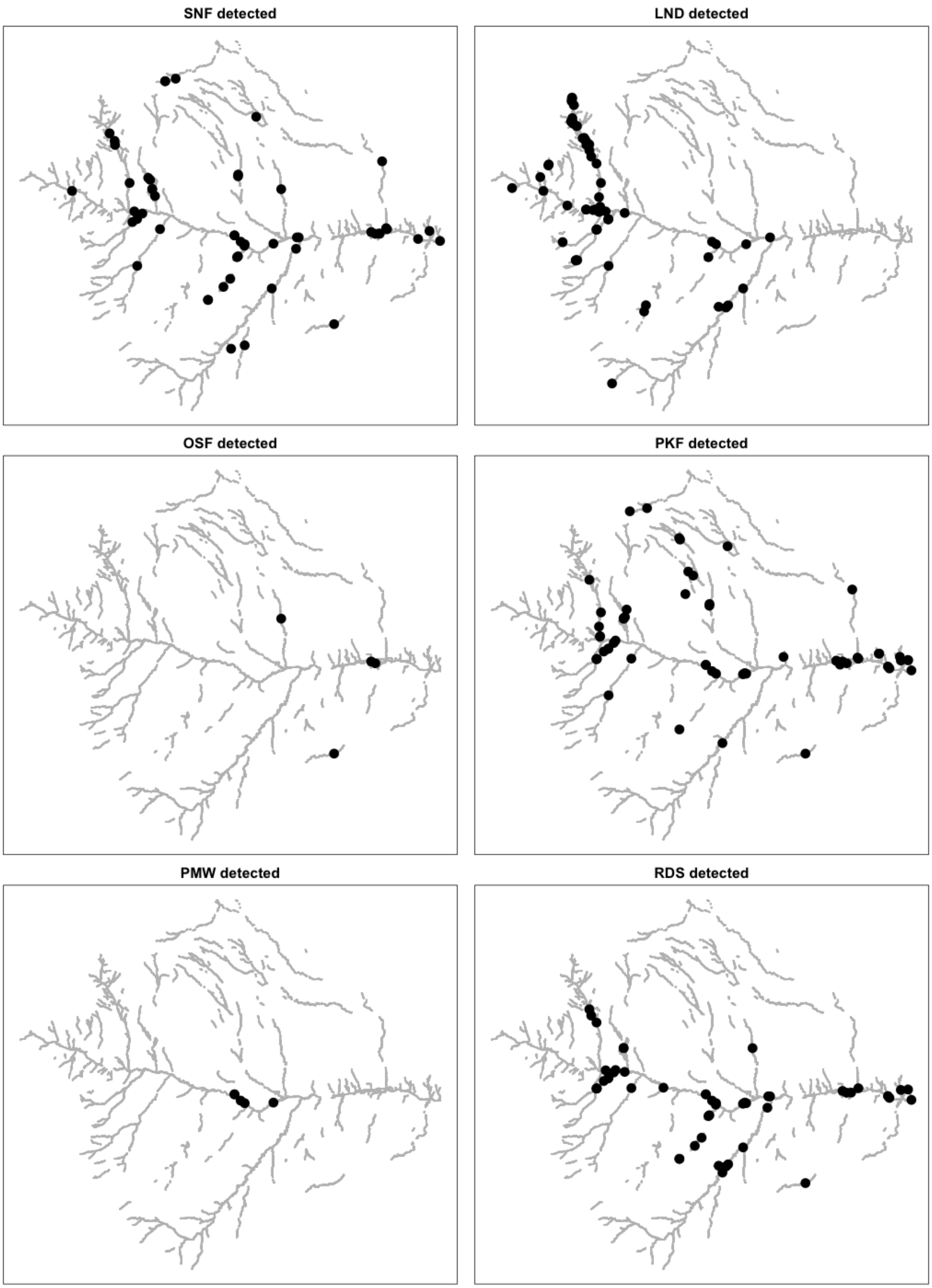
Water Name	Date	Types of passes
MONUMENT CREEK #2	13-Aug-14	E1
NO NAME CREEK	26-Oct-10	E1, E2
NO NAME CREEK	12-Oct-12	E1
PURGATOIRE R #1	29-Sep-09	E1, S1, S2
PURGATOIRE R #1	20-Oct-09	E1, E2, E3
PURGATOIRE R #1	3-Jun-11	E1, E2, S1, S2, S3, S4
PURGATOIRE R #1	13-Jun-13	E1
PURGATOIRE R #1	11-Sep-13	E1, S1, S2
PURGATOIRE R #1	24-Oct-13	E1, E2
Rush Creek	8-Oct-15	E1, E2, S1
Rush Creek, South	9-Oct-13	S1, S2, S3
ST CHARLES R #1	8-Oct-08	E1, E2, E3, E4, S1, S2, S3
ST CHARLES R #1	19-Aug-09	E1, E2, E3
ST CHARLES R #1	20-Jul-10	E1, E2
ST CHARLES R #1	24-May-11	E1, E2
ST CHARLES R #1	25-May-11	E1, E2
ST CHARLES R #1	25-May-11	E1, E2
ST CHARLES R #1	26-May-11	E1, E2
ST CHARLES R #1	26-May-11	E1, E2
ST CHARLES R #1	31-Oct-11	E1, E2
ST CHARLES R #1	1-Nov-11	E1, E2
ST CHARLES R #1	1-Nov-11	E1, E2
ST CHARLES R #1	2-Nov-11	E1, E2
ST CHARLES R #1	2-Nov-11	E1, E2
ST CHARLES R, NORTH	20-Aug-10	E1, E2
TIMPAS CREEK	24-Jul-08	E1, S1
TIMPAS CREEK	24-Jun-11	S1, S2
TIMPAS CREEK	21-Sep-11	E1, E2
TIMPAS CREEK	21-Sep-11	S1, S2
TIMPAS CREEK	21-Sep-11	S1, S2, S3
TIMPAS CREEK	22-Sep-11	S1, S2
TIMPAS CREEK	17-Jul-12	E1, S1
TURKEY CREEK	1-Jul-15	E1, E2, E3
TWO BUTTE CREEK	29-Oct-08	E1, S1, S2, S3
UNMANAGED STM AR MJ DRAIN	2-Sep-08	E1, E2, S1
UNMANAGED STM AR MJ DRAIN	3-Sep-08	E1, S1
UNMANAGED STM AR MJ DRAIN	4-Sep-08	E1, E2
UNMANAGED STM AR MJ DRAIN	1-Oct-08	E1, S1, S2
UNMANAGED STM AR MJ DRAIN	10-Jun-10	S1

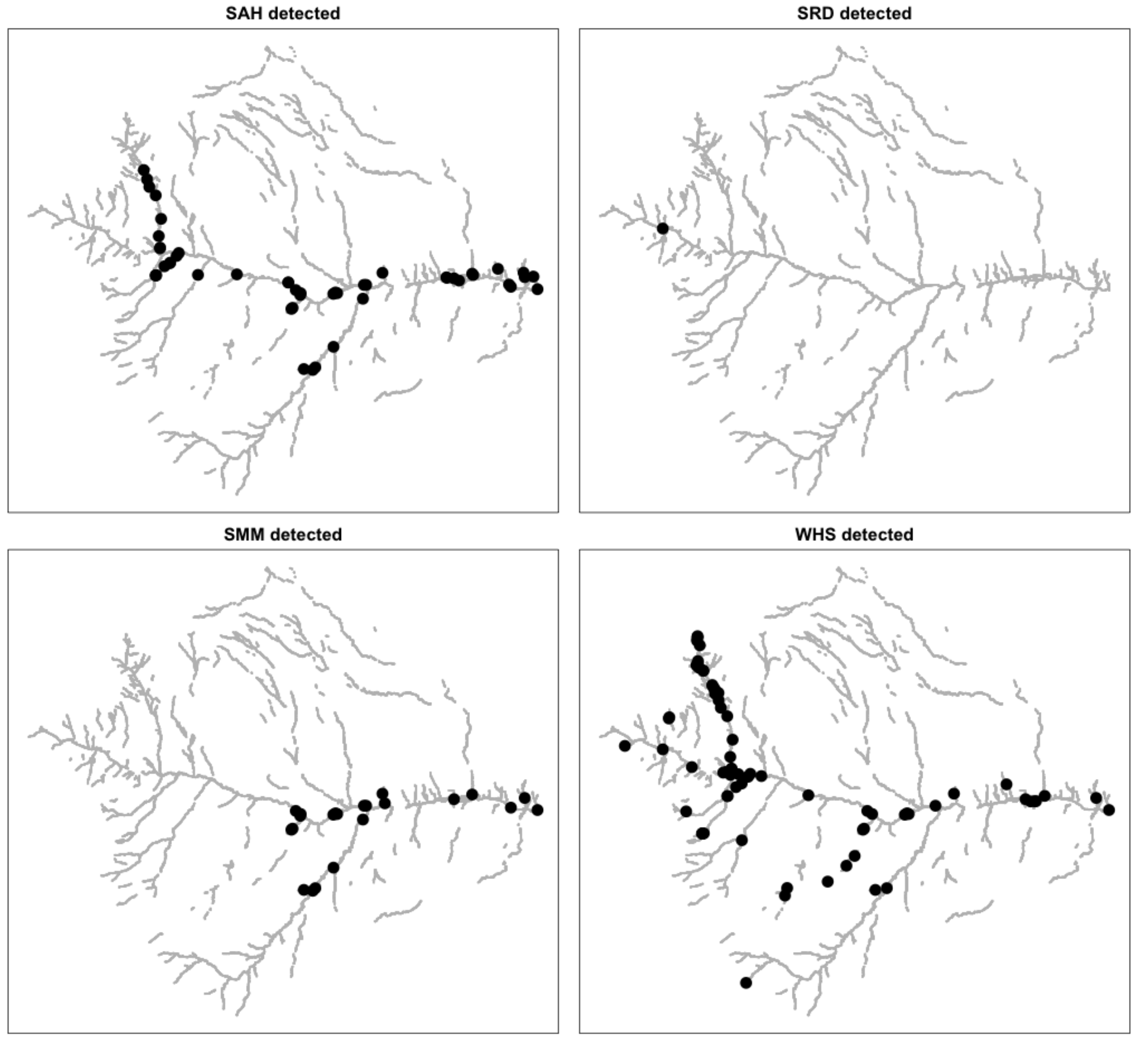
Table A9: Water name, date, and passes associated with each sampling occasion.

Water Name	Date	Types of passes
UNMANAGED STM AR MJ DRAIN	5-Oct-10	E1
UNMANAGED STM AR MJ DRAIN	2-Jun-11	E1, E2, S1, S2
UNMANAGED STM AR MJ DRAIN	2-Nov-12	S1
UNMANAGED STM AR MJ DRAIN	19-Sep-13	S1, S2
Vista Del Rio	18-Sep-13	E1, S1
WILD HORSE CREEK	23-Jul-08	E1
WILD HORSE CREEK	13-Aug-08	E1, E2, S1
WILLOW CREEK	30-Oct-08	E1, E2, S1
Willow Creek	19-Sep-13	S1, S2

Figure A17: The sites where each native species was detected.




SNF detected
LND detected
OSF detected
PKF detected
PMW detected
RDS detected


SAH detected
SRD detected
SMM detected
WHS detected

3.B Arkansas model results.

Table B1: Models fit the Arkansas River basin data. See Tables 3.1 and 3.2 for descriptions of the covariates.

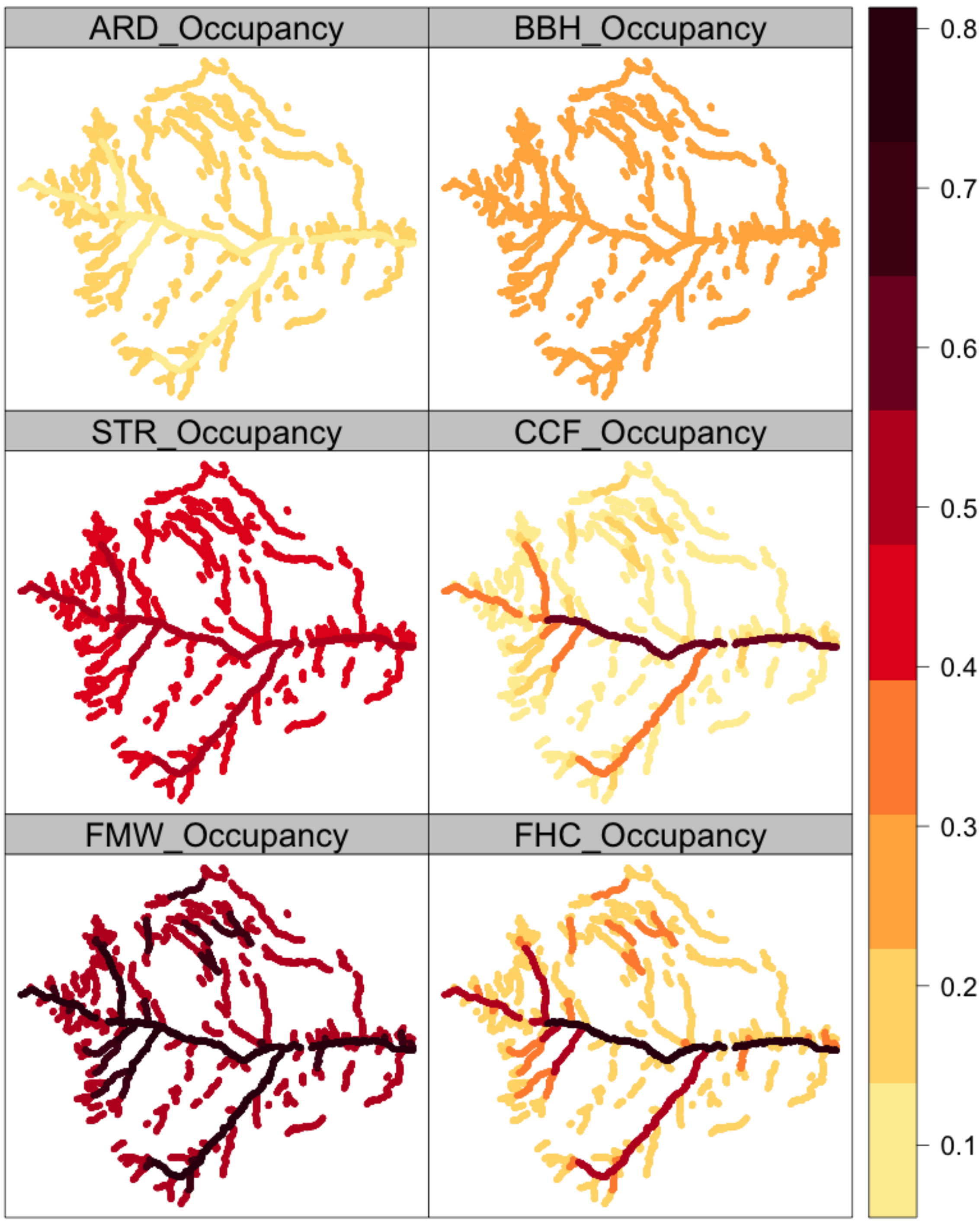
Model name	Occupancy variables	Detection variables
full	x, x^2, y, y^2, elev, $elev^2$, crops, dvlpd, wtlnds, unconnect, size, reservoirs, ftn, main, purg	yday, $yday^2$, seine, pass no, year, y, y^2, elev, $elev^2$, crops, dvlpd, wtlnds, unconnect, size, reservoirs, ftn, main, purg
full occu	x, x^2, y, y^2, elev, $elev^2$, crops, dvlpd, wtlnds, unconnect, size, reservoirs, ftn, main, purg	yday, $yday^2$, seine, pass no, year
full occu-2	y, y^2, elev, $elev^2$, crops, dvlpd, wtlnds, unconnect, size, reservoirs, ftn, main, purg	yday, $yday^2$, seine, year, size
no corrs	y, y^2, elev, unconnect, reservoirs, ftn, main	yday, $yday^2$, seine, pass no, year
land cover, size	y, y^2, crops, dvlpd, wtlnds, size	yday, $yday^2$, seine, pass no, year, size
combined	y, y^2, elev, dvlpd, wtlnds, unconnect, reservoirs, ftn	yday, $yday^2$, seine, year
reservoir	y, y^2, elev, $elev^2$, unconnect, reservoirs,	yday, seine, year
stream	y, y^2, elev, $elev^2$, unconnect,ftn, main, purg	yday, seine, year
size	y, y^2, elev, $elev^2$, size	yday, seine, year
no corrs-2	y, y^2, elev, unconnect, reservoirs, ftn, main, size	yday, seine, year
combined-2	y, elev, wtlnds, unconnect, reservoirs, ftn, main, purg	yday, seine, year, size
alt size	x, x^2, y, y^2, size	yday, $yday^2$, seine, year, size

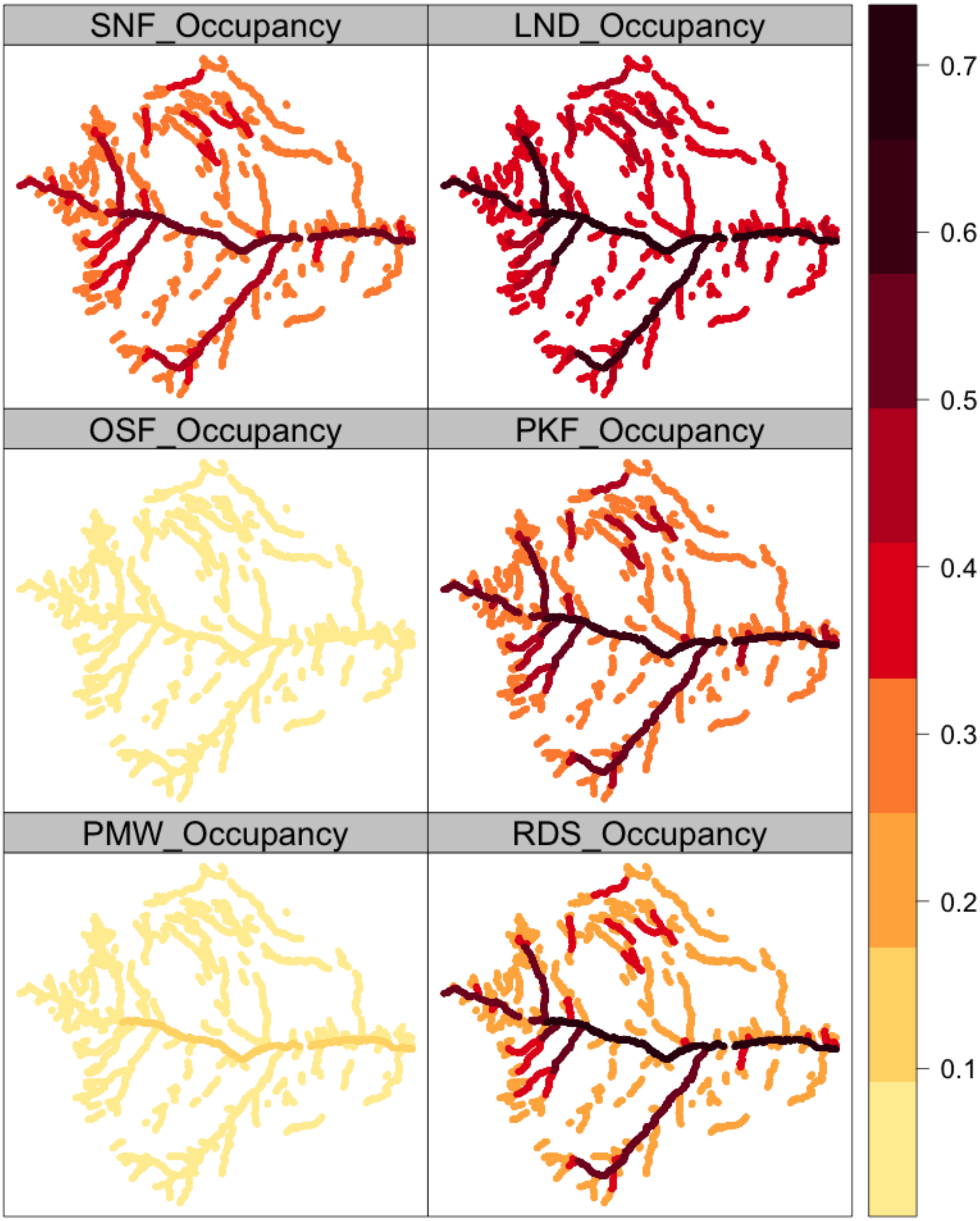
Table B1: Models fit the Arkansas River basin data. See Tables 3.1 and 3.2 for descriptions of the covariates.

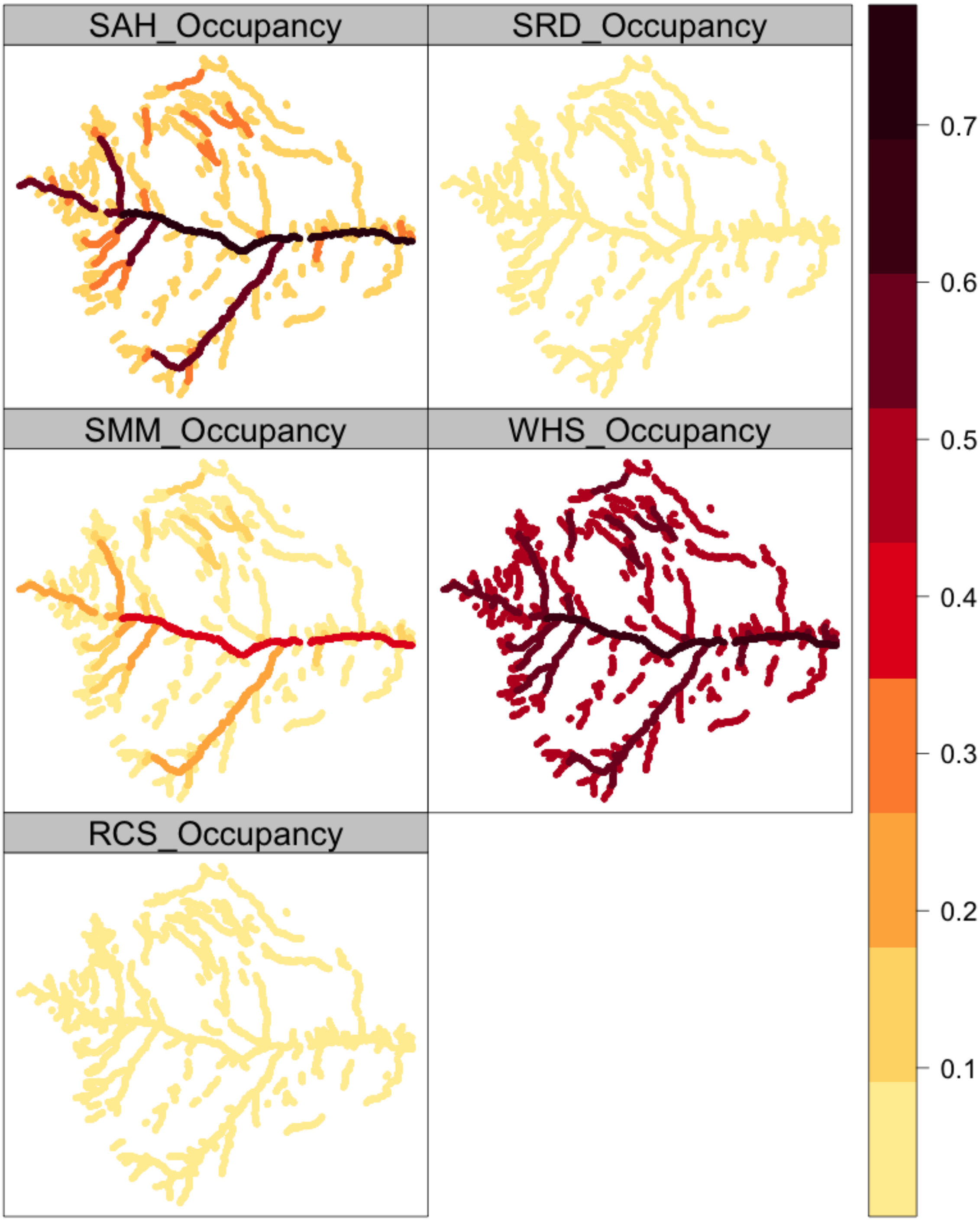
Model name	Occupancy variables	Detection variables
alt stream	x, x^2, y, y^2, unconnect, ftn, main, purg	yday, $yday^2$, seine, year, size
simple size	size	yday, $yday^2$, seine, year, size
simpe size-2	size	seine, year, size
simple alt stream	unconnect, ftn, main, purg	yday, $yday^2$, seine, year, size
simple alt stream-2	unconnect, ftn, main, purg	seine, year, size
simple land cover, size	crops, dvlpd, wtlnds, size	yday, $yday^2$, pass no, seine, year, size
simple land cover, size-2	crops, dvlpd, wtlnds, size	seine, year, size
simple size, count	size	seine, year, size, total ct
simple size, count, no yr	size	seine, size, total ct
simpe size-2, no yr	size	seine, size
simple size, no year	size	yday, seine, size
simple alt stream-2, no yr	unconnect, ftn, main, purg	seine, size
simple size, yday, no yr, connect	size, unconnect	seine, size, yday

3.B.1 Predicted occupancy maps

Figure B1: Predicted occupancy probabilities for all native species in the Arkansas River basin. Scientific and common names for each species may be found in Section 3.A.2 in Appendix 3.A.

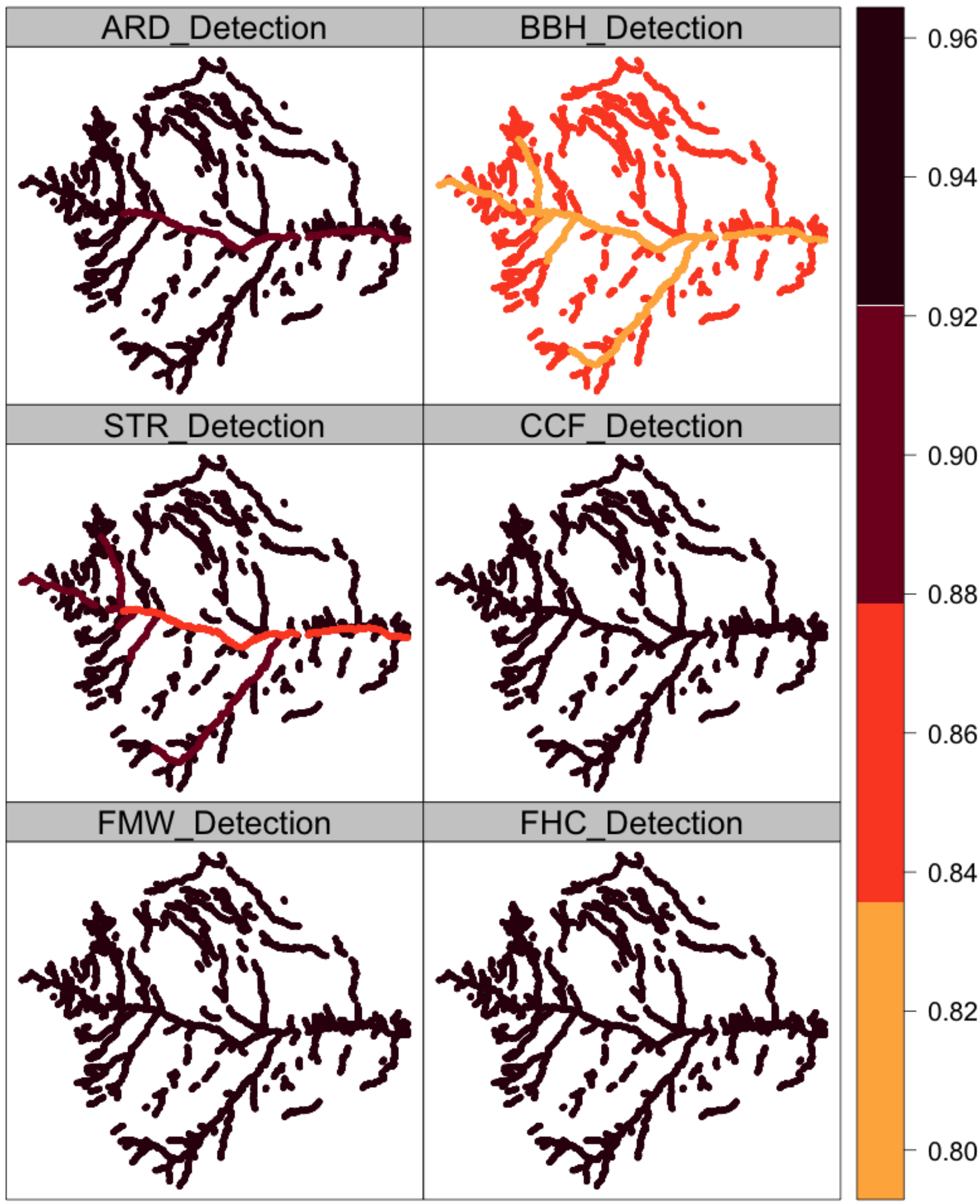


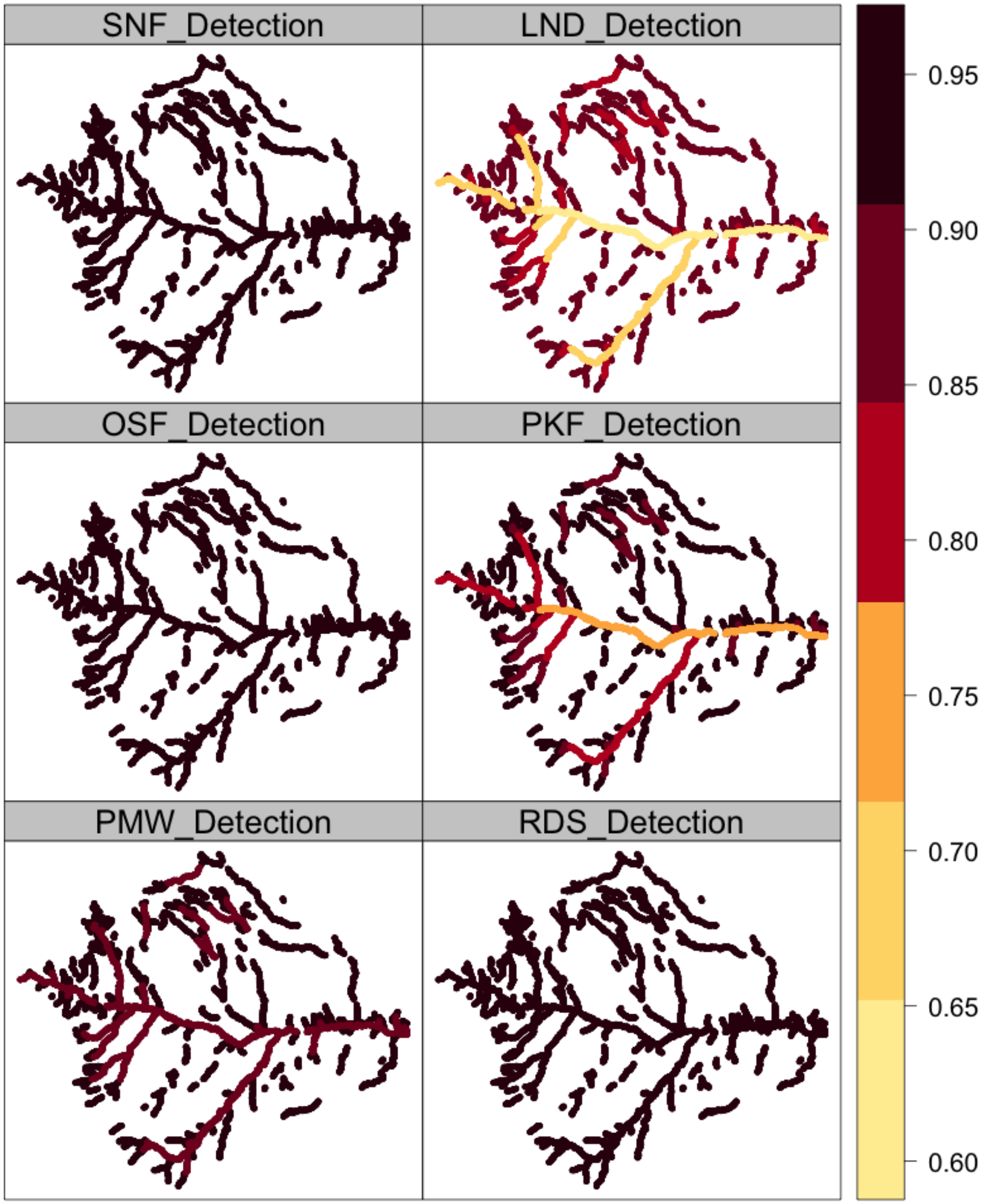

SNF_Occupancy
LND_Occupancy
OSF_Occupancy
PKF_Occupancy
PMW_Occupancy
RDS_Occupancy
0.7
0.6
0.5
0.4
0.3
0.2
0.1

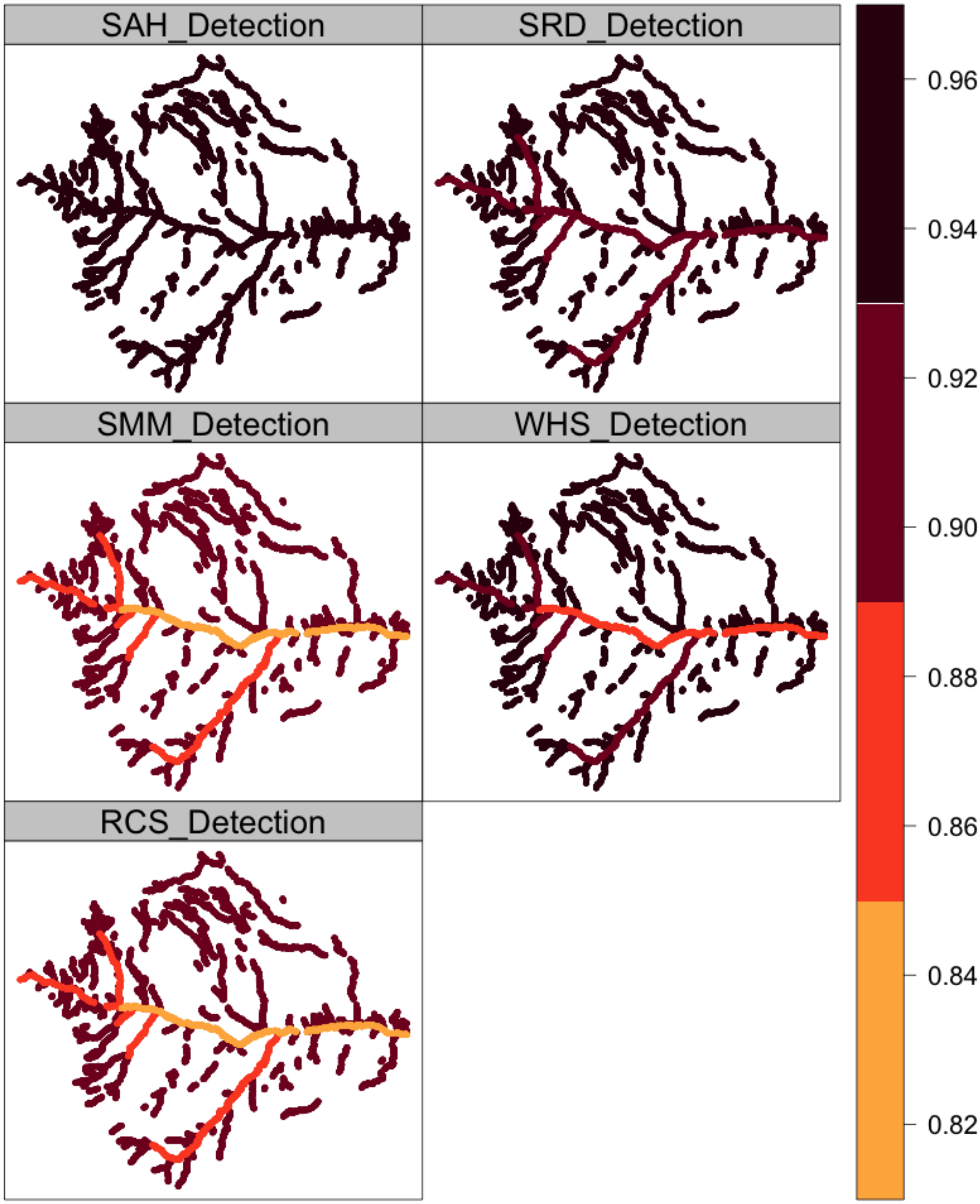

SAH_Occupancy
SRD_Occupancy
SMM_Occupancy
WHS_Occupancy
RCS_Occupancy
0.7
0.6
0.5
0.4
0.3
0.2
0.1

3.B.2 Predicted detection maps

Figure B2: Predicted detection probabilities for all native species in the Arkansas River basin. Scientific and common names for each species may be found in Appendix 3.A. The predictions assume a mean `total ct`, and the method used to detect fish was an electrofishing pass.

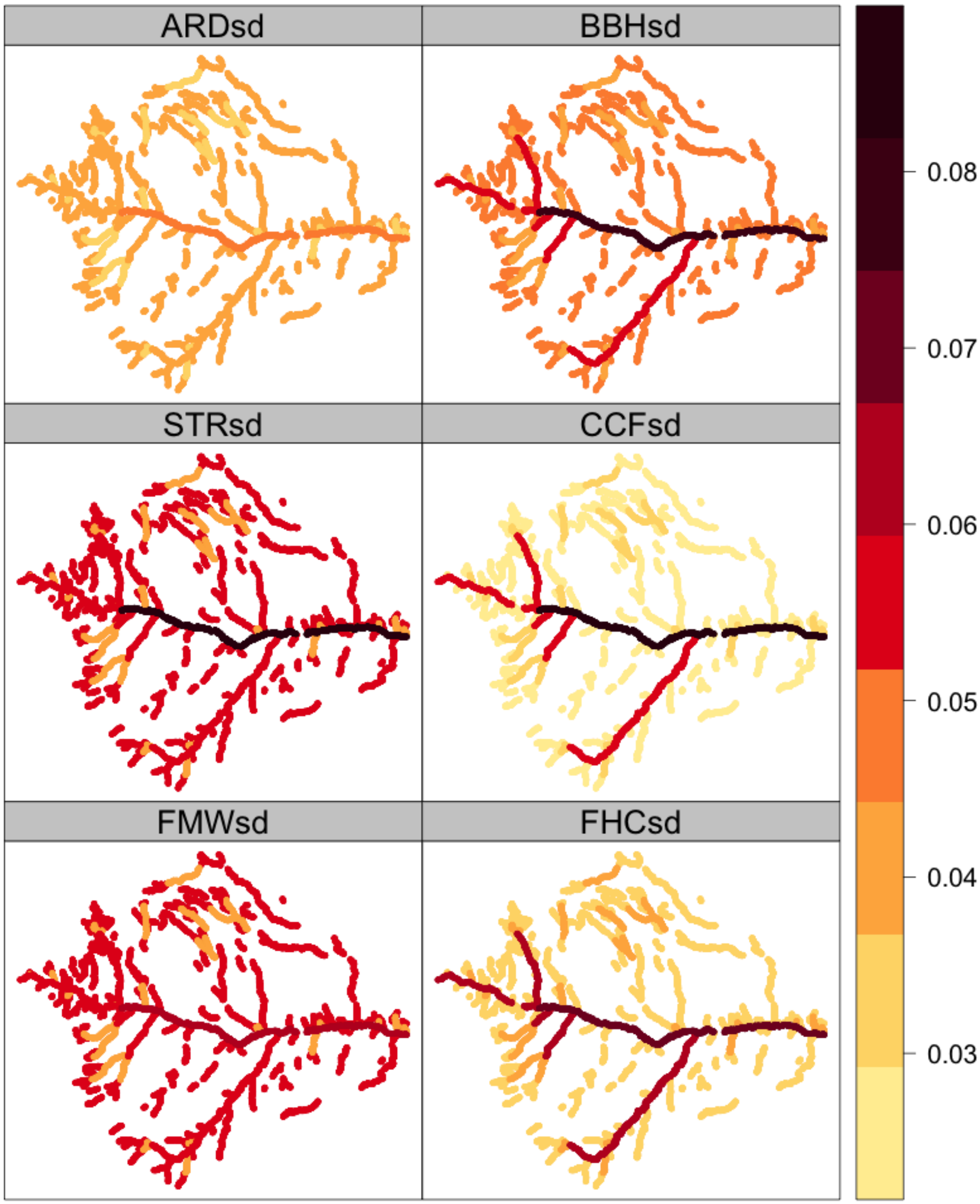


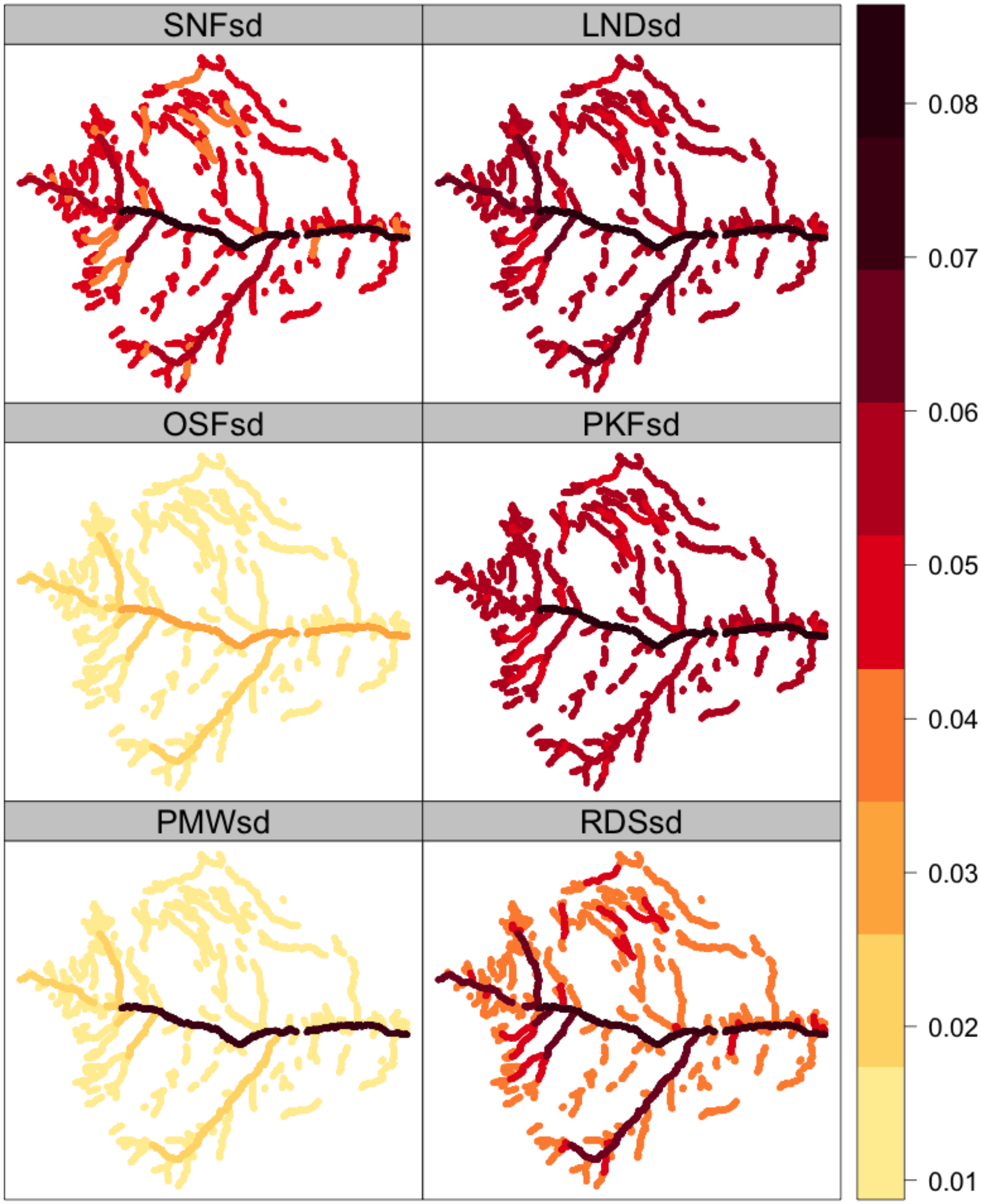

SNF_Detection
LND_Detection
OSF_Detection
PKF_Detection
PMW_Detection
RDS_Detection
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60

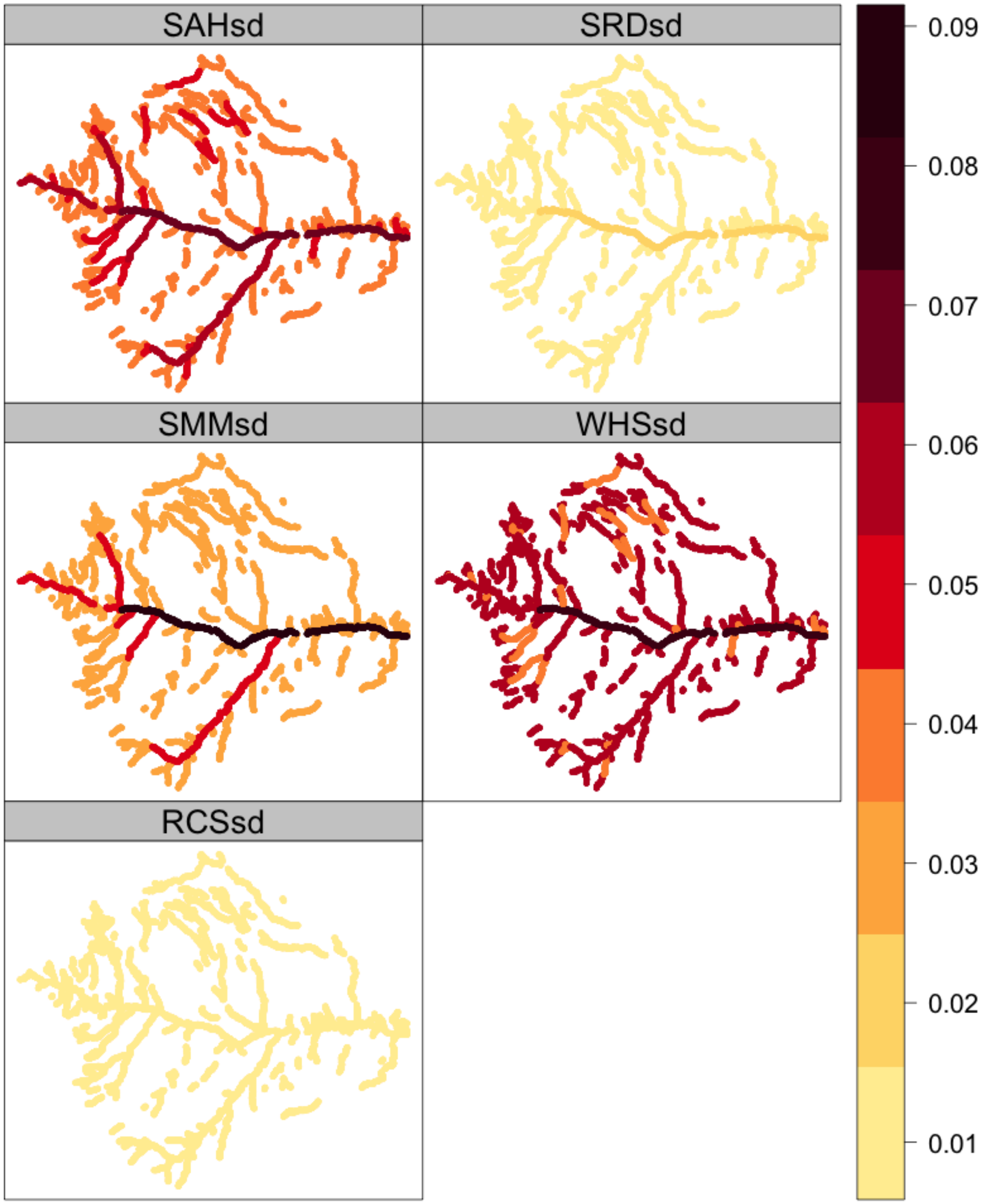

SAH_Detection
SRD_Detection
SMM_Detection
WHS_Detection
RCS_Detection
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82

3.B.3 Standard deviations of the predicted occupancies

Figure B3: Standard deviations associated with the occupancy probability estimate for all native species in the Arkansas River basin. Scientific and common names for each species may be found in Appendix 3.A.

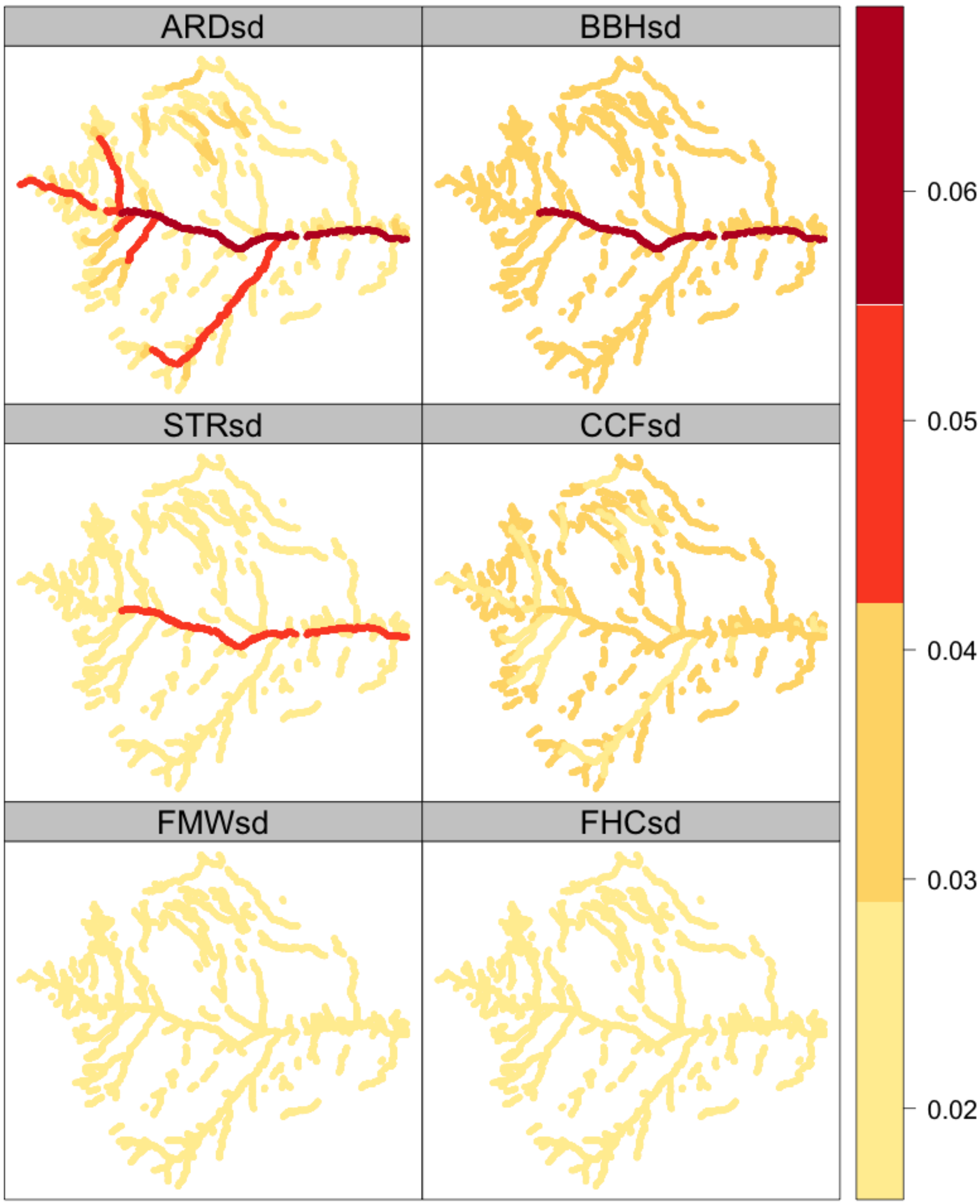


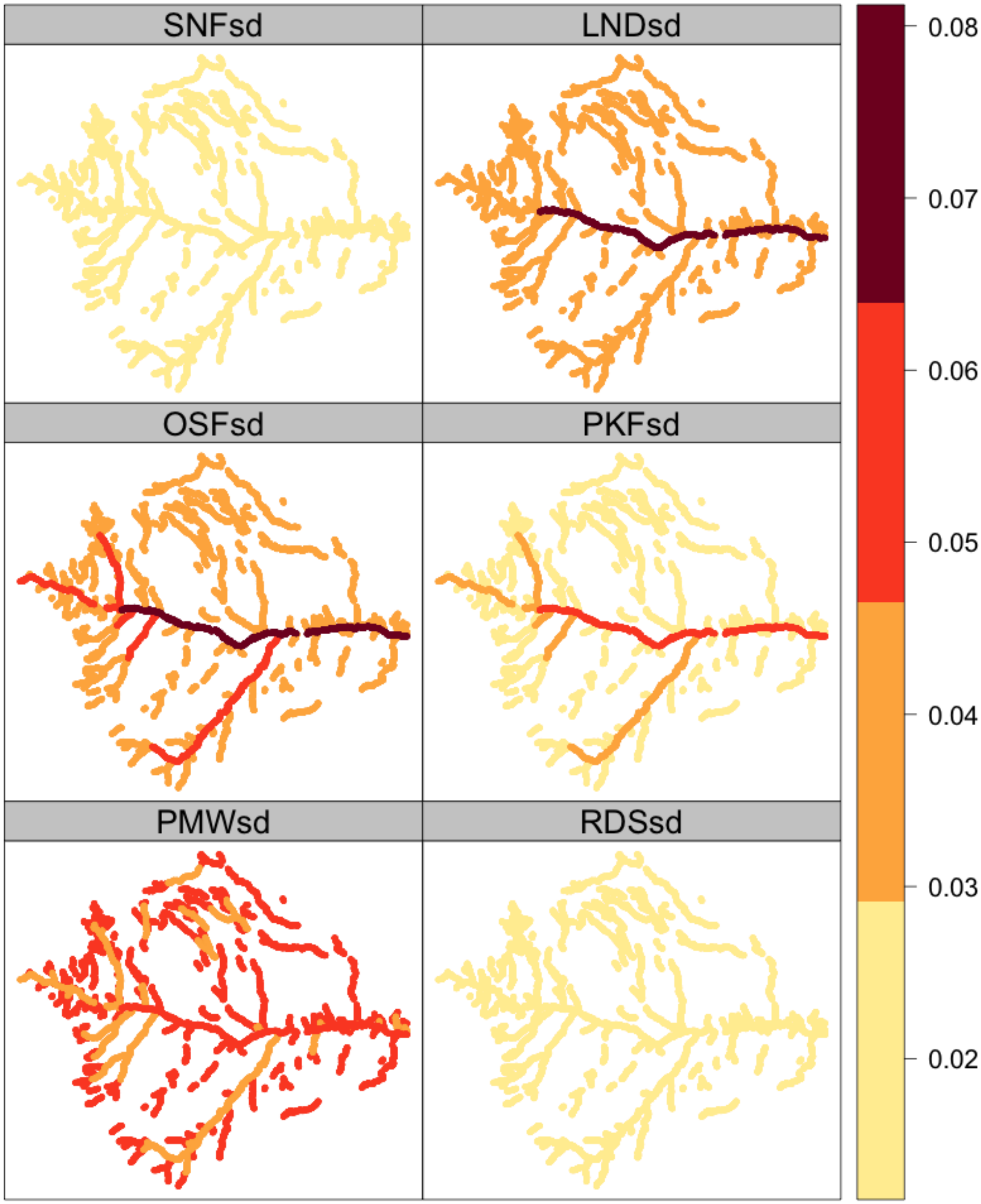

SNFsd
LNDsd
OSFsd
PKFsd
PMWsd
RDSsd
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01

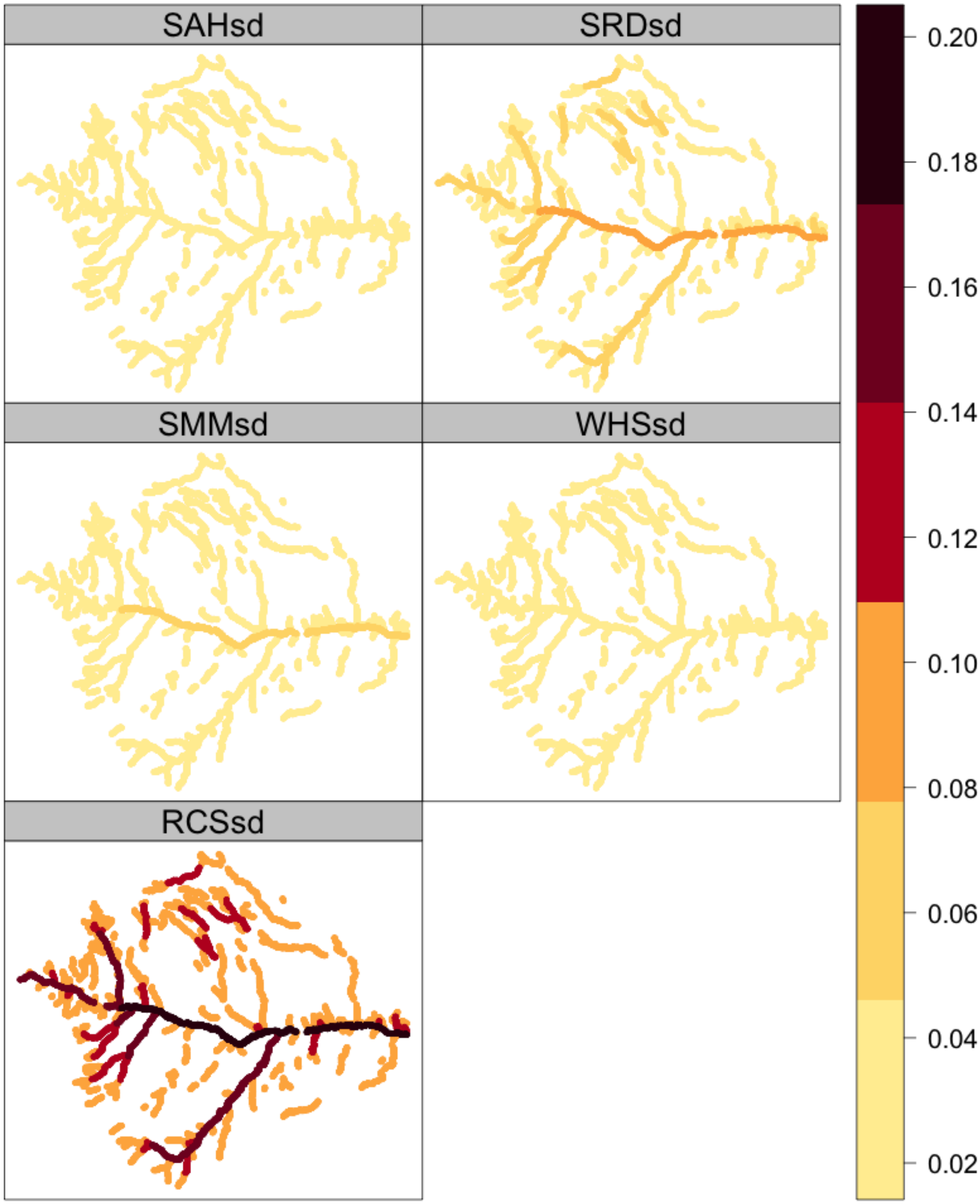

SAHsd
SRDsd
SMMsd
WHSsd
RCSsd
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01

3.B.4 Predicted detection standard deviation maps

Figure B4: Standard deviations associated with the detection probability estimates for all native species in the Arkansas River basin. Scientific and common names for each species may be found in Appendix 3.A. The predictions assume a mean `total ct`, and the method used to detect fish was an electrofishing pass.




SNFsd
LNDsd
OSFsd
PKFsd
PMWsd
RDSsd
0.08
0.07
0.06
0.05
0.04
0.03
0.02


SAHsd
SRDsd
SMMsd
WHSsd
RCSsd
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02

3.B.5 Parameter estimates

Table B2: Arkansas Darter (ARD) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-1.31	(0.46)
`size`	-0.24	(0.22)
Detection:		
	Mean	(SD)
(Intercept)	3.02	(0.58)
`seine`	-0.1	(0.31)
`total ct`	-0.11	(0.27)

Table B3: Black Bullhead (BBH) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-0.95	(0.39)
`size`	0	(0.17)
Detection:		
	Mean	(SD)
(Intercept)	2.23	(0.46)
`seine`	-0.17	(0.26)
`total ct`	-0.21	(0.15)

Table B4: Channel Catfish (CCF) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-4.05	(0.62)
`size`	1.12	(0.22)
Detection:		
	Mean	(SD)
(Intercept)	2.95	(0.67)
`seine`	-0.19	(0.29)
`total ct`	-0.09	(0.19)

Table B5: Orangespotted Sunfish (OSF) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-3.58	(0.83)
`size`	-0.02	(0.36)
Detection:		
	Mean	(SD)
(Intercept)	3.48	(0.84)
`seine`	-0.11	(0.33)
`total ct`	-0.06	(0.34)

Table B6: Plains Killifish (PKF) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-1.21	(0.37)
`size`	0.45	(0.16)
Detection:		
	Mean	(SD)
(Intercept)	2.91	(0.46)
`seine`	0.01	(0.29)
`total ct`	-0.48	(0.15)

Table B7: Plains Minnow (PMW) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-5.73	(1.13)
`size`	0.99	(0.34)
Detection:		
	Mean	(SD)
(Intercept)	2.93	(0.8)
`seine`	-0.13	(0.3)
`total ct`	-0.28	(0.21)

Table B8: River Carpsucker (RCS) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-5.77	(1.57)
`size`	-0.04	(0.52)
Detection:		
	Mean	(SD)
(Intercept)	3.07	(0.97)
`seine`	-0.14	(0.33)
`total ct`	-0.2	(0.38)

Table B9: Red Shiner (RDS) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-2.37	(0.42)
`size`	0.86	(0.18)
Detection:		
	Mean	(SD)
(Intercept)	3.31	(0.64)
`seine`	-0.1	(0.3)
`total ct`	0.08	(0.22)

Table B10: Sand Shiner (SAH) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-2.74	(0.44)
`size`	1.01	(0.18)
Detection:		
	Mean	(SD)
(Intercept)	2.89	(0.62)
`seine`	-0.09	(0.31)
`total ct`	0.14	(0.22)

Table B11: Suckermouth Minnow (SMM) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-3.38	(0.56)
`size`	0.75	(0.2)
Detection:		
	Mean	(SD)
(Intercept)	2.98	(0.62)
`seine`	-0.21	(0.28)
`total ct`	-0.37	(0.18)

Table B12: Green Sunfish (SNF) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-1.13	(0.36)
`size`	0.29	(0.15)
Detection:		
	Mean	(SD)
(Intercept)	3.61	(0.66)
`seine`	-0.16	(0.3)
`total ct`	0.02	(0.23)

Table B13: Southern Redbelly Dace (SRD) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-5.18	(1.15)
`size`	0.19	(0.42)
Detection:		
	Mean	(SD)
(Intercept)	3.34	(0.9)
`seine`	-0.13	(0.35)
`total ct`	-0.08	(0.34)

Table B14: Central Stoneroller (STR) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-0.26	(0.35)
`size`	0.06	(0.15)
Detection:		
	Mean	(SD)
(Intercept)	3.73	(0.61)
`seine`	-0.18	(0.28)
`total ct`	-0.47	(0.21)

Table B15: White Sucker (WHS) parameter estimates and standard deviations.

Occupancy:		
	Mean	(SD)
(Intercept)	-0.3	(0.34)
`size`	0.21	(0.15)
Detection:		
	Mean	(SD)
(Intercept)	4.1	(0.72)
`seine`	-0.17	(0.28)
`total ct`	-0.51	(0.22)

3.B.6 Predicted detection probabilities

Table B16: An example of the detection probabilities associated with one electrofishing pass. Streams of size 1 are lower order streams with lower flows, and stream size 4 represents the main stem of the Arkansas River.

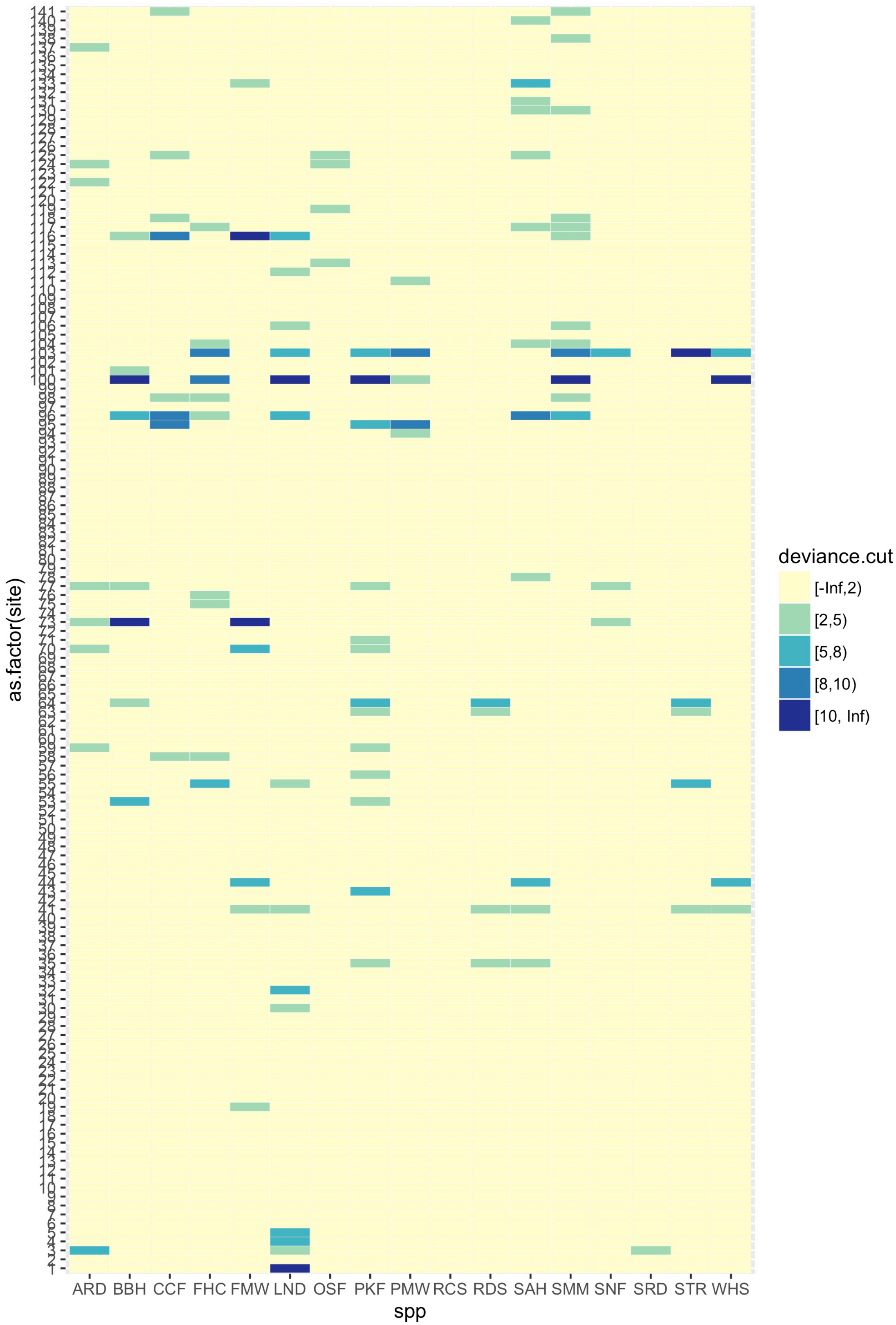
SPP	size1	size2	size3	size4
ARD	0.94	0.94	0.92	0.91
BBH	0.88	0.86	0.83	0.79
STR	0.96	0.94	0.91	0.86
CCF	0.94	0.94	0.93	0.92
FMW	0.92	0.93	0.94	0.94
FHC	0.96	0.96	0.94	0.93
SNF	0.97	0.97	0.97	0.97
LND	0.88	0.81	0.71	0.59
OSF	0.96	0.95	0.94	0.93
PKF	0.92	0.87	0.81	0.73
PMW	0.92	0.91	0.88	0.85
RDS	0.96	0.97	0.97	0.97
SAH	0.95	0.96	0.96	0.96
SRD	0.95	0.94	0.93	0.91
SMM	0.92	0.90	0.86	0.81
WHS	0.97	0.95	0.93	0.88
RCS	0.92	0.90	0.87	0.83

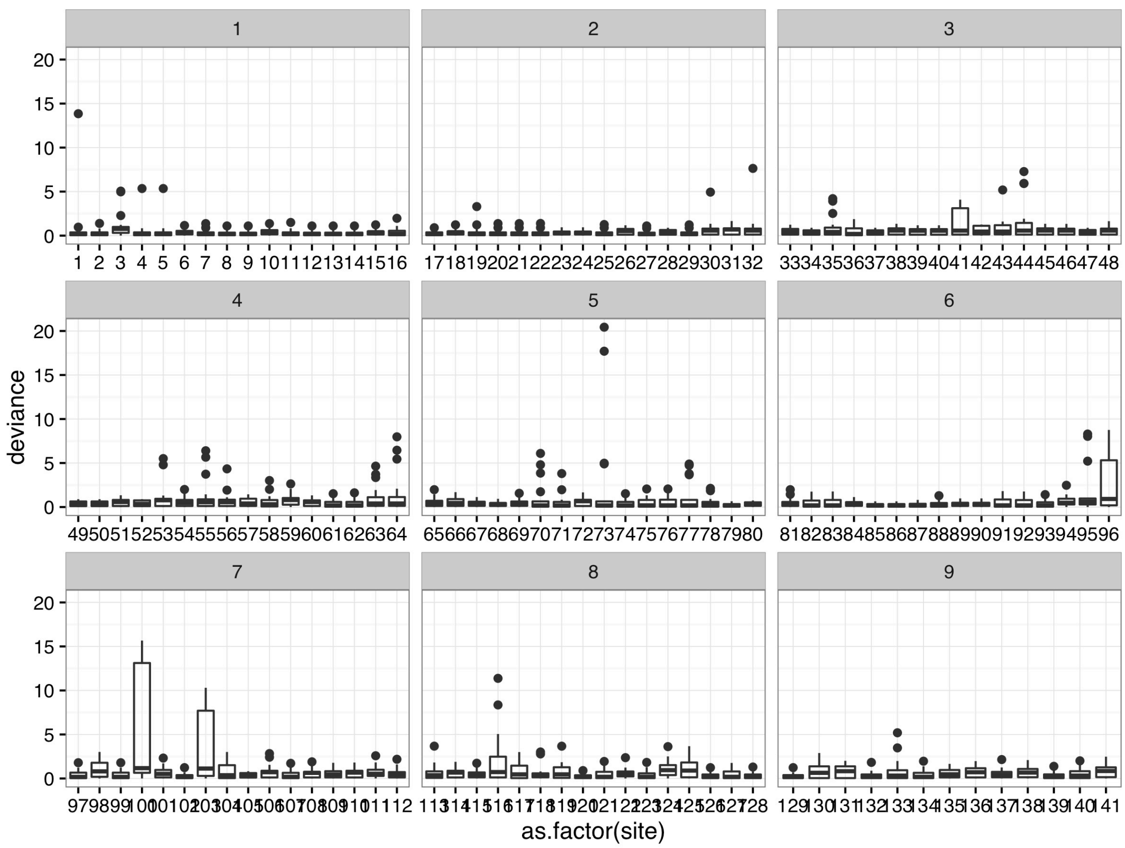
Table B17: An example of the detection probabilities associated with one seining pass. Streams of size 1 are lower order streams with lower flows, and stream size 4 represents the main stem of the Arkansas River.

SPP	size1	size2	size3	size4
ARD	0.94	0.93	0.92	0.90
BBH	0.86	0.83	0.80	0.76
STR	0.95	0.93	0.89	0.83
CCF	0.93	0.92	0.92	0.91
FMW	0.91	0.92	0.92	0.93
FHC	0.96	0.95	0.94	0.92
SNF	0.97	0.97	0.97	0.97
LND	0.85	0.77	0.66	0.53
OSF	0.95	0.95	0.94	0.92
PKF	0.91	0.87	0.81	0.73
PMW	0.91	0.90	0.87	0.84
RDS	0.96	0.96	0.97	0.97
SAH	0.94	0.95	0.96	0.96
SRD	0.94	0.93	0.92	0.90
SMM	0.91	0.88	0.83	0.78
WHS	0.96	0.95	0.91	0.86
RCS	0.91	0.88	0.85	0.81

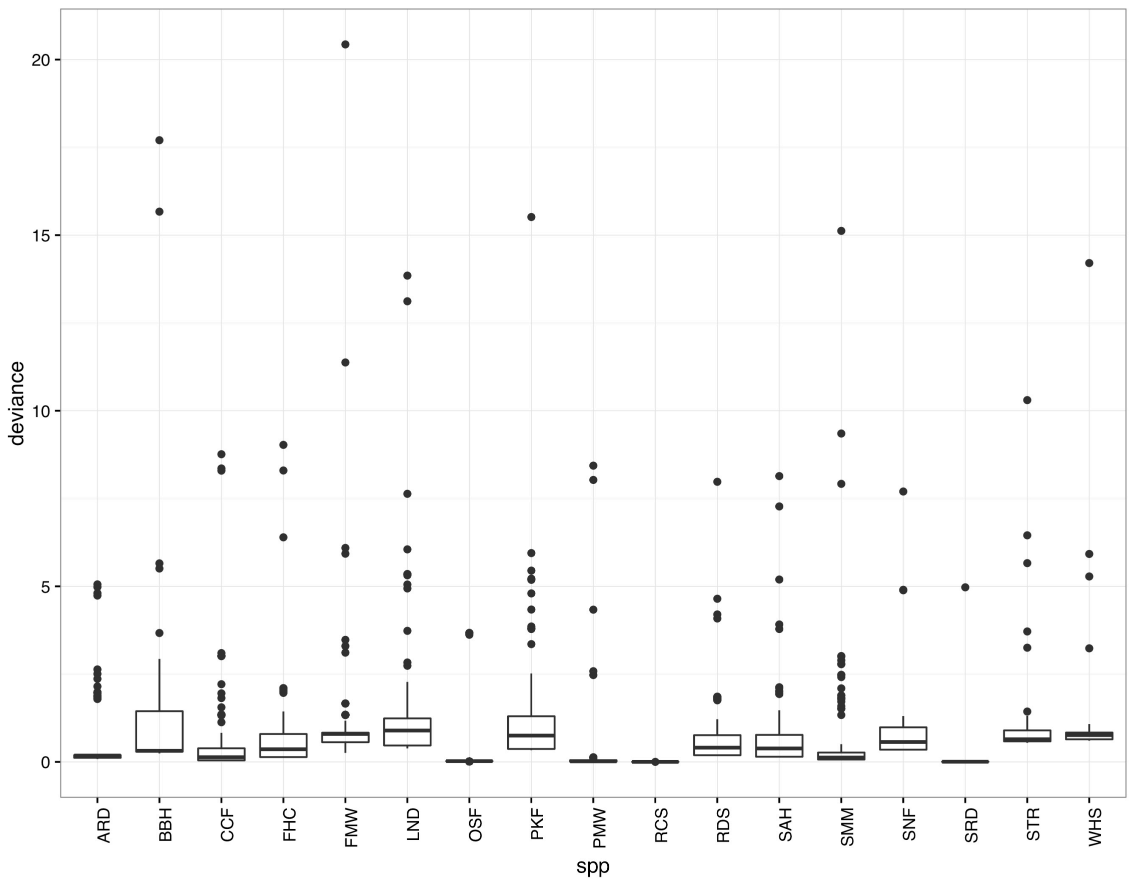
3.B.7 Goodness-of-fit plots

Plots of the deviance residuals are included to indicate the chosen model's goodness-of-fit (Broms et al. 2016) . High values of the residuals potentially indicate sites or species that do not fit well. For the Arkansas River data, high deviance residual values are correlated with the sites with many surveys associated with them.


as.factor(site)
ARD BBH CCF FHC FMW LND OSF PKF PMW RCS RDS SAH SMM SNF SRD STR WHS
spp
deviance.cut
[-Inf,2)
[2,5)
[5,8)
[8,10)
[10, Inf)



1
2
3
4
5
6
7
8
9
deviance
as.factor(site)


deviance
20
15
10
5
0
ARD
BBH
CCF
FHC
FMW
LND
OSF
PKF
PMW
RCS
RDS
SAH
SMM
SNF
SRD
STR
WHS
spp

3.C Sampling Locations for 2016–2018.

The sites labeled ‘GRTS’ are the sites selected through the space-filling algorithm. These sites are also known as the balanced or historic sites because they are sites that have been previously sampled. If any of these sites are not accessible or are dry, CPW should select sites labeled ’OS’ to replace any of the GRTS sites. Going forward, the sampling of these sites should continue in subsequent years. Therefore the sites sampled in 2016 should be resampled in 2019, the sites sampled in 2017 should be resampled in 2020, and so on.

The sites labeled ‘OASD’ are the sites selected through the optimal adaptive sampling design. These sites are also known as the ‘optimal’ or ‘random’ sites because the locations have not been previously sampled. If any of these sites are not accessible, then OASD sites from 2017 should be sampled in 2016, and OASD sites from 2018 should be sampled in 2017. Sampling at these locations should not be repeated. Therefore, if a 2017 site needs to be sampled in 2016, continue to go down the list so that 10 unique OASD sites are sampled each year.

Ideally, the OASD process will be repeated each year. After more data is collected, a different model may be chosen. The new model will be refit to all of the data and new sites will be selected for each year of sampling.

An ‘order’ column has been added to the table as a suggestion of the order of importance of the sampling locations for 2016. This column has been added because it is unlikely that there will be time to sample all listed locations in 2016. Because much of the sampling in the Arkansas River basin has been opportunistic, sampling the balanced / GRTS sites is most important.

order	SiteType	year	UTMX	UTMY	size	crops	dvlpd	wtlnds	reservoir	ftn	main	purg
1	GRTS	2016	485187	4237192	1	0.00	0.00	0.00	abovePueblo	0	0	0
2	GRTS	2016	518687	4163492	1	0.00	0.44	0.02	between	0	0	0
3	GRTS	2016	534587	4233992	3	0.00	0.85	0.05	between	0	1	0
4	GRTS	2016	742687	4216092	4	0.66	0.02	0.15	belowJM	0	1	0
5	GRTS	2016	539687	4228192	3	0.07	0.00	0.12	between	0	0	0
6	GRTS	2016	587387	4196292	1	0.00	0.00	0.00	between	0	0	0
7	GRTS	2016	670687	4281592	1	0.00	0.00	0.04	belowJM	0	0	0
8	GRTS	2016	616687	4135992	1	0.00	0.00	0.02	between	0	0	0
9	GRTS	2016	595187	4221192	4	0.38	0.00	0.22	between	0	1	0
10	GRTS	2016	528387	4274392	3	0.02	0.00	0.23	between	1	0	0
	GRTS	2017	642187	4185892	3	0.00	0.00	0.03	between	0	0	1
	GRTS	2017	750187	4214292	4	0.52	0.01	0.28	belowJM	0	1	0
	GRTS	2017	603587	4348892	1	0.09	0.01	0.14	belowJM	0	0	0
	GRTS	2017	618587	4156292	3	0.00	0.00	0.08	between	0	0	1
	GRTS	2017	688387	4278392	1	0.00	0.00	0.02	belowJM	0	0	0
	GRTS	2017	657187	4216392	4	0.28	0.03	0.37	between	0	1	0

order	SiteType	year	UTMX	UTMY	size	crops	dvlpd	wtlnds	reservoir	ftn	main	purg
	GRTS	2017	722287	4220792	4	0.32	0.00	0.21	belowJM	0	1	0
	GRTS	2017	609487	4147092	3	0.00	0.00	0.02	between	0	0	1
	GRTS	2017	622487	4228992	1	0.00	0.00	0.04	between	0	0	0
	GRTS	2017	701387	4219692	4	0.57	0.02	0.26	belowJM	0	1	0
	GRTS	2018	545287	4233792	3	0.18	0.11	0.25	between	0	0	0
	GRTS	2018	728687	4221092	4	0.58	0.00	0.18	belowJM	0	1	0
	GRTS	2018	520087	4293492	2	0.00	0.89	0.01	between	1	0	0
	GRTS	2018	562487	4326792	1	0.02	0.00	0.12	belowJM	0	0	0
	GRTS	2018	515287	4188292	1	0.03	0.01	0.01	between	0	0	0
	GRTS	2018	504087	4247592	1	0.03	0.05	0.04	abovePueblo	0	0	0
	GRTS	2018	573187	4117592	3	0.02	0.00	0.15	between	0	0	1
	GRTS	2018	733687	4220192	4	0.53	0.00	0.21	belowJM	0	1	0
	GRTS	2018	644387	4213492	4	0.12	0.00	0.08	between	0	1	0
	GRTS	2018	613487	4244392	1	0.00	0.00	0.00	between	0	0	0
	GRTS	OS	678787	4154392	1	0.00	0.00	0.00	belowJM	0	0	0
	GRTS	OS	574287	4227392	4	0.02	0.03	0.34	between	0	1	0
	GRTS	OS	606287	4217392	4	0.47	0.00	0.17	between	0	1	0

order	SiteType	year	UTMX	UTMY	size	crops	dvlpd	wtlnds	reservoir	ftn	main	purg
	GRTS	OS	635387	4209792	4	0.30	0.02	0.41	between	0	1	0
	GRTS	OS	548487	4129192	1	0.00	0.00	0.06	between	0	0	1
	GRTS	OS	513387	4251492	1	0.03	0.00	0.01	abovePueblo	0	0	0
	GRTS	OS	542487	4202692	3	0.00	0.00	0.00	between	0	0	0
	GRTS	OS	688787	4212892	2	0.00	0.00	0.00	belowJM	0	0	0
	GRTS	OS	633387	4297092	2	0.00	0.00	0.06	belowJM	0	0	0
	GRTS	OS	586587	4305792	1	0.21	0.00	0.05	between	0	0	0
17	OASD	2016	586687	4105892	2	0.00	0.00	0.00	between	0	0	1
16	OASD	2016	583987	4335592	2	0.00	0.00	0.08	belowJM	0	0	0
18	OASD	2016	587687	4107792	2	0.00	0.00	0.00	between	0	0	1
19	OASD	2016	587487	4109092	2	0.00	0.00	0.00	between	0	0	1
12	OASD	2016	686287	4206192	2	0.00	0.00	0.00	belowJM	0	0	0
11	OASD	2016	587087	4110392	2	0.00	0.00	0.00	between	0	0	1
15	OASD	2016	590087	4307992	2	0.00	0.00	0.11	between	0	0	0
14	OASD	2016	556187	4292992	2	0.05	0.00	0.00	between	0	0	0
20	OASD	2016	571987	4117992	3	0.04	0.00	0.10	between	0	0	1
13	OASD	2016	750287	4226392	2	0.18	0.02	0.04	belowJM	0	0	0

order	SiteType	year	UTMX	UTMY	size	crops	dvlpd	wtlnds	reservoir	ftn	main	purg
	OASD	2017	525287	4189292	2	0.00	0.00	0.09	between	0	0	0
	OASD	2017	587487	4308692	2	0.09	0.00	0.06	between	0	0	0
	OASD	2017	515887	4211292	2	0.00	0.00	0.00	between	0	0	0
	OASD	2017	582587	4117692	3	0.00	0.00	0.00	between	0	0	1
	OASD	2017	574087	4117292	3	0.02	0.00	0.16	between	0	0	1
	OASD	2017	596587	4342692	2	0.01	0.00	0.05	belowJM	0	0	0
	OASD	2017	642987	4216892	2	0.38	0.00	0.14	between	0	0	0
	OASD	2017	750687	4223292	2	0.50	0.00	0.04	belowJM	0	0	0
	OASD	2017	574787	4117392	3	0.02	0.00	0.13	between	0	0	1
	OASD	2017	575087	4117392	3	0.02	0.00	0.10	between	0	0	1
	OASD	2018	494687	4249192	3	0.06	0.04	0.14	abovePueblo	0	1	0
	OASD	2018	643187	4218992	2	0.14	0.00	0.28	between	0	0	0
	OASD	2018	625087	4165892	3	0.01	0.00	0.03	between	0	0	1
	OASD	2018	560787	4227492	3	0.15	0.00	0.08	between	0	0	0
	OASD	2018	539687	4126192	1	0.00	0.00	0.01	between	0	0	1
	OASD	2018	614387	4125092	1	0.00	0.00	0.00	between	0	0	0
	OASD	2018	751587	4220792	2	0.61	0.00	0.06	belowJM	0	0	0

order	SiteType	year	UTMX	UTMY	size	crops	dvlpd	wtlnds	reservoir	ftn	main	purg
	OASD	2018	539187	4197092	2	0.00	0.00	0.00	between	0	0	0
	OASD	2018	528087	4219092	2	0.00	0.03	0.04	between	0	0	0
	OASD	2018	638987	4157292	1	0.00	0.00	0.00	between	0	0	1

3.D Steps to select future sampling locations.

In order for the site selection to be reproducibile and to use the process for future years, implementation details are described here.

3.D.1 Data

The data was organized through the '`ArkBasinDataCreation.docx`' file, included in this appendix. The steps in this file describe how the sampling frame and the covariates were created.

To add additional sampling occasions to the data files, follow the steps at the end of the '`ArkBasinDataCreation.docx`' document. The data organization step culminates in an `ArkData.RData` R workspace to be used for the subsequent sampling design steps.

Ark. Basin Data Creation/Organization

This document describes how the raw data are cleaned and organized for the optimal adaptive sampling design. It contains three main sections. The first section creates the sampling frame and covariates. This section only needs to be revisited if the sampling frame changes and/or if additional covariates are needed. The second section adds the sampling occasions. This section needs to be revisited each year as more data are collected. The third section describes how the data are then organized in R. If any section is revisited, then subsequent sections will need to be rerun.

I. CREATE THE SAMPLING FRAME/ STREAM NETWORK MAP

Inputted files:

File Name	Description	File type and source
ua_annotated_map.shp	A set of flowlines that is often used by CPW to represent the Arkansas River basin.	Shapefile. From Grant.
NHDflowlines.shp	The set of potential waterways of the Arkansas River basin	Shapefile. Originally from Grant, but clipped to Ark Basin and with Nulll flowlines removed.
ArkBasinPolygon.shp	HUC4	Shapefile. Originally from Grant, but with only Ark Basin HUC selected.
ArkBasinBelow6000.shp	Polygon of the basin that exists solely below 6500 feet.	Shapefile. Derived from the ArkBasinPolygon.shp and elevation DEM files.
ArkBasinBelow6500	Polygon of the basin that exists solely below 6500 feet.	Shapefile. Derived from the ArkBasinPolygon.shp and elevation DEM files.
SampOccasions.dbf	Table of the locations of all Ark Basin sampling locations.	Created in R file: "OrgSampOccForExport.R" from database download from Andrew Treble.

[1] Also from:
ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Hydrography/NHD/State/

Outputted files:

File name	File type	Description
SurveyDesignStreams.shp	Shapefile	Polylines representing the sampling frame.

1. Begin with Grant's "ua_annotated_map" set of flowlines.
    a. Also load the NHDflowlines.shp, ArkBasinPolygon.shp, and ArkBasinBelow6000.shp files.
2. Clip "ua_annotated_map" streams to only include segments below 6496 ft (1980m). (Geoprocessing drop-down > Clip) Save as "SurveyStreamsTmp.shp".
3. Clip "NHDflowlines" to only include segments below 6496 ft (1980m).
4. Project streams into "NAD_1983_13N." (Toolbox > Data Management > Projections > Project)
5. Add the Sampling Locations to the map. **This step is done now to make sure all important waterways are include in map, but step may need to be repeated when more sampling is complete.** First, convert the "DATA_KristinBroms_RevisedPull_03172016.xlsx" file to a .csv file and then use R to convert the .csv file to a .dbf file using the "OrgSampOccForExport.R" file. Add the .dbf file to ArcGIS. Right click on the table, go to "Display XY Data" to display the data. Change the Symbology so that it is color-coded as to whether the site should be included or excluded. Export the table to create a .shp file of the data points. (Make sure the SamplingLocations.shp file has the same projection.)
6. Using the Editor Toolbar, remove from "SurveyStreamsTmp.shp" file:
    a. Ponds
    b. Lines that do not match any NHD flowlines
    c. Dry intermittent streams that do not match ARD assessment map.
7. Using the Editor Toolbar, add to "SurveyStreamsTmp.shp" file:
    a. NHD flowlines where sampling took place.
    b. Add wet NHD flowlines that look wet in Google Earth and were not in original map, when possible.
    c. Create ditches lines for sampling locations that do not exist on NHD flowlines.
    d. BE SURE TO CHANGE THE ATTRIBUTES ASSOCIATED WITH NEW FLOW LINES. ***
8. "Snap" sampling locations to stream segments. (And/or move some stream segments to match sampling locations—GIS line does not always match stream flow on Google Earth.) Toolbox > Editing > Snap. Use 100 Meters as distance.
    a. Double check that all sampling locations land on a stream segment, and add stream segments if necessary.
    b. Re-snap if necessary and/or use Editor toolbar to move points.
9. Confirm Stream Network and Sampling Locations (Exclude/Include) with P. Foutz.
10. The final sampling frame is the "SurveyDesignStreams.shp" shapefile.

B. ADD COVARIATES.- PART 1

Inputted files:

File name	Description	File type and source
SurveyDesignStreams.shp		Shapefile. Created above.
Elev100mNAD	100-meter elevations projected into NAD Zone 13N to match other data.	Raster. Originally from http//ned.usgs.gov, but projected into common projection.
Land Cover Covariates	Raster where each cell value represents a different land type.	Raster from National Land Cover Database.

Outputted files:

File name	Description	File type
SurveyDesignStreams.shp	Updated version of previously created file. Updated to include columns of covariates	Shapefile.
SurveyDesignStreamsAsPoints	Discretized version of the above file.	Shapefile.

1. Add Field to say if line is Perennial or (detached) Intermittent stream segment. A stream is intermittent if it is more than 2000m from the connected stream network. (Open Attribute Table. File > Add Field… Add a field named "Stream Type". Use selections (and ruler) to define if site is INT or PER.) Right click > Field Calculator. Put the string in double "quotations." **NOTE: In this step, we are using the term "perennial" to describe streams that are *connected* to the main stem of the Ark, and "intermittent to describe streams that are *unconnected*. In subsequent clean-up and R, the terminology is corrected.
2. Create categorical covariate: if a site is above Pueblo reservoir, between Pueblo and John Martin reservoir, or if a site is below John Martin reservoir. (Open Attribute Table. File > Add Field… Add a field named "ReservoirLocation". Use selections (and ruler) to define if site is "abovePueblo", "between", or "belowJM".)

3. Create an indicator covariate to separate Fountain Creek from rest of basin; include longitude to reflect changes along Fountain Creek. (Open Attribute Table. File > Add Field… Add a field named "FountainCrk". Use selections (and ruler) to define if site is YES or NO.)
4. Create an indicator covariate to separate Purgatoire River from rest of basin. (Open Attribute Table. File > Add Field… Add a field named "PURG". Use selections (and ruler) to define if site is YES or NO.)
5. Create an indicator covariate to separate the main stem of the Arkansas River from rest of basin. (Open Attribute Table. File > Add Field… Add a field named "MAIN". Use selections (and ruler) to define if site is YES or NO.)
6. Create Stream Size covariate. I calculated it by hand with the "Select" tool, Editing, and the "Field Calculator" but there is probably an easier way. (The existing field called STRAHLER does not make sense for all stream segments.) Open the attribute table of the "SurveyDesignStreams" file and Add a new Field-"Stream Size" as a Short Integer. Select by attributes, select all Intermittent streams and use the "Field Calculator" to set their Stream Size = 1. Then manually select other stream segments and create a stream size for them based on Strahler stream order properties. Change intermittent streams to correctly follow Strahler stream order properties as well.

7. Create zone covariate from Nesler et al. (1999) booklet, p. 53. NOT DONE. No map/ not enough in Nesler et al. (1999) for me to reproduce.

<u>C. ADD COVARIATES.- PART 2</u>

The continuous version of the stream network is represented by a series of stream segments. However, these stream segments are of very unequal length. To equalize every portion of the stream and make it more objective when calculating covariates, we will discretize it into a raster and then convert it to points.

1. Add relevant data: elevation raster, gradient raster (or create it, Spatial Analyst > Surface > Slope), and land cover feature class/shapefile. Make sure all have the "NAD_1983_13N" projection. If not, Toolbox > Data Management > Projections and Transformations > Raster > Project Raster.
2. Rasterize the stream network. (The steps below basically follow steps 6 and 9 in the "STARS: Spatial tools for the analysis of river systems version 2.0.0" Tutorial.) Each raster cell will then have a value equal to the reach ID. This field will help in joining stream names and other attributes to the stream points.
    a. Add the STARS toolbox.
    b. Make sure stream network ("SurveyDesignStreams" shapefile) has a projected coordinate system, e.g., "NAD_1983_13N".
    c. Enable Spatial Analyst Extension. Customize > Extensions. Make sure Spatial Analyst is checked.

d. Change the Environment Settings. Menu > Geoprocessing > Environments. Expand M Values and set "Output has M Values" to Disabled. Repeat for Z Values. Under Processing Extent, set Extent to Same as layer elev100mNAD. Under Raster Analysis, set cell size to Same as layer elev100mNAD. No Mask is used. Click OK.
e. Overwrite outputs by default. Geoprocessing > Geoprocessing Options > check box next to "Overwrite…"
f. Add a long integer field named reached to the stream attribute table. Calculate field: reachid = OBJECTID. (OBJECTID field could change.)
g. Convert the stream to raster format. Toolbox > Conversion> To Raster > Polyline to Raster. Use Value field= reachid. Zoom in and check that cells align with elevation.

3. Convert the stream raster into points. Toolbox > Converstion > From Raster > Raster to Point. Save the file as "SurveyDesignStreamsAsPoints".
    a. Add long integer field- reachid = grid_code. Used in R to join with continuous stream network and get stream names, those covariates, etc.
        i. Right click on "SurveyDesignStreamsAsPoints" and Join with "SurveyDesignStreams". Join by reachid. (Double-check how/if this changed files in ArcGIS vs doing it in R.

4. Add the elevation and gradient values to each stream point.
    a. Add long integer field Elevation, and double/float field Gradient.
    b. Spatial Analyst > Extraction > Extract Values to Points. Extract the elev100mNAD raster values to each point. This creates a new shapefile/feature class: "ArkStreamElevations."
    c. Spatial Analyst > Extraction > Extract Values to Points. Extract the grad100mNAD raster values to each point. This creates a new shapefile/feature class : "ArkStreamGradients." **NOTE: Because of misalignment between the elevation DEM and the NHD flowlines, the gradient values do not make sense and were not used in subsequent analyses.
    d. Add two new fields to the "SurveyDesignStreamsAsPoints.shp" file: Elevation and Gradient.
    e. Join the "SurveyDesignStreamsAsPoints.shp" file with the "ArkStreamElevations.shp". Join by pointid.
        i. After Join, Field Calculator… Elevation = RASTERVALUE.
        ii. Remove Join.
    f. Repeat with the "ArkStreamGradients" file.
        i. After Join, Field Calculator… gradient = RASTERVALUE.
        ii. Remove Join.

5. Create the land cover covariates.

a. First create buffered polygons from the stream points. Geoprocessing Drop-down > Buffer. Use a 1000m buffer, and then repeat with a 2000m buffer for the crops covariate. This will create two new shapefiles/ feature classes: "SurveyDesignStreamsAs1000mBuff" and "SurveyDesignStreamsAs2000mBuff," respectively.
b. The landcover raster has many different categories in it. We need to reclassify it into many different rasters with each land cover given its own raster. (This step mirrors step 10 of the STARS tutorial). First, make sure projections match the stream network. Spatial Analyst > Reclass > Reclassify. Set the Landscape cell value(s) of interest to 1, and all other cell values to 0. This step creates the cropsNAD.tiff, dvlpdNAD.tiff, and the wtlndsNAD.tiff raster files.
c. Now calculate the percent of the land area of each point that is covered by the given land type. Because these polygons overlap, we cannot use the "Zonal Statistics" tool and will instead use a "cheat".
    i. Convert the land cover raster to points. Toolbox > Conversion > From Raster > Raster to Points. Double-check the projection.
    ii. Create new Fields in the "SurveyDesignStreamsAsPoints" file to hold the crops, dvlpd, wtlnds covariates. I call the new fields "cropsCount", "dvlpdCount", "wtlndsCount".
    iii. Intersect the crop point file with the 2000m buffered polygon file. Use outpoint type = POINT. OK to create the files in a temporary directory here.
        1. Open the attribute table of the "CropsBuffIntersect" file. Right click the "FID_SurveyDesignStreamsAs2000mBuff" Field > Summarize… Create SumCrops table.
        2. Join the SumTable to the "SurveyDesignStreamsAsPoints" file (use the pointid Field). Some row will be <Null> because not all sites have crops nearby.
        3. Set "cropsCount" Field = BuffID Count to make permanent. (Click "yes" to the warning message.)
        4. Remove Join. Delete "CropsIntersect" file. Delete SummTable.
    iv. Repeat the above step with the dvlpd points file and the 1000m buffered polygon file.
    v. Repeat the above step with the wtlnds points file and the 1000m buffered polygon file.

D. EXPORT

1. The "SurveyDesignStreamsAsPoints" file should have (at least) the following fields/columns:
    i. reachid,
    ii. elevation,
    iii. gradient,

iv. cropsCount,
v. dvlpdCount,
vi. wtlndsCount
2. The "SurveyDesignStreams" file should have (at least) the following fields/columns:
   i. GNIS_Name
   ii. reachid
   iii. Stream Type (INT or PER)
   iv. ReservoirLocation (abovePueblo, between, belowJM)
   v. FtnCreek (NO or YES)
   vi. PURG (NO or YES)
   vii. MAIN (NO or YES)
   viii. StreamSize (integer values 1 – 4)
3. Add UTM coords to the "SurveyDesignStreamsAsPoints" files. Add Long Integer fields. Then right-click > Calculate Geometry…
4. Export the two files as .dbf files (dBASE table). We will merge them in R through the "reachid" Field.

II. MATCHING SAMPLING POINTS TO STREAM-AS-POINTS NETWORK.

Inputted files:

File name	Description	File type and source
includeSampOcc.dbf**	This file is a subset of the SampOccasions.dbf file, which contains all potential sampling occasions. The file has been cleaned in R to exclude occasions that did not follow protocol.	Created in R file: "OrgSampOccForExport.R"
SurveyDesignStreamsAsPoints.shp		Shapefile. Created in previous steps.

** File must first be created in R.

Outputted files:

File name	Description	File type and source
snappedSurveys.dbf	A file very similar to the includeSampOcc.dbf file, but with new UTMs that match to points on the stream network.	Created through ArcGIS

1. First use the "Ark_OrgSampOccForExport.R" file to clean up the survey data (from the SampOccasions.xlsx file) and to create a file that only includes the sampling occasions to be used in the analyses (e.g., Arkansas R headwaters will be excluded).
    a. This file begins with the original data pull. The main spreadsheet of this file should have the following columns: SurveyPurpose, Protocol, Gear, TotalEffort, EffortMetric, WaterID, WaterName, SampleDate, Location, Elevation, UTMZone, UTMX, UTMY, Basin, StationLength, AvgWidth, StationCode, SiteType, SurveyID, SpeciesCode, Status, Catch, and Source.
    b. Add a Column called "NewStatus", and a column called "sameStatus" right after the "Status" column. The Status codes were not uniform. For codes that did not follow protocol, e.g., only had numbers without a letter in front describing the sampling method, check the notes and see if you can fill in the correct status. The NewStatus column should then be similar to the original Status column, but with more information.
    c. Sometimes multiple passes were labelled: E1, E2, S1, S2, and sometimes the same four passes were labelled: E1, S2, S3, S4. Make the statuses consistent by using the former labelling. Therefore the "sameStatus" column should have the most consistent and updated via notes Status information.
2. Add the newly created "IncludedSampOcc.dbf" file to ArcGIS. And then right-click to Display Data… Double check that all sites that appear should be included and are near stream segments.
3. Toolbox > Editing > Snap. And snap the includeSampOcc Events to the "SurveyDesignStreamsAsPoints" file. I used a distance of 300 Meters. Once tool is completed, zoom in and make sure it worked and all sites are on the stream points. Remove files and repeat above 3 steps as necessary.
4. Open Attribute Table, and Export records as "snappedSurveys.dbf" (dBASE table). We will merge it with the "SurveyDesignStreamsAsPoints.dbf" file in R through their common UTMs.

<u>ADDING NEW SAMPLING OCCASIONS</u>

After each field season, add the new data to the SampOccasions.xlsx file. Repeat the above steps of the "MATCHING SAMPLING POINTS TO STREAM-AS-POINTS NETWORK." section.

III. ORGANIZING DATA FOR MODELS AND DESIGN

Use the "Ark_OrganizeDataNew.R" file in R to create.

3.D.2 Model

Use the `RunCrossVal.R` file select a best-predicting model, and then use the `RunModels.R` file to fit the model to the full data set. You will need to have JAGS software installed on your computer. It is the output from the `RunModels.R` file that is used in the design criterion and site selection.

The `ModelResults.R` and `BestModResidPlots.R` files may be used to examine the output from the chosen model and to reproduce the figures and tables contained within this report.

3.D.3 Design criterion and selection of sites

First select the spatially balanced GRTS sites with the `SelectBalancedSites.R` file, and then select the optimal adaptive sampling sites with the `SelectOASDSites.R` file. A Google Earth file and .csv file to display and utilize the sampling locations may be created with the `ArkPlotFutureSites.R` file.