

How a monitoring dataset, an adaptive management framework, and ecological comparisons of  
selected fish groups can guide conservation

by

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## Abstract

Freshwater habitats are amongst the most threatened systems globally, and stream and river biodiversity is extremely vulnerable to human and climate impacts. A challenge for research and management professionals seeking to conserve native, freshwater biodiversity is how to develop a process that links past and present data to guide future data collection, restoration actions, and management decisions. The purpose of this research is to illustrate how an adaptive management framework, applied to monitoring data for carefully chosen groups of fish, can guide conservation planning. Chapter 1 develops my team's adaptive management framework and illustrates the use of the framework for one stable, native Kansas fish species. Chapter 2 demonstrates how the framework can be used to analyze monitoring data for three native Kansas fish species (two common and one uncommon). Our framework is comprised of an iterative 10-step cycle within which we embedded a 6-step, statistical subloop. Each iteration of this framework prioritizes a tractable question, identifies focused taxa and scales, uses a directed literature review to provide context, wrangles appropriate fish-relevant habitat variables, and applies data cleaning procedures. Then weight of evidence is accumulated by combining many visualization tools (i.e., fish maps, proportional resource maps, prediction maps, ridgeline plots, box plots, histograms, pie plots), multiple logistic regression, and probability plots. The final step of the 1<sup>st</sup> iteration identifies data gaps and testable predictions for future field sampling that will be analyzed in the 2<sup>nd</sup> iteration. In a proof of concept, my team compared data analysis of two common fish [Emerald Shiner (*Notropis atherinoides*), Central Stoneroller (*Camptostoma anomalum*)] and one uncommon fish [Plains Minnow (*Hybognathus placitus*), Kansas threatened]. Data analysis of combined fish taxa, chosen based on a thoughtful, multi-criteria decision tree, enhanced conservation insights. Our multiple logistic regression models

consistently identified priority regressors. Our weight of evidence approach clarified ambiguous regression trends. Prediction maps, paired with visualization tools, identified promising sites for future Plains Minnow restoration. Our approach proposes a continually evolving series of structured interactions among researcher-manager teams to accumulate actionable knowledge through a process of shared question identification, data analysis, and discussion of next steps. Monitoring data, research data, and data tests of management outcomes all have value for applied problem solving. However, if different types of data and different datasets are not connected and coordinated, opportunities for conservation success are lost. Our framework and proof of concept show a way to make these connections. This framework is an example of an implementable, adaptive management approach that can compare distributional patterns of thoughtfully chosen fish taxa to aid restoration efforts of threatened, freshwater systems.



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## **Dedication**

I dedicate this thesis to my loved ones (all of you!), who made each trip up and down I-70 worth it every. single. time. To mom and dad: your respect and admiration for the natural world left a massive mark on me – so much so that I chose to integrate it into my education and career. Thank you for your unwavering support in my pursuit of the field I love – I owe every bit of it to you. To Dan: Each part of this process was made easier with you by my side. Everyday is a good day thanks to you. To Kansas fish (and beyond): my appreciation for the world around us has only grown tenfold during my time spent here. Being provided the opportunity to study such an extraordinary organism in the state I've been lucky to call home my entire life is a gift. To the ladies of 106 Armour (and beyond): my home away from home! What would I do without you? Finally, to my cat: my perfect research companion and the light of my life – you are the best spontaneous decision I've ever made. Convinced I have the greatest support system in the world – love you all so much.

## Preface

Appropriate keywords for this document are adaptive management; fish monitoring data; freshwater fish; conservation; weight of evidence approach; implementable framework. Chapter 1 is a general framework that applies to any species in any system and provides an implementable way to link monitoring data sets to each other (across years) and management actions (future sampling or restoration action). Chapter 1 is more about conservation and applied ecology than about a specific system or taxa. We have therefore formatted the chapter for applied ecology and general conservation journals (*Biological Conservation*; *Environmental Management*; *Ecological Indicators*). Chapter 2 is two different papers; the first is how to select taxa to compare and could be related to any species. This is formatted for a general ecology audience and could therefore be submitted to *Ecological Applications* or another applied ecology journal. The second is using the framework to gain new ecological and conservation knowledge about specific taxa, and as such the results are fish-specific. This is formatted for a fish-specific journal (*Ecology of Freshwater Fish*; *Fisheries*).

# **Chapter 1 - An adaptive management framework for extracting additional insights from fish monitoring data to aid conservation**

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Pratap

## **Abstract**

Creating a data-driven plan for monitoring the status and trends of native organisms is an important component of resource conservation. The overarching issue that we address here is how to develop a step-by-step framework that improves how conservation professionals use existing fish monitoring data to effectively guide future data collection, facilitate data interpretation, and promote justifiable decision-making. Our framework is an example of an implementable adaptive management approach for biodiversity monitoring and provides a tool to accumulate learning through multiple iterations of the framework. In this prototype, we address the general question of “if, when, and why might a specific fish taxon be present or absent at specific locations?” Our framework consists of a cycle of 10 steps within which six additional statistical steps are embedded. This framework is not a strategic planning document, but instead provides a way to implement a mutually-agreed-upon bigger picture. We developed this framework for native Kansas stream fish and use the common and stable native fish, Emerald Shiner (*Notropis atherinoides*), as a proof of concept. The keys that allow our framework to link past, present, and future data are first identifying information gaps in the existing monitoring dataset, then proposing related testable questions that can guide future data collection. Our weight-of-evidence framework integrates results from (a) fish and variable maps, (b) multiple exploratory analyses (e.g., pie charts, box plots, proportional symbol maps, ridgeline plots), (c)



statistical models (multiple logistic regression, probability plots, confusion matrices that estimate model accuracy) and (d) the existing literature. Our expectation is that for every general question of interest, a team of fisheries professionals will go around our iterative framework multiple times during which trends are systematically synthesized. In summary, our interactive framework provides a different way that teams of fisheries professionals can interact to strategize about what information is needed, plan for future field seasons, and have more productive, discussions about future data needs and conservation actions.

## **Introduction**

### **Overview and Purpose**

Developing a strategy and associated, structured process that ensures a functioning environmental landscape in which native biota coexist with humans is a grand biological challenge that is a high priority for society. Creating a data-driven plan for monitoring the status and trends of native organisms is an important component of this critical conservation challenge. The overarching issue we address here is how to develop a framework that improves how professionals use existing fish monitoring survey data to effectively guide future data collection, facilitate data interpretation, and promote justifiable decision-making. In spite of much progress by very-qualified and expertly-trained environmental professionals, at least three categories of information gaps impede advances on this overarching issue. The first gap is the lack of a useful and useable planning tool that identifies and guides realistic, long-term expectations for monitoring data (> 5-10 years). The second gap is the absence of a philosophical guideline for choosing, using, and interpreting quantitative tools that are effective with the unique features of monitoring datasets. A third gap is the need for practical and implementable approaches to connect multiple datasets (e.g., across-year and across project datasets, monitoring with

research). Our purpose in this perspective is to address these information gaps by developing a step-by-step adaptive management framework for biodiversity monitoring that uses a combined weight of evidence approach. In so doing, we do not review specific monitoring data collection designs or individual statistical analyses because these summaries exist elsewhere. Instead, we discuss strategic planning and philosophical approaches that can result in a better use of monitoring data. Although we address biodiversity monitoring for Great Plains stream fishes, our framework can be adapted for other taxa and locations.

### **Information Gap 1 - Guiding Realistic Expectations**

Developing realistic expectations for longer-term monitoring data is challenging because of the complexity of the conservation problem addressed, unpredictability in outcomes, complex data structures, multiple data sets, and administrative constraints (e.g., presence or lack of specific types of accountability). No monitoring dataset, no matter how well designed and executed, can concurrently answer all questions of interest for all taxa in all systems. Often multiple components, diverse stakeholders, and competing priorities interact in conservation projects (Davis et al. 2006; Vidal and Marle 2008). Acknowledging that a single model or dataset cannot account for the complexity of environmental processes is an important part of working through a difficult problem (Flather et al. 1997). An institutional acceptance that complex problems will require multiple bouts of data collection can provide new avenues for addressing difficult conservation problems (Mather and Dettmers 2022). By establishing a long-term, strategic plan with key milestones, conservation professionals can break grand challenges into smaller, more manageable segments that enable participants to monitor progress more effectively and make amendments as needed (Dinerstein et al. 2019; Sunmola 2020; Warm et al. 2020). Thus, realistic expectations for monitoring include the acceptance of a longer, multi-

project timeframe within which shorter, individual projects with realistic timeframes are sited and for which thoughtful, but flexible milestones guide progress (Kolltveit and Grønhaug 2004; San Cristóbal et al. 2018; Warm et al. 2020).

### **Information Gap 2 - Appropriate Quantitative Tools**

Monitoring datasets are essential for conservation, but have messy-data features that influence the effectiveness of commonly-used statistical techniques. As examples of the strengths of this unique type of data, monitoring data are often the only source for geographically and temporally broad assessments of resource status and trends on which decisions and future actions can be based (Walters 1986; Vihervaara et al. 2013). Furthermore, monitoring data is often the only data type that can reveal long-term patterns and processes, and separate long-term trends from short-term changes (NRC 1996; Magurren 2010). Conversely, by definition, monitoring data, contain a large number of observations that are highly variable with numerous and significant gaps in spatial and temporal coverage. Identifying significance for datasets with the above messy-data characteristics using common statistical analyses can be difficult (Milliken and Johnson 1989, 2001; Slater and Villarini 2017; Fischer et al. 2021). In fact, partial answers from monitoring data, presented with unwarranted statistical certainty, may be misleading for planning future actions. Considering multiple analyses as individual pieces of a shared puzzle for which each piece provides partial insights into the bigger picture is a different way of thinking about monitoring data. Creating a body of evidence (e.g., maps, exploratory data, and generalized linear models) may be a more productive approach than seeking (or claiming) a definitive model.

### **Information Gap 3 - Connecting and Coordinating Datasets**

Linking datasets that were independently collected (multiple monitoring datasets, research and monitoring data), and applying the assembled information to future efforts are difficult tasks (Culina et al. 2021; Ladouceur and Shackelford 2021). For multiple longer-term data collection efforts, however, making these connections is essential. Adaptive management (AM) is a structured process in which professionals connect past, present, and future data to inform decision making (Walters 1986; Holling 1978). Examples of adaptive management exist that have resulted in efficient responses to environmental change (e.g., Kingsford et al. 2017; d'Armengol et al. 2018). Yet outside of commercial harvest models, relatively few adaptive management plans make implementable recommendations with detailed actions that address specific natural resource problems (Fontaine 2011; Stern et al. 2012; Rist et al. 2013). Especially rare is guidance that connects data sets, addresses gaps, identifies new, relevant specific questions, and facilitates testable predictions that can guide field data collection (Mather and Dettmers 2022).

### **Our Objectives**

To address these information gaps, in this perspective, we tackle three objectives. Our first objective is to develop and illustrate a specific step-by-step adaptive management framework for fish biodiversity monitoring, in which data needs and predictions, identified in the first iteration, guide future activities and decisions in subsequent iterations. As a second objective, using a large state-wide monitoring dataset ( $n=8,844$  fish samples), we provide proof of our concept using a stable, native fish species, the Emerald Shiner (*Notropis atherinoides*). Our third objective is to discuss gaps, benefits, utility, and next steps. Our hope is that researcher-manager teams can collaboratively use this process for strategic data planning

discussions so that adaptive management can guide how professionals use past, present, and future monitoring data.

## **Methods**

### **Objective 1 – Our Framework**

#### **General Framework Overview**

Our adaptive management framework is an iterative, structured process with 10 steps (Figure 1.1A) within which six additional statistical steps are embedded (Fig. 1.1B). This framework is not a strategic planning document, but instead provides a way to operationalize a mutually-agreed-upon bigger picture. In brief, our framework asks data analysts to prioritize a general question of interest (Step 1; Fig. 1.1A), choose specific taxa and scales for examination (Step 2), review literature to provide an appropriate context (Step 3), incorporate cleaning and vetting procedures for fish and habitat-impact data (Steps 4, 7), select appropriate fish-relevant data variables (Step 5), and wrangle individual habitat-impact regressor data for each fish sampling locations (GIS or empirical; Step 6). Next the general question from step 1 is partitioned into specific questions, each of which can be answered with an individual data analysis procedure. (Step 8). Then a 6-step statistical loop addresses each of these specific questions (Steps 9A-F; Fig. 1.1B) to systematically inform the original general question (Step 1; Fig. 1.1A). Finally, iteration-specific, weight of evidence leads to synthesis, interpretation, identification of future data needs, development of relevant new questions, and formulation of testable predictions (Step 10; Fig. 1.1A). These new directions can be tested in the next iteration (or cycle) of the framework. This cycle of steps continues until teams (managers, researchers, researcher and managers) are satisfied that they have adequate knowledge for future data collection decisions and management actions.

## **General Framework Step 1: Identify and Prioritize a General Question of High Interest**

Step 1 requires that the manager-researcher team carefully evaluate, limit, and prioritize the general question that is of greatest interest to them. Realistically, only a limited amount of information can be obtained in a single project (or a single iteration of our framework). If too many questions are asked within each iteration, none will be answered satisfactorily. In this prototype framework example, we ask the general question of “*if, when, and why might a specific fish taxon be present or absent at specific locations?*” Although a single, general question can be addressed in each cycle of our adaptive management framework, related questions can be addressed in additional cycles (Appendix Table 1.1). By systematically addressing and connecting multiple, thoughtfully-selected, general questions, new information is accumulated in each cycle of the framework.

## **General Framework Step 2: Choose Taxa and Scale for Fish**

In step 2, the manager-researcher team carefully prioritizes taxa and a physical area of interest. As with step 1, if too many fish taxa and too many locations are prioritized as targets, no results will be satisfying. In developing our general framework, we examined native fish taxa, across the state of Kansas. Using the Kansas State Wildlife Action Plan (SWAP; Rohweder 2022), we reviewed some fish taxa with very limited distribution [threatened and endangered (T&E); 3 taxa)], some fish taxa that are currently experiencing declines in distribution [species in need of conservation (SINC); 3 taxa)], and some commonly distributed fish (common and stable; 9 taxa; Table 1.1). T&E and SINC taxa are of obvious conservation interest but often have limited data sets. Common and stable species have large data sets, which can help build robust models. Furthermore, common species can be compared with appropriately-chosen T&E and

SINC fish in subsequent iterations of the framework to better understand distributional trends and related drivers of rare fish taxa (Chapter 2).

### **General Framework Step 3: Review Relevant Literature**

For this step, we first evaluated the literature on overall fish habitat to gain a broad understanding of the important habitat and impact variables that affect fish in all ecosystems. Next, we reviewed fish habitat for prairie streams in Kansas. Finally, we reviewed the habitat and impact literature for our target taxa in Kansas. In developing our general framework, we included peer reviewed publications from Web of Science, Kansas-specific reviews (Distler et al. 2014), and the NatureServe Database. Although site- and time-specific data exist on how Kansas fish taxa respond to individual habitat variables and impacts, many gaps are still present in the literature. For example, the published literature contained relatively few quantitative expectations about how a specific fish taxon might respond to specific habitat-impact variables across the state of Kansas. Furthermore, relevant data that were available typically were not synthesized in a format that was comparable to the output provided by very popular generalized linear and species distribution models (Step 9).

### **General Framework Step 4 and 7: Clean and Vet Fish and Regressor Datasets**

In steps 4 and 7 of our general framework, we carefully examined data in the fish and habitat-impact regressor databases. Because monitoring data are often collected by different people, thoroughly examining distributions and undertaking select quality control checks are essential. To develop our general framework, we used monitoring data for our focal taxa. In total, we used 8,844 fish samples collected from 7,872 unique locations by the Kansas Department of Wildlife and Parks (KDWP) and associated partners (Table 1.1). Samples were collected statewide with the most samples collected in the Lower Arkansas (2,494 samples),

Kansas-Lower Republican (2,447 samples), and Neosho (1,442 samples) River Basins (Figure 1.2).

### **General Framework Step 5: Choose Fish-Relevant Habitat and Impact Variables**

In step 5, teams carefully choose fish-relevant habitat and impact variables from the technical literature. In our general framework, we considered all fish, prairie fish, and analysis-specific fish taxa. Specifically, literature related to our overall, general question of “*if, when, and why might a specific fish taxon be present or absent at specific locations?*” included 11 ecological categories: (1) flow, (2) substrate, (3) position (order), (4) reach size [(A)width, (B)depth], (5) catchment size, (6) sinuosity, (7) land use-agriculture, (8) land use-developed, (9) land use-natural, (10) dam characteristics, (11) gradient. Physical characteristics (e.g., flow, substrate, order, size, gradient) are often described in fish habitat publications and fish keys (Distler et al. 2014). Impacts such as agricultural activity, human development, and dams are often identified as adverse stressors in Kansas streams (Distler et al. 2014). For comparison, natural land use types (e.g., grassland, forest, scrubland, wetland) were also included.

### **General Framework Step 6: Wrangle Regressor Data from Existing GIS Databases**

Step 6 is to obtain physical and impact data from five GIS datasets (Table 1.2) that correspond to the latitude and longitude at which fish samples were collected. We wrangled multiple metrics for each of our eleven ecological categories at multiple scales (Appendix Table 1.2). As an illustration of a benefit to using GIS, we were able to obtain habitat and impact data at most of the 7,872 locations in our fish monitoring database. As a point of comparison, matching empirical habitat data were only available at 1,679 sites (Reed 2023). Fish samples in our dataset spanned from 1925 to 2021: 51% of these samples were collected between the years of 2015-2021, 70% were collected between the years of 2010-2021, and 81% were collected



after the year 2000. Because these collections largely took place in recent years, we also used recent physical and impact GIS data. For example, the land use metrics discussed below in our proof of concept represent cover conditions from 2021. However, we include land use data across multiple years within our dataset, so other years may be explored in future iterations of the framework. Of course, land use conditions in individual years could make a difference in the fish responses, and this variation could be worth exploring. However, because most samples were concentrated in a narrow, recent time period our choice of years represents adequate, default selections.

### **General Framework Step 8: Refine General Question into Specific Statistical Questions**

Step 8 (Fig. 1.1A) breaks down our general question of interest into specific questions that can be tested in individual statistical steps (Fig. 1.1B). These focused questions (Step 8) are identified in the statistical steps below (Step 9). These specific questions provide individual project milestones and team discussion points.

### **General Framework Step 9: Quantitative & Statistical Analyses**

Step 9, our statistical sub-loop, includes six quantitative steps (Steps 9A-9F; Fig. 1.1B). Each statistical step addresses a specific statistical question from step 8 that can be answered with a single analysis. In our general framework, we used R Version 2022.12.0 for all steps [presence absence maps, proportional symbol maps, histograms, box plots, probability plots: *ggplot2* (Wickham 2016); ridgeline plots: *ggribes* (Wilke 2022); pie plots: *plotly* (Sievert 2020); correlations: *corrplot* (Wei and Simko 2021); multiple logistic regressions, *MuMIn* (Bartoń 2022); 10-K fold cross validation: *caret* (Kuhn 2022) and *tidyverse* (Wickham et al. 2019)] (R Core Team 2022). More detail for each statistical step (Steps 9A-9F) are included in the sections below.

### **General Framework Step 9A: Where are Fish Present and Absent?**

For our general framework, in statistical step 9A, we mapped presence and absence of each individual taxon to assess statewide spatial patterns, basin-specific patterns, gaps in distribution, and spatial heterogeneity (e.g., are there a few presences in a sea of absences or a few absences in a sea of presences).

### **General Framework Step 9B: At What Habitat Conditions were Fish Sampled?**

In our general framework, for this statistical step, we constructed histograms [i.e., visualizations of the frequency distribution (Y axis) for specific values of numerical data (X axis)] for each potential habitat or impact regressor across all fish samples. Statewide proportional symbol maps (i.e., maps in which symbols for target quantitative variables vary in size) were also made to visualize the distribution of habitat and impact variables across all sampling locations within our study area. Monitoring data cannot be collected everywhere for logistical reasons (e.g., time, gear issues, availability). Consequently, to interpret patterns accurately, data analysts need to assess what range of conditions were sampled. Using a hypothetical example, if a given species was caught only at stream orders  $<3$ , and stream orders  $>4$  were not sampled, limited convincing support would exist for the conclusion that this taxon was only found in smaller stream orders. Likely, no field monitoring survey can sample representative conditions everywhere, so this step aids in appropriate interpretation and can help guide future data collection needs.

### **General Framework Step 9C: What Metric and Scale Options Exist for Habitat-Impact Metrics and Scales?**

We explored how fish presences and absences varied across metrics and scales within each of our 11 ecological categories using three tools (i.e., exploratory boxplots, pie charts, and

exploratory best-subsets logistic regressions). Most GIS datasets include many metrics (i.e., measurements) for the same ecological variables. For example, in the substrate ecological category, metric options included (sand, slit, clay, and rock fragments). By using exploratory boxplots (i.e., depiction of median, minimum, maximum, and quartiles) to compare overlap between fish presence and absence sites for different metrics, we could thoughtfully prioritize which variable metric might best represent a specific ecological category. For example, if % silt differed little and % sand differed greatly in locations where fish were present compared to locations where fish were absent, % sand would be chosen as a starting metric for our ecological substrate category.

Most GIS datasets include metrics measured at multiple spatial scales. For example, GIS land use metrics can be measured at multiple scales [e.g., point, flowline, catchment, network flowline, network catchment (listed as small to large)]. Land use values can shift significantly based on the location of the sample and the scale at which the land uses are measured. Pie charts helped to visualize what land use types were found at each site where fish were sampled. With the exploratory box plots discussed above, these pie plots can inform decisions about scale priorities. For example, if differences between sites where fish were present vs absent were large at a broader geographic scale for a specific metric and reduced at a more limited geographic scale, the larger scale metric would be chosen as the most thoughtful starting metric for a specific ecological category.

The third approach we used to compare and prioritize multiple metrics within an ecological category was to use exploratory best-subsets multiple logistic regressions on (a) metrics within an ecological category and (b) metrics measured at different scales. Along with ecological expectations (Step 3), the above-described three exploratory analyses contributed a

quantitative filter that we used to systematically choose variable and scale metrics for a set of all-ecological-category, multiple logistic regressions (Step 9E). In summary, using our adaptive management framework to compare GIS metrics and scales for a specific ecological category represented an opportunity to learn more about fish taxa distribution rather than a series of tedious, unsupported guesses. Because we seek to learn something from this monitoring dataset rather than make exact predictions, as with machine learning, we are not concerned about overall or accumulated error rates.

#### **General Framework Step 9D: How Do Habitat and Impact Variables Differ Where a Fish Taxon is Present or Absent?**

For this step in our general framework, we used two types of exploratory visualizations (boxplots, and ridgeline plots) to better understand differences in habitat and impact conditions where an individual fish taxon was present compared to where the same fish taxon was absent. Box plots showed quantitative overlap in habitat and impact conditions for a specific variable for a specific fish. Ridgeline plots (i.e., partially overlapping line plots that create the impression of a mountain range) visualized the extent of overlap between fish presence and absence sites for each calculated habitat-impact across all sites.

#### **General Framework Step 9E-F: Can We Create Generalized Linear Models and Evaluate Their Quality? In the Top Models, Which Variables are Associated with Fish Presence and Absence?**

We created a set of taxa-specific, all-ecological-category, multiple logistic regression models to identify what variables might influence the probability of presence or absence of each fish taxon across Kansas. As a reminder, our goal was not to provide a definitive model or to be limited by a single measure of statistical significance. Instead, we sought to create a reasonably-

accurate, transitional model that was ecologically interpretable and consistent with patterns seen in other statistical steps (weight of evidence). From this transitional model, we identified new, relevant questions and made predictions that can be tested in a future monitoring survey. As a result, the original model can be updated and future models can be continually improved.

To create and evaluate our models (Step 9E), we followed the following process: (1) First, we selected one scale-specific metric from each ecological category based on the results of steps 9C-D. (2) Next, we balanced our dataset by randomly removing data points from the larger of the two classes (usually absences) until presences equaled absences. (3) Then, we examined correlations among model-specific regressors, and one of any highly correlated ( $P > 0.7$ ) pair was removed. (4) Next, we fit a multiple logistic regression model to uncorrelated metrics that each represented one of 11 ecological categories. (5) For top models with ( $\Delta AIC < 2$ ), we evaluated the size and direction of the parameter estimates, error size, and parameter specific P-values. (6) For regressors with  $P < 0.05$  in the top (lowest AIC) and best set of taxa-specific models ( $\Delta AIC < 2$ ), we examined probability plots to visually examine the relationship between significant regressors and fish presence and absence. We appreciate that P-values do not have an exact meaning for messy field data; here we use them to prioritize trends (Murtaugh 2014). (7) To evaluate the accuracy of the model, we applied a 10-K fold cross validation. The 10-K fold cross validation is a training and test classification approach that creates a confusion matrix to identify % correct and incorrect classifications made for both presence and absence data points (Manorathna 2020). (8) Finally, we calculated the  $D^2$  statistic for each top model to observe the amount of variance that the model explained (*stats*; R Core Team 2022). We appreciate that many ways exist to analyze presence-absence data and many ways exist to select and evaluate regressors for multiple regressions. We believe our approach is sound, but it is certainly not the

only approach. We recommend additional iterations of the framework to test alternate analyses (e.g., random forest), evaluate different ways of balancing datasets, assess the impact of adding interactions among variables, as well as considering other statistical options.

### **General Framework Step 10: Summarize (Interpretation, Synthesis), Identify Information Gaps, Formulate New Relevant Questions, and Make Testable Predictions**

Step 10, possibly the most important step in our framework, is to summarize what was learned from statistical steps 9A-9F (via the weight of evidence), identify areas where more information is needed, formulate relevant new questions, and compile testable predictions. As a result, output from our reasonably-accurate, transitional model guides future sampling, provides a stepping-stone to building and testing more informative models, and can inform restoration and regulation decisions. This step is what connects past, present, and future datasets together and allows us to learn about the taxa and system. Iterations continue until researcher-manager teams judge that enough is known. The proof of concept we walk through below is just one simplified representation of the kind of information that can be uncovered and accumulated through our framework.

## **Results**

### **Objective 2 – Proof of Concept**

#### **Steps 1-2: Identify and Prioritize a General Question, Choose Taxa and Scale for Fish**

For the proof of concept that illustrates how our framework works, we continue to focus on the general question of “*if, when, and why might a specific fish taxon be present or absent at specific locations?*” For our proof of concept, we have chosen the Emerald Shiner as our target taxa and the Kansas-wide distribution as our scale. The Emerald Shiner has a wide US distribution (Page and Burr 2011), is an ecologically important fish in many aquatic food webs

(Etnier and Starnes 1993), has some physical habitat preferences but also occurs in diverse habitats (Distler et al. 2014), and is relatively common and stable across Kansas (i.e., 1,131 presences). We chose this fish because Emerald Shiner is in the middle of rare and common target taxa based on number of presences in our database (Table 1.1; seven more common taxa, seven less common taxa). The steps outlined in this section (Steps 1-4, 9-10) build on information described in our general framework above. Steps 5-8 are the same as those described above.

### **Step 3: Review Relevant Literature**

For our proof of concept, we review the expectations for Emerald Shiner habitat use and response to impacts from the literature (Table 1.3). A goal of our framework and adaptive management in general is to build on what is known. To build on what we know, we must first establish a general consensus of knowledge to which we can compare multiple logistic regression model results and assess information gaps. As stated previously, our goal is to learn something about the focal fish taxa and not to demonstrate that our expectations are correct or incorrect.

**Step 3 - Flow (Ecological Category 1).** Few stream flow preferences (velocity and discharge) are documented in the literature for Emerald Shiner. Although they can be abundant in lacustrine, reservoir conditions (NatureServe 2023), in Kansas streams these fish have been found in areas of moderate current (Cross 1967). Thus, for lotic systems, we expect that Emerald Shiner will be more likely to be present at sites with moderate flow and absent from sites with extreme values (Table 1.3 – Row 1).

**Step 3 - Substrate (Ecological Category 2).** The literature on Emerald Shiner reports that although these fish can exhibit broad substrate preferences, in Kansas they are most

abundant over sand beds (Cross 1967; Boschung and Mayden 2004). Thus, we expect that Emerald Shiner presence will peak with sand and decline as substrate size increases (Table 1.3 – Row 2).

**Step 3 - River size (Ecological Categories 3, 4, 5).** Emerald Shiner is reported to be a big-river fish (Distler et al. 2014; Haupt and Phelps 2016; NatureServe 2023), but they can be found in a wide variety of depths (Becker 1983; Distler et al. 2014; Haupt and Phelps 2016). Little information exists on the effect of stream width and catchment size for Emerald Shiner. Based on generalizations of the common assertion about river size, we expect that the probability of Emerald Shiner presence will increase with increasing stream order, stream width, stream depth, and catchment size (Table 1.3 – Rows 3, 4A, 4B, 5).

**Step 3 - Sinuosity (Ecological Category 6).** Few associations between fish taxa and sinuosity (curviness measured as the ratio of thalweg to valley lengths) are reported in the literature. Hence, there are no established expectations about this variable. However, Emerald Shiner are reported in runs and channels of rivers (Jenkins and Burkhead 1994), which can lack sinuosity (Minnesota DNR 2006). Therefore, one expectation might be that Emerald Shiner presence could decrease as sinuosity values increase (Table 1.3 – Row 6).

**Step 3 - Land Use Impacts (Ecological Categories 7-9).** The conventional wisdom is that native prairie fish will be adversely affected by agricultural land use (Lange et al. 2014) and anthropogenic activity such as human developments (Jenkins and Burkhead 1994). Based on these generalities, we expect that Emerald Shiner presence in Kansas will decline as agricultural land use and developed land cover increase (Table 1.3 – Rows 7, 8). No data on Emerald Shiner and natural land use exists in the literature, but these common fish do occur in streams in heavily



populated areas. For this reason, multiple outcomes could be possible for Emerald Shiner related to natural land use (Table 1.3 – Row 9).

**Step 3 - Dam Proximity (Ecological Category 10).** Dams adversely affect many stream fish (Barbarossa et al. 2020), but the literature on Emerald Shiner and dams is mixed. Dams are reported to create a negative reduction in flow and a positive reduction in turbidity (Pflieger and Grace 1987; Cross and Collins 1995). As a result, we expect that Emerald Shiner presence and absence will not follow a consistent response to dam proximity (Table 1.3 – Row 10).

**Step 3 - Gradient (Ecological Category 11).** In Kansas rivers, Emerald Shiner have been caught at low to moderate gradients (i.e., the change in longitudinal elevation per unit distance; Cross 1967; Jenkins and Burkhead 1994). Thus, we expect the trend line for this variable will decrease as gradients increase near higher values (Table 1.3 – Row 11).

**Steps 4 – 8: Clean and Vet Datasets, Choose Fish-Relevant Habitat and Impact Variables, Wrangle Regressor Data from Existing GIS Databases, Refine General Question into Specific Statistical Questions**

For these steps, we followed the guidance identified in the general framework section above.

**Step 9A: Where are Fish Present or Absent?**

Emerald Shiner were widely distributed across the state of Kansas (presence=1,131 samples at 903 unique locations, absence=7,713 samples at 7,076 unique locations) (Figure 1.3). These fish were present most often at sampling sites in the Northeastern and South-Central regions. They were almost entirely absent from watersheds in the western third of the state. They frequently occurred in the Lower Arkansas ( $n=696$  samples) and Kansas-Lower Republican ( $n=354$  samples) river basins (Fig. 1.3). They were uncommon in the Missouri ( $n=27$  samples),

Marais Des Cygnes ( $n=16$  samples), Walnut ( $n=11$  samples), Cimarron ( $n=8$  samples), Neosho ( $n=8$  samples) and Smoky Hill-Saline ( $n=8$  samples) river basins. There was only one record of occurrence in the Upper Arkansas, Solomon, and Verdigris river basins, and they were completely absent from the Upper Republican river basin. Thus, the geographic pattern of this common and stable fish differed dramatically across regions with patchiness within the regions that Emerald Shiner inhabits.

### **Step 9B: What Habitat Conditions are Found in Our Study Area?**

We examined the frequency distributions of all metrics prioritized in our Emerald Shiner taxa-specific models using histograms (Figure 1.4A-B; Appendix Figure 1.1) and proportional symbol maps (Figure 1.5A-B, Appendix Figure 1.2). As an example of conditions where fish were sampled, here we show two substrate metrics. Using histograms, high loads of silt were found statewide with most sites exhibiting  $> 40\%$  (Fig. 1.4A). Some sand was present at all sites sampled for fish, but sites with low ( $\sim 10\%$ ) and moderate ( $\sim 60\%$ ) amounts of sand were much more commonly sampled than sites with partial ( $\sim 30\%$ ) or very high ( $> 90\%$ ) amounts of sand (Fig. 1.4B). For proportional symbol maps, large, royal blue circles indicate high amounts of the target substrate. Using these maps, geographically, high percentages of silt were found in the entire Eastern third of the state, as well as the northern half of the Central and Western regions (Fig. 1.5A). High percentages of sand were most common in the mainstem of the Kansas-Lower Republican river basin, located in the northeast region of the state, and the Lower Arkansas River basin located in the south-central portion of the state (Fig. 1.5B). Emerald Shiner presences and absences (Fig. 1.3) show a high density of presence sites in the basin where there are high sand percentages (Kansas-Lower Republican and Lower Arkansas river basins; Fig.

1.5B). However, the Kansas-Lower Republican River Basin also has high percentages of silt (Fig. 1.5A).

### **Step 9C: What Metric and Scale Options Exist for Habitat-Impact Variables?**

We examined all metrics and all scales in each ecological category as they related to Emerald Shiner presence and absence. Here, we illustrate two examples of variation across metrics and scales for the ecological categories: substrate and natural land cover. Using exploratory pie plots at the catchment scale, one type of substrate (sand,  $n=45.5\%$ ) made up the largest substrate slice at sites where Emerald Shiner were sampled (Figure 1.6A). Pie plots at the entire network catchment scale, showed that one type of natural land use (grassland,  $n=44.5\%$ ), made up the largest proportion of land use at sites where Emerald Shiner were present (Fig. 1.6B; note: human-modified land use is also common - agriculture,  $n=35.3\%$ ). Consequently, we used an exploratory graphical analysis to compare three scales (point, flowline, catchment) for substrate metrics (Figure 1.7A-O) and five scales (point, flowline, catchment, network flowline, network catchment) for natural land metrics (grassland cover, natural cover) (Figure 1.8A-J). Land use metrics (agriculture, development, natural) were sourced from two GIS databases (NLCD, CDL) to prioritize metrics in these ecological categories. When substrates were plotted at multiple scales against Emerald Shiner presence and absence, two metric scales for two substrate-types stood out. These were sand measured at the flowline and catchment scale (Fig. 1.7G, H), and silt measured at the flowline and catchment scale (Fig. 1.7J, K). When natural land at multiple scales was plotted against Emerald Shiner presence and absence, two metric scales stood out from two databases. These were grassland cover at the catchment scale (CDL; Fig. 1.8G) and natural cover at the flowline scale (CDL; Fig. 1.8I). Each of these metrics above exhibited the least overlap between presence and absence values of Emerald Shiner. As a result,

these two-substrate metrics and two natural land use metrics at medium and large scales were prioritized for use in our all-ecological-category multiple logistic regression model for Emerald Shiner (Step 9E).

#### **Step 9D: How Does Habitat Differ Where Fish are Present or Absent?**

We used ridgeline plots to quantitatively compare habitat-impact conditions where Emerald Shiner were present or absent (Figure 1.9A-C) (Appendix Figure 1.3). As an example, here we show ridgeline plots for two substrate metrics (silt, sand), and one stream size metric (stream order). Emerald Shiner were present at sites with low silt, and absent from sites with higher percentages (Fig. 1.9A). However, they appeared to tolerate silt overall, as we can observe by their presence across all silt conditions (Fig. 1.9A). Emerald Shiner displayed the opposite trend for sand proportions, with presences at sites with high sand, and absence at sites with lower percentages (Fig. 1.9B). In the ridgeline plot for stream order, we could observe Emerald Shiner presence in stream orders 7-8 and primarily absence in stream orders < 6 (Fig. 1.9C). Worth noting is that quantitative patterns (histograms), geographic patterns (maps), and statistical tests (Step 9F) can show different views of the same data that can enhance or obscure understanding. Looking for consistency across data visualizations and analyses via a weight of evidence approach can boost confidence in analysis results.

#### **Step 9E - F: Can We Create Models and Evaluate Their Quality? In Top Models, Which Variables are Associated with Fish Presence and Absence?**

Two of the six models that used a single uncorrelated metric from each ecological category had a  $\Delta AIC < 2$  (Table 1.4, Model A, B, AIC 2303, 2304,  $\Delta AIC=1$ ). The top model predicted presence and absences with 74% accuracy, i.e., of 1,067 presences, 809 samples were correctly identified (Table 1.5 – A, B). The  $D^2$  suggested that our top model explained 23% of

the variation between the balanced sample classes for Emerald Shiner (Table 1.5 – C). All flow variables, one reach measure [width], and one type of natural land use, were removed because they were highly correlated with other regressors. Correlated substrates and land use types were tested in separate models (Figure 1.10). The randomization used to balance presence and absence sample sizes did not change mean values substantially (Table 1.6). These two best models had five significant regressors that represented the same ecological categories ( $P < 0.05$ ; Table 1.4). Significant variables in the two top models included (1) silt substrate, (2) stream order, (3) sinuosity, (4) a type of agricultural land use (pasture cover or cultivated crop cover), and (5) natural grassland land cover.

For the substrate ecological category, in both top models, surprisingly, an increase in silt decreased the probability that Emerald Shiner would be present at a site ( $\beta = -0.04, -0.03$ ; Table 1.4; Figure 1.11A). Albeit not in the top two models, as expected, a significant increase in sand increased the probability of Emerald Shiner being present at a site (Table 1.4; Fig. 1.11B). In both top models, as expected, as stream order increased so did the likelihood of Emerald Shiner being present ( $\beta = 0.19, 0.18$ ; Table 1.4, Fig 1.11C). In both top models, the probability of Emerald Shiner presence was inversely related to sinuosity ( $\beta = -0.09$ ; Table 1.4; Fig. 1.11D). In both top models, as expected, a type of agricultural land use adversely affected Emerald Shiner. In the second-best model, pasture cover was inversely related to the probability of Emerald Shiner being present ( $\beta = -0.01$ ; Table 1.4; Fig. 1.11E). In the top model, the percentage of cultivated crops was also inversely related to the probability of Emerald Shiner being present ( $\beta = -0.01$ ; Table 1.4; Fig. 1.11F). Surprisingly, the percent of natural grassland cover also decreased the probability of Emerald Shiner being present at a site ( $\beta = -3.03$ ; Table 1.4; Fig. 1.11G). Clay, catchment size, developed land, total distance to a mainstem dam (TM2D), and

gradient were never significant in top models (Table 1.4). Sand and silt were never in the same model (Table 1.4).

### **Step 10: Summarize (Interpretation and Synthesis)**

The interpretation and synthesis of our results (i.e., from maps, exploratory data, generalized linear models, literature) can be classified into four categories. (1) Variables responded as we expected. (2) Variables did not respond as we expected, but which we could understand by looking at other data. (3) Variables appear to be potentially important although we had no expectations. (4) Variables did not trend as we expected. All four of these categories can provide useful and useable actionable science that identifies information gaps, poses new questions, and makes testable predictions. Below, we first interpret results for each variable (Step 10A – Interpretation), then, we address gaps, questions, and predictions (Step 10B – New directions).

**Step 10A Interpretation - Category 1 - What We Expected.** Several variables trended as expected. We expected the observed positive relationship between stream order and the probability of Emerald Shiner presence (Fig. 1.11C). Emerald Shiner is considered a big river fish (Distler et al. 2014; Haupt and Phelps 2016). The adverse effect that both types of agricultural land had on Emerald Shiner was also expected. In our analysis, both pastureland (Fig. 1.11E) and cultivated crops (Fig. 1.11F) produced similar, negative trends even though these two human-altered land uses represent very different types of agriculture. Cultivated crops include any land that is used for annual crop production such as wheat, corn, sorghum and soybean (Danielson et al. 2016; Laird 2022). Pasture and hay agricultural land include grass monocultures and can be associated with livestock grazing (Broom 2019). We were not surprised

at the lack of significance for developed land and gradient as Kansas is a low elevation, rural state.

**Step 10A Interpretation - Category 2 - Not What We Expected But Understandable.**

Substrate is an example of a variable that did not trend as expected, but which we can understand better by looking at additional data. We expected that Emerald Shiner would be positively associated with sand substrate (0.05mm to 2.0mm; Fig. 1.11B; Cross 1967; Boschung and Mayden 2004), yet we found this taxon was negatively associated with silt substrate (0.002 to 0.05mm; Fig. 1.11A). Silt was highly and inversely correlated to sand (Fig. 1.10). Proportional substrate maps show that silt is common throughout Kansas (Fig. 1.5A), but high levels of sand are patchily distributed (Fig. 1.5B), and generally correspond to the basins in which Emerald Shiner are found (Kansas-Lower Republican and Lower Arkansas; Fig. 1.3). These complex spatial patterns can make consistent statistical interpretations difficult.

**Step 10A Interpretation - Category 3 - New Avenues for Investigation.** Sinuosity (significant) and dams (not significant) are examples of regressors for which more information could benefit conservation. Sinuosity is a habitat variable about which we know little, but which could be relevant to understanding the relationship between instream habitat features and lotic fish distribution. In our analyses, the probability of Emerald Shiner presence was inversely related to sinuosity (Fig. 1.11D). Emerald Shiner school in stream channels or runs (Jenkins and Burkhead 1994), which are more common in straighter, non-sinuuous locations. Hence, a useful relationship might exist between sinuosity and physical microhabitat and macrohabitat.

**Step 10A Interpretation - Category 4 - Puzzlers.** The literature we assessed for Emerald Shiner did not include expectations of how this taxon might respond to natural land cover. In a generalization that reversed expectations about negative effects of human impacts, we

expected either a neutral or weak positive relationship between natural land use and Emerald Shiner. However, we found a strong inverse relationship with grassland cover (Fig. 1.11G), a trend for which we have no immediate explanation.

**Step 10B New Directions (Identify Gaps).** Our results point the way to additional questions that can increase the precision of expected trends if additional relevant data were collected and analyzed. Because Emerald Shiner are stable in their Kansas distribution, future directions for this taxon might not be of especial interest to managers, but the methodology by which future directions are developed from framework data can be of broad conservation interest. Examples of new questions that emerge from this first iteration of our framework relative to physical river size and geomorphology of instream habitats include the following. (i) Can a better understanding and more detailed quantification of channel morphometry (width vs depth within an order) help predict the presence and absence of Emerald Shiner and other prairie stream fish? (ii) Can sinuosity provide a link to instream habitat features (deep pools, channels, drop-offs, sand bars) that can predict Emerald Shiner and other prairie stream fish distribution?

**Step 10B New Directions— New Questions That Enhance What We Know.** Many prairie stream fish are linked to specific substrate conditions in the literature (e.g., Cross 1967; Boschung and Mayden 2004). For Emerald Shiner, silt can be an indicator of an unsuitable substrate. Alternatively, silt can contribute to turbidity, which can impair foraging success of sight feeders like the Emerald Shiner (Pflieger and Grace 1987). Sedimentation has led to population decline for Emerald Shiner in various portions of its range (Jenkins and Burkhead 1994). While the literature mentions that sedimentation and turbidity are drivers of Emerald Shiner decline, it does not include silt load in any description of threats (Jenkins and Burkhead



1994; Distler et al. 2014). Thus, some (but not all) of our expectations about substrate were supported by our weight of evidence results.

For prairie fish-substrate relationships, why is there a consistent disconnect between the importance of an assumed relationship and related empirical support? Perhaps, our conceptual framework for fish-substrate relationships is incomplete or flawed. Or perhaps we are not sampling and analyzing substrate effectively. Instead of just asking for a simple association between fish and one type of substrate, perhaps we need to investigate thresholds and links between substrates and geographic associations. Examples of questions that have emerged that can guide future sampling and analyses for substrate follow. (i) What is the minimum percentage of sand (and other substrate types) that Emerald Shiner and other native prairie fish need? (ii) Is there a silt load tipping point where Emerald Shiner and other prairie stream fish populations begin to fall off, since they often are tolerant of moderate levels of turbidity? (iii) Are sand habitats more common in the basins where these fish are common (e.g., Kansas-Lower Republican and Lower Arkansas river basins)?

**Step 10B – New Directions – New Questions that Address Puzzlers.** Fisheries professionals need more information on complex interactions between basin location, percentages of different land use types, and fish distribution. In general, the literature regarding land use and prairie stream fish is very thin. Our land use metrics exhibit more complexity than other metrics. Future field tests on isolated and aggregated land use types, site-specific land use patterns, spatial arrangement of land use patches, and future analyses of correlations between land use and more direct drivers of fish distribution could yield useful information. Examples of questions that could yield useful information from future samples include the following. (i) Does natural land use have adverse effects on Emerald Shiner and other prairie fish (and why) or is

this land use classification just an amalgamation of land use types that have different effects? (ii) Does crop land necessarily have more dewatering, fragmentation, and barriers that would adversely affect Emerald Shiner and other prairie stream fish? Overall, a number of information gaps, new questions, and testable predictions have been identified in this first iteration of our framework.

## **Discussion**

### **Objective 3 – Gaps, Benefits, Utility and Next Steps**

#### **Critical Role of Monitoring Data and the Need for Additional Tools to Extract Insights**

Monitoring data are uniquely useful for fish conservation because they provide a rare big picture assessment of resource distribution. However, monitoring datasets are often underused because these datasets have high variability, making meaningful statistical analysis challenging. Approaches and tools for the effective use and analysis of monitoring data differ from those used for research data. Below, we review five major take home messages that show how systematically and consistently using a methodology that meshes with the unique features of a monitoring database can accumulate new information.

#### **Take Home Message 1. An Implementable Adaptive Management Framework is Useful**

Our framework is an example of an implementable adaptive management (AM) approach for biodiversity monitoring that can accumulate learning through multiple iterations of the framework. Elsewhere, AM has been proposed as a helpful tool for planning multifaceted projects (McFadden et al. 2011; Rist, et al. 2013, Rohweder 2022). Unfortunately, outside of harvest models, relatively few discussions of adaptive management provide detailed, implementable steps for specific resource management problems (Fontaine 2011; Rist et al. 2013). What is needed is an AM plan that (a) can facilitate learning new insights from existing

monitoring data, (b) can be repeated for additional data sets in a standardized way to accumulate insights across analyses and data sets, and (c) that can guide future data collection (Armitage et al. 2008, 2009). The accuracy of our all-ecological-category multiple logistic regression model for Emerald Shiner was quite high suggesting we had a strong model that provided much information about influential regressors. Yet, the important contribution of our approach is not the output of a single statistical model, but the ability of our framework to build on existing results through new iterations that (a) add new fish data, (b) only focus on empirical data, (c) only focus on a specific basin or year, (d) test other habitat and impact regressors, (e) add biotic regressors (i.e. invasive species, predators, species richness), (f) examine interactions among regressors, (g) balance presence and absence sites using different selection methods, and (h) include other analytical approaches (e.g., random forest).

## **Take Home Message 2. Identifying Testable Future Questions is a Game-Changer**

Identifying data gaps and testable future questions that guide future data collection are the keys that allow our framework to link past, present, and future data. Asking a series of questions for which the data-based answers are systematically summarized is a powerful way to use monitoring data. Being realistic about expectations for what can be achieved in a single iteration of the framework is critical. However, our results illustrate the potential for adding new information through multiple framework iterations using focused, connected, and tractable individual projects. As one example, we learned much about the spatial distribution of Emerald Shiner, but our distribution maps also raised testable questions about prominent spatial gaps, i.e., why is this fish primarily restricted to the Kansas-Lower Republican and Lower Arkansas river basins? Is this distribution related to preferred sand substrate? In contrast to our approach, a more traditional reporting of the results of large-scale species distribution models with unwarranted

certainty, based on a rigid adherence to specific statistical significance thresholds, can be counterproductive. This inflexible approach to summarizing monitoring data can lead to disagreements among data analysts, may limit collaboration, and can stymie the development of future directions. Our framework is an evolving process in which insights from the framework can be tested in the field. As a result, pretty good models (with high accuracy from a confusion matrix) are constantly improved by data collected in future cycles. In summary, the important outputs of our framework approach are (a) what is learned, (b) what relevant new data should be collected, and (c) how can models be improved, rather than (d) is the model right or wrong. This perspective changes the expectations of monitoring data and analysis and results in more realistic planning.

### **Take Home Message 3. A Weight of Evidence Approach Works Well for Monitoring Data**

A weight of evidence approach has advantages for conservation when used with monitoring datasets. Our framework integrated results from (a) fish and variable maps, (b) multiple exploratory analyses (e.g., pie charts, box plots, variable importance maps, ridgeline plots), (c) statistical models (multiple logistic regression, probability plots, confusion matrices that estimate model accuracy), and (d) existing literature. As an example, using the weight of evidence, we developed an approach that prioritized metrics and scales within an ecological category. This prioritization helped select regressors for our model, taught us something about how these regressors vary, and illustrated relationships between the regressors and the fish of interest. For example, we found that both much useful information and much complexity existed in site-specific land use variables and related interactions with scale. Thus, more can be learned from future data analysis experiments that compare metrics and scales using our standardized

process. Many data analysts use one or more of the visualization and analysis tools we propose here, but our structured process provides a systematic way of integrating all of these analyses.

#### **Take Home Message 4. Gaining Answers and Raising New Questions are Both Important Parts of the Process**

Our expectation is that for every general question of interest, a team of fisheries professionals will go around our framework multiple times. We learned many things about Emerald Shiner and other fish of interest, yet fish conservation professionals can still benefit from examining new questions raised about GIS metrics and fish taxa of interest. As an example, dams are complex variables, which most fisheries professionals assume have adverse effects. However, there is relatively little published information about mechanisms by which dams harm non-migratory fish. Nor is there clear guidance in the literature about which metrics might best detect the stress that dams inflict on prairie fish. We used a detailed database of dam metrics that has recently been made available (Ostroff et al. 2013). Although we did not find specific dam impacts for Emerald Shiner, a more detailed testing of the impacts of multiple dam metrics for this and other fish would be useful. Specifically, what is the effect of dam proximity, number, density? Does the direction of dam location relative to the fish sample site matter (upstream or downstream)? Which scales of dam effects are consistently more influential (local or watershed)? How do different fish respond to these dam metrics? Are there accumulated and interactive effects? GIS provides a pathway for testing these questions which could help direct future sampling. Our framework provides a system for getting this information.

#### **Take Home Message 5. How Can Our Framework Be Used By Fisheries Teams (Managers and Researchers)?**

Our framework provides a new way that teams of fisheries professionals can interact to strategize about what information is needed and plan for future field seasons. Environmental problems are rarely straightforward, and they often involve complicated interactions between natural systems, human dimensions, and social and economic influences (NRC 1996; Biber 2013, Burke et al. 2017). Real time data analysis conducted in a professional group setting can lead to useful conversations about priorities (Mather et al. 2023). In the future, a plug and play computerized version of the framework with a dashboard of appropriate data layers could provide regular opportunities for teams of researchers and managers to collaboratively engage in data-driven discussions about future monitoring, research, restoration/stocking initiatives, and management decisions. Our adaptive framework can introduce a different way to address present and future grand conservation challenges.

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## Tables

**Table 1.1.** Fish taxa chosen for the general framework. Columns include: (1) Focal taxa by common name, (2) Conservation status within Kansas [Stable, Species in Need of Conservation (SINC), Threatened or Endangered (T&E)]; conservation status within Kansas, (3) State Wildlife Action Plan Priority ranking (N/A, Tier I, Tier II). and (4) The number of site records per taxa used in our analysis. The taxon we use as our proof of concept is Emerald Shiner.

| Focal Taxa - Common Name  | Conservation Status (KS,<br>Federal)     | SWAP Prioritization | Fish Site Records (#) |
|---------------------------|------------------------------------------|---------------------|-----------------------|
| Banded Darter             | SINC                                     | SGCN – Tier II      | 107                   |
| Blue Catfish              | Stable                                   | N/A                 | 723                   |
| Blue Sucker               | SINC                                     | SGCN – Tier II      | 271                   |
| Brassy Minnow             | SINC                                     | SGCN – Tier II      | 480                   |
| Bullhead Minnow           | Stable                                   | N/A                 | 1914                  |
| Central Stoneroller       | Stable                                   | N/A                 | 3251                  |
| Emerald Shiner            | Stable                                   | N/A                 | 1131                  |
| Freshwater Drum           | Stable                                   | N/A                 | 1367                  |
| Longnose Gar              | Stable                                   | N/A                 | 933                   |
| Neosho Madtom             | Threatened (KS),<br>Threatened (Federal) | SGCN – Tier I       | 177                   |
| Northern Plains Killifish | Stable                                   | SGCN – Tier II      | 1337                  |
| Orangespotted Sunfish     | Stable                                   | N/A                 | 2159                  |
| Plains Minnow             | Threatened (KS)                          | SGCN – Tier I       | 750                   |
| Red Shiner                | Stable                                   | N/A                 | 4890                  |
| Topeka Shiner             | Threatened (KS),<br>Endangered (Federal) | SGCN – Tier I       | 341                   |

**Table 1.2.** The database name, source, citation, and metrics used for each GIS database that we used to wrangle habitat and impact data for our framework.

| Name of Database                                         | Source                                                                                          | Citation & Year            | Metrics Used                                                                                                                           |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| National Hydrography Database Plus Volume 2 (NHDPlus V2) | United State Environmental Protection Agency (EPA),<br>United States Geological Survey (USGS)   | NHDPlus V2 2019            | Flow (Discharge and Velocities),<br>Stream Position (Order), Sinuosity<br>Gradients, Reach Measures (Width,<br>Depth), Catchment Sizes |
| CropScape - Cropland Data Layer (CDL)                    | United States Department of Agriculture (USDA): National Agricultural Statistics Service (NASS) | Han 2015-2021              | Land Use (Agriculture, Natural,<br>Developed)                                                                                          |
| Soil Survey Geographic Database (SSURGO)                 | United States Department of Agriculture (USDA): Natural Resources Conservation Service (NRCS)   | Soil Survey Staff<br>2022  | Substrates                                                                                                                             |
| National Land Cover Database (NLCD)                      | United States Geological Survey (USGS)                                                          | Dewitz 2021;<br>NLCD 2019  | Land Use (Agriculture, Natural,<br>Developed)                                                                                          |
| National Anthropogenic Barrier Dataset (NABD)            | United States Geological Survey (USGS), United States Army Corp of Engineers (USACE)            | USGS 2013;<br>Ostroff 2013 | Dam Metrics                                                                                                                            |

**Table 1.3.** Literature review for habitat and impact associations of Emerald Shiner. Included are ecological category, numerical value, description, expected trend from the literature and a possible trend noted by the authors. ? = no information for Kansas. Citation: Web of Science<sup>1</sup>, NatureServe<sup>2</sup>, Kansas Fishes<sup>3</sup>

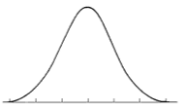
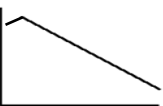
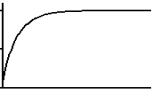
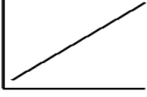
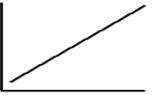
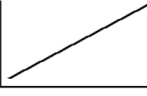
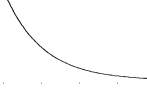
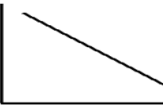
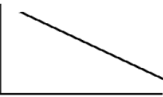
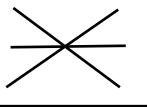
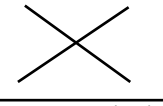
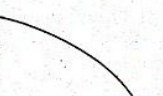
| #  | Ecological Category           | Emerald Shiner Literature                                                           |                                                                                                                    |                                                                                                              | Possible Trend                                                                        |
|----|-------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|    |                               | Value                                                                               | Description                                                                                                        | Expected Trend                                                                                               |                                                                                       |
| 1  | Flow (Discharge and Velocity) | Age 0 fish: (<0.6 m/s) <sup>1</sup>                                                 | Moderate current (but can thrive in lacustrine conditions) <sup>3</sup>                                            | <br>non reservoir sites   |                                                                                       |
| 2  | Substrates                    | ?                                                                                   | Sandy (but tolerant of many kinds) <sup>3</sup> , silt - rock <sup>1</sup> , typically sand or gravel <sup>2</sup> |                           |                                                                                       |
| 3  | Stream Order                  | ?                                                                                   | Large rivers <sup>3</sup> , medium-large <sup>2</sup>                                                              |                           |                                                                                       |
| 4A | Reach Measures - Stream Width | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |    |
| 4B | Reach Measures - Stream Depth | Age 0: Avg. <1.5, Range: 1-3 (m) <sup>1</sup> , Lake spawning: 2-6 (m) <sup>2</sup> | Can be found in shallow and deep water <sup>2,3</sup>                                                              |                          |                                                                                       |
| 5  | Catchment Area                | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |  |
| 6  | Sinuosity                     | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |  |
| 7  | Land Use - Agriculture        | ?                                                                                   | Sedimentation and water withdrawal (irrigation) cause declines <sup>3</sup>                                        |                         |                                                                                       |
| 8  | Land Use - Development        | ?                                                                                   | Pollution has led to imperilment in some populations <sup>3</sup>                                                  |                         |                                                                                       |
| 9  | Land Use - Natural            | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |  |
| 10 | Dams (Proximity)              | ?                                                                                   | Impoundments cause decline (flow regulation) or increase (reduce turbidity) <sup>2,3</sup>                         | <br>non reservoir sites |                                                                                       |
| 11 | Gradient                      | ?                                                                                   | Low gradient <sup>3</sup> , low-moderate <sup>2</sup>                                                              |                         |                                                                                       |



**Table 1.4.** The top 6 multiple logistic regression models for Emerald Shiner. Each model includes 1 non-correlated, prioritized variable from each ecological category. Columns include model identifier, parameter estimate and standard error for 11 regressors, and  $\Delta$  AIC. Models are listed in order of descending AIC. Models A, B have a  $\Delta$  AIC < 2 and are both considered top models. Metrics that were significant ( $P < 0.5$ ) are **bolded** and underlined. Regressors include Catchment scale silt (%), catchment scale sand (%), catchment scale clay (%), stream order, average sinuosity for the flowline in which the fish was sampled, catchment area, catchment scale pasture cover (%), catchment scale cultivated crop cover (%), developed land cover (%), catchment scale grassland cover (%), total distance to adjacent upstream and downstream dams, and gradient.

| Models | Coefficients - Habitat and Impact Metrics |                |          |    |          |      |       |                     |                          |                         |                      |                           |             |      |          |                           |                  |      |               |      |                   |      |              |      |        |       |       |       |
|--------|-------------------------------------------|----------------|----------|----|----------|------|-------|---------------------|--------------------------|-------------------------|----------------------|---------------------------|-------------|------|----------|---------------------------|------------------|------|---------------|------|-------------------|------|--------------|------|--------|-------|-------|-------|
|        | NHDPlus<br>Flow (CFS<br>or FPS)           | Substrates (%) |          |    |          |      |       | Stream<br>Order (#) | Reach<br>Measures<br>(m) | Catchment<br>Area (km²) | Average<br>Sinuosity | Agricultural Land Use (%) |             |      |          | Developed<br>Land Use (%) | Natural Land (%) |      | Dams          |      | Gradient<br>(m/m) |      |              |      |        |       |       |       |
|        | Emerald Shiner                            |                |          |    |          |      |       |                     |                          |                         |                      |                           |             |      |          |                           |                  |      |               |      |                   |      |              |      |        |       |       |       |
|        | Prioritized Metrics                       |                |          |    |          |      |       |                     |                          |                         |                      |                           |             |      |          |                           |                  |      |               |      |                   |      |              |      |        |       |       |       |
|        | Silt (C)                                  |                | Sand (C) |    | Clay (C) |      | Order |                     | Area (N)                 |                         | Sinuosity (F)        |                           | Pasture (C) |      | Crop (C) |                           | All Types (C)    |      | Grassland (C) |      | TM2D (km)         |      | Gradient (F) |      |        |       |       |       |
|        | β                                         | SE             | β        | SE | β        | SE   | β     | SE                  | β                        | SE                      | β                    | SE                        | β           | SE   | β        | SE                        | β                | SE   | β             | SE   | β                 | SE   | β            | SE   |        |       |       |       |
| A      | -0.04                                     | 0.00           |          |    |          |      | 0.19  | 0.05                |                          |                         | 0.00                 | 0.00                      | -0.09       | 0.04 |          |                           | -0.01            | 0.00 | -0.33         | 0.27 | -3.03             | 0.32 | 0.00         | 0.00 | -9.91  | 20.26 |       |       |
| B      | -0.03                                     | 0.00           |          |    |          |      | 0.18  | 0.05                |                          |                         | 0.00                 | 0.00                      | -0.09       | 0.04 | -0.01    | 0.01                      |                  |      | -0.07         | 0.24 | -2.63             | 0.28 | 0.00         | 0.00 | -6.08  | 19.98 |       |       |
| C      | NA (corr)                                 |                |          |    | 0.02     | 0.00 |       |                     | 0.18                     | 0.05                    | NA (Corr)            |                           |             |      | -0.09    | 0.04                      |                  |      | -0.01         | 0.00 | -0.39             | 0.27 | -2.94        | 0.32 | 0.00   | 0.00  | -8.42 | 19.81 |
| D      |                                           |                |          |    | 0.02     | 0.00 |       |                     | 0.18                     | 0.05                    | 0.00                 | 0.00                      | -0.10       | 0.04 | -0.01    | 0.01                      |                  |      | -0.12         | 0.24 | -2.53             | 0.28 | 0.00         | 0.00 | -5.02  | 19.64 |       |       |
| E      |                                           |                |          |    |          |      | -0.03 | 0.01                | 0.23                     | 0.05                    | 0.00                 | 0.00                      | -0.16       | 0.04 | -0.02    | 0.01                      |                  |      | -0.19         | 0.23 | -2.13             | 0.26 | 0.00         | 0.00 | -10.20 | 19.52 |       |       |
| F      |                                           |                |          |    |          |      | -0.04 | 0.01                | 0.25                     | 0.05                    | 0.00                 | 0.00                      | -0.15       | 0.04 |          |                           | -0.01            | 0.00 | -0.45         | 0.26 | -2.50             | 0.30 | 0.00         | 0.00 | -11.10 | 19.52 |       |       |

**Table 1.5.** For the model with the lowest AIC (Table 1.4 – Model A), shown are (A) The output of our 10-fold cross validation confusion matrix that identifies how accurately the model predicted. (B) Accuracy values show the precision of the classifier or prediction model. (C)  $D^2$  demonstrates the proportion of deviance accounted for by the input model predictions.

| <b>A.</b>                                       |           |     |
|-------------------------------------------------|-----------|-----|
| 10-Fold Cross<br>Validation Confusion<br>Matrix | Reference |     |
|                                                 | 0         | 1   |
| 0                                               | 767       | 258 |
| Prediction                                      |           |     |
| 1                                               | 300       | 809 |

| <b>B.</b>                   |                     |                  |
|-----------------------------|---------------------|------------------|
| Cross Validation<br>Output: | Accuracy: 0.7385328 | Kappa: 0.4770176 |

| <b>C.</b>       |                 |
|-----------------|-----------------|
| $D^2$ Function: | $D^2$ : 0.22862 |

**Table 1.6.** Changes in regressor means that resulted from the randomization process undertaken to balance presences and absences. Shown are the metric, total observation mean, the mean when absences were randomly reduced until the number of sites where fish were present equaled the number of sites where fish were absent.

| Significant Metric in Emerald Shiner Final<br>Predictive Model(s): | Metric Mean –<br>Original Dataset | Metric Mean –<br>Balanced Dataset | Overall Change<br>in Value (+/-) |
|--------------------------------------------------------------------|-----------------------------------|-----------------------------------|----------------------------------|
| Sand (%) – Catchment Scale                                         | 31.68 %                           | 37.59 %                           | 5.91 %                           |
| Silt (%) – Catchment Scale                                         | 43.83 %                           | 40.51 %                           | 3.32 %                           |
| Stream Order                                                       | 4.61                              | 5.32                              | 0.71                             |
| Sinuosity – Flowline Scale                                         | 26. 57                            | 26.09                             | 0.48                             |
| Pasture / Hay Cover (%) – Catchment Scale                          | 7.27 %                            | 5.68 %                            | 1.59 %                           |
| Crop Cover (%) – Catchment Scale                                   | 19.25 %                           | 17.21 %                           | 2.04 %                           |
| Grassland Cover (%) – Catchment Scale                              | 39.0 %                            | 30.0 %                            | 9.0 %                            |

## Figures

**Figure 1.1.** (A) Our 10-step iterative, adaptive management framework, and (B) Our statistical loop with 6 additional steps. This framework organizes the entire paper including all figures and tables. Small red circles with arrows in A indicate obvious opportunities for additional iterations of the framework.

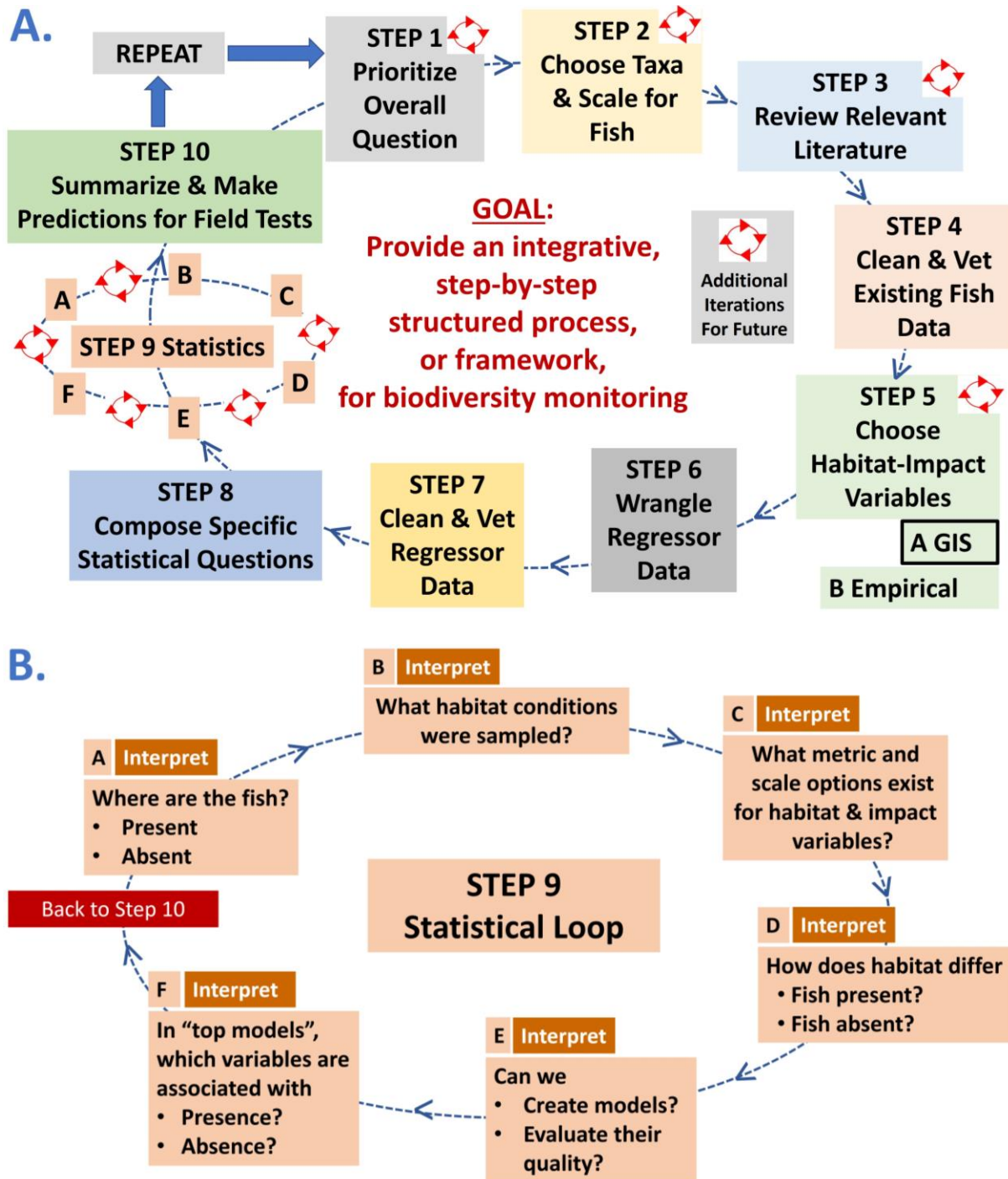


**Figure 1.2.** Map of our study area with fish sampling locations indicated. Each black dot represents a unique sample site. The main river basins are indicated.

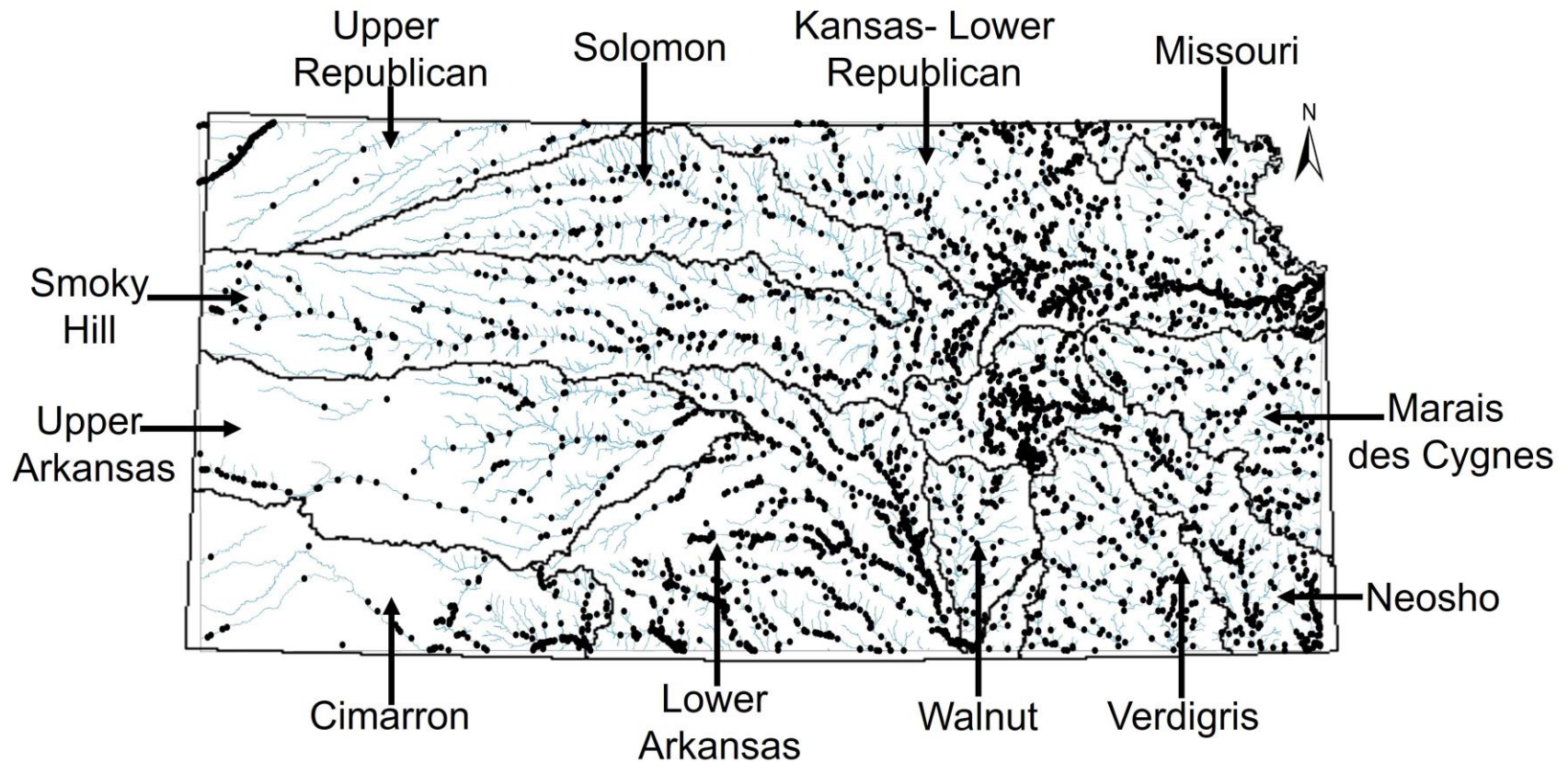


**Figure 1.3.** Fish sample sites at which Emerald Shiner is present (gold symbols) and absent (blue symbols). Presences are marked by gold points ( $n=1131$  total presences at 903 unique locations), and absence points are in blue ( $n=7713$  total absences at 7,076 unique locations). Major river basins in Kansas are indicated.

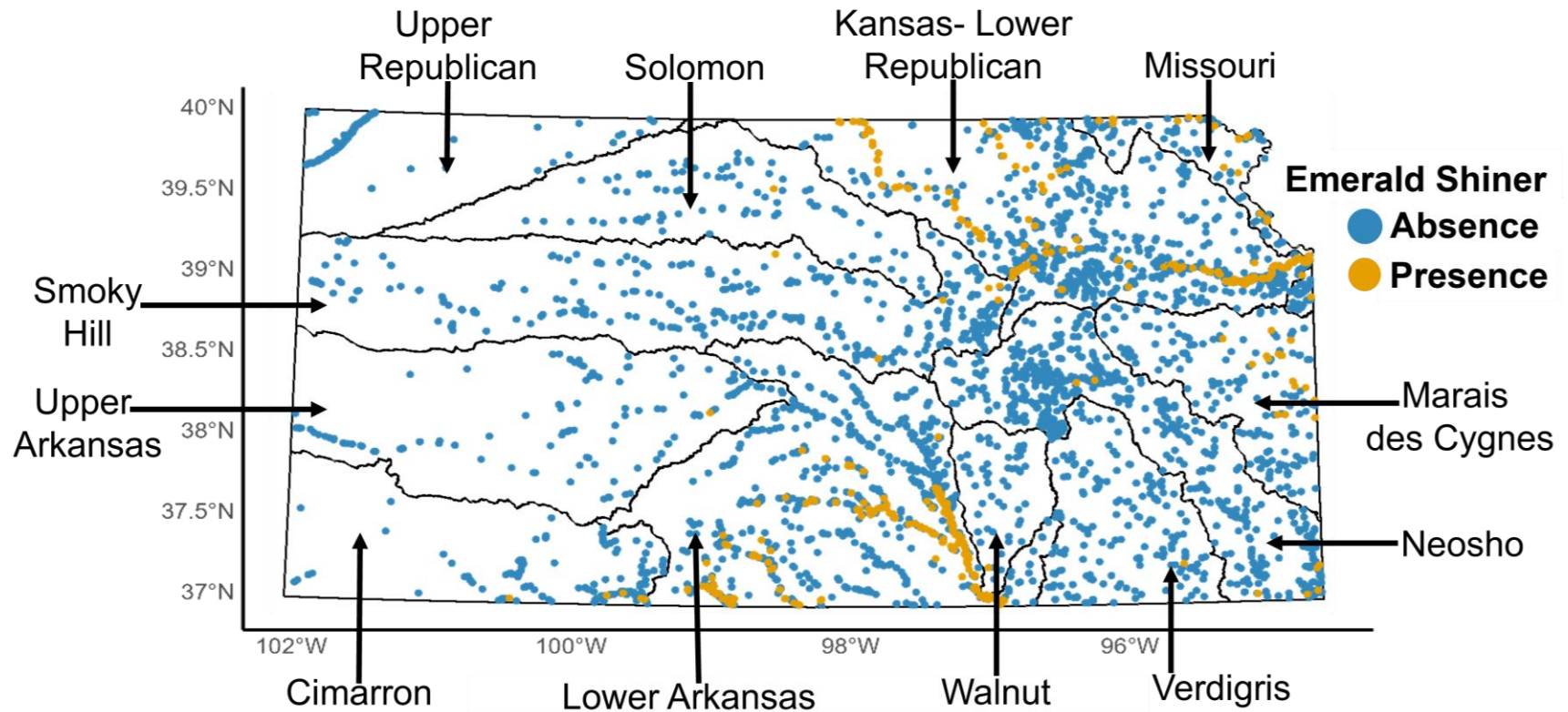


**Figure 1.4.** Frequency distributions of two types of substrate: (A) silt (%) and (B) sand (%) for all samples taken within our study area. These substrate values were calculated for the local catchment area scale.

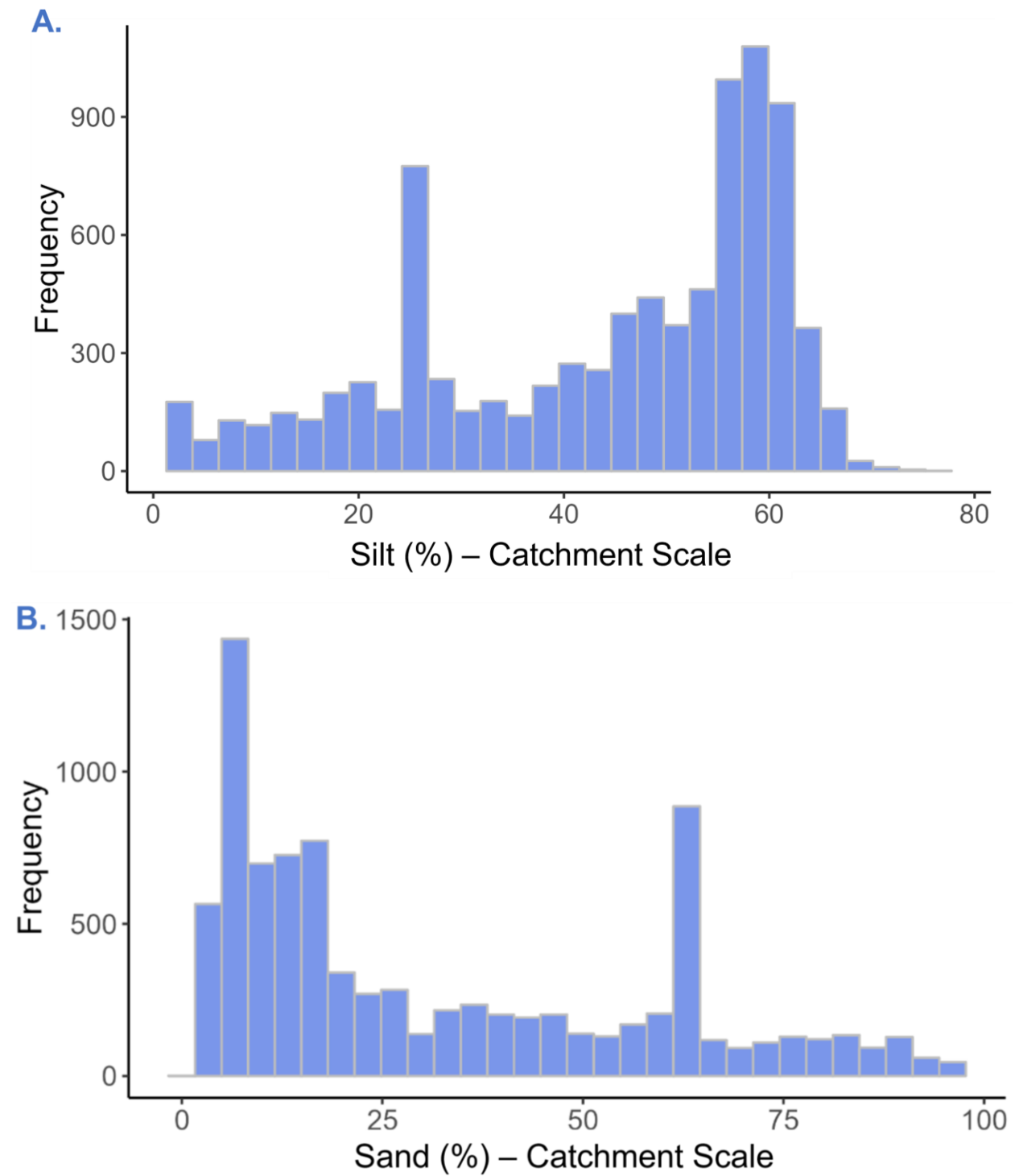




**Figure 1.5.** Proportional symbol map for two substate types across our study area: (A) silt (%) and (B) sand (%). Values are calculated at the catchment scale. Dot size and color both indicate the magnitude of the substrate type at that site (Ex: A large, royal blue dot indicates high amounts of silt or sand at that site, while a small, dark blue dot indicates low amounts). Major river basins are indicated. Dots represent all unique locations sampled within our study area.

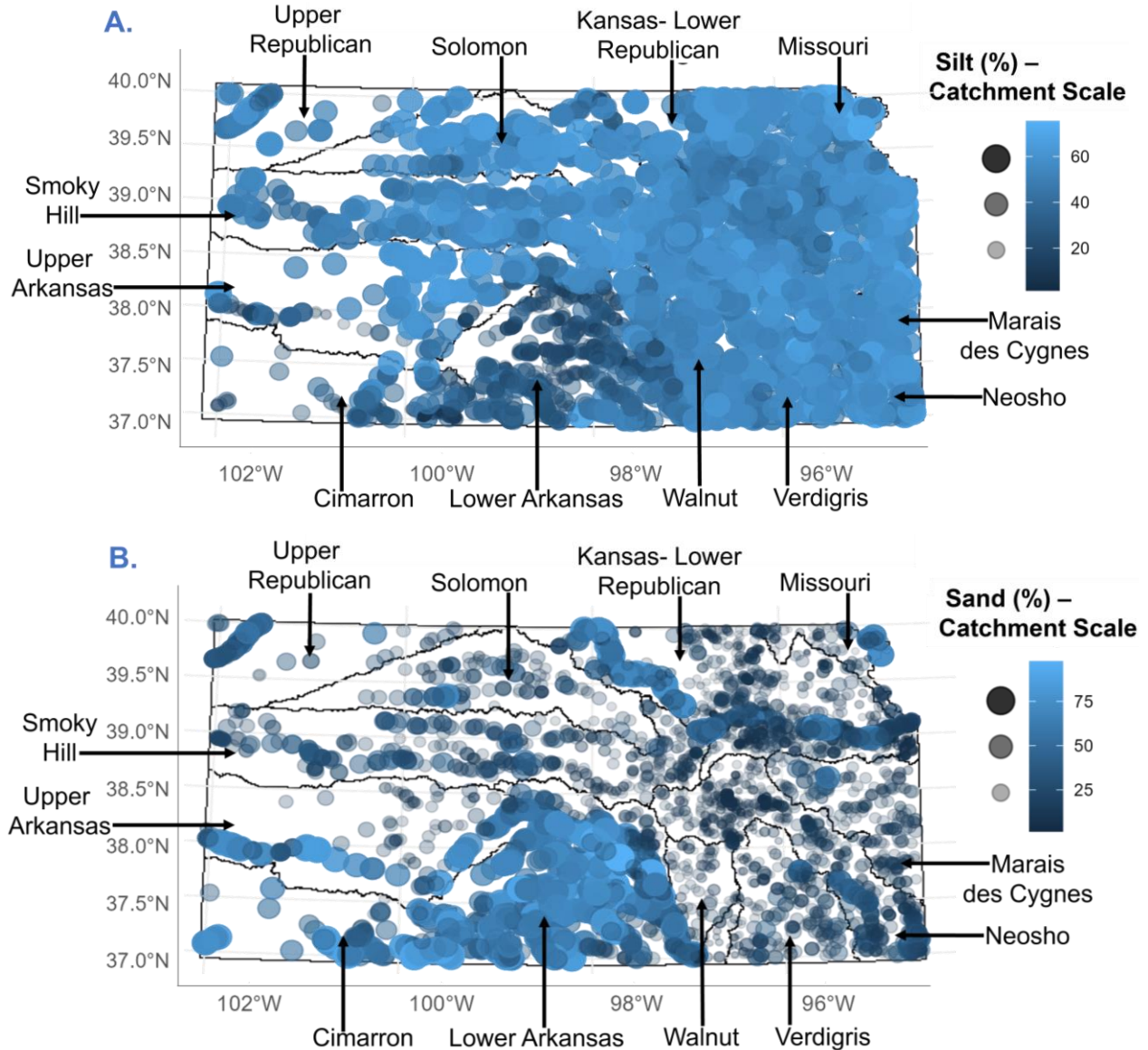




**Figure 1.6. (A)** The average percent of catchment scale substrate metrics for all samples where Emerald Shiner were present. Sand substrates were most common (45.5%), followed by silt (35.6%). **(B)** The average percent of entire network catchment scale land use metrics for all samples where Emerald Shiner were present. Grassland, a natural land use type, was most common (44.5%), closely followed by agricultural land use, which includes both pasture and cultivated crop cover (35.3%).

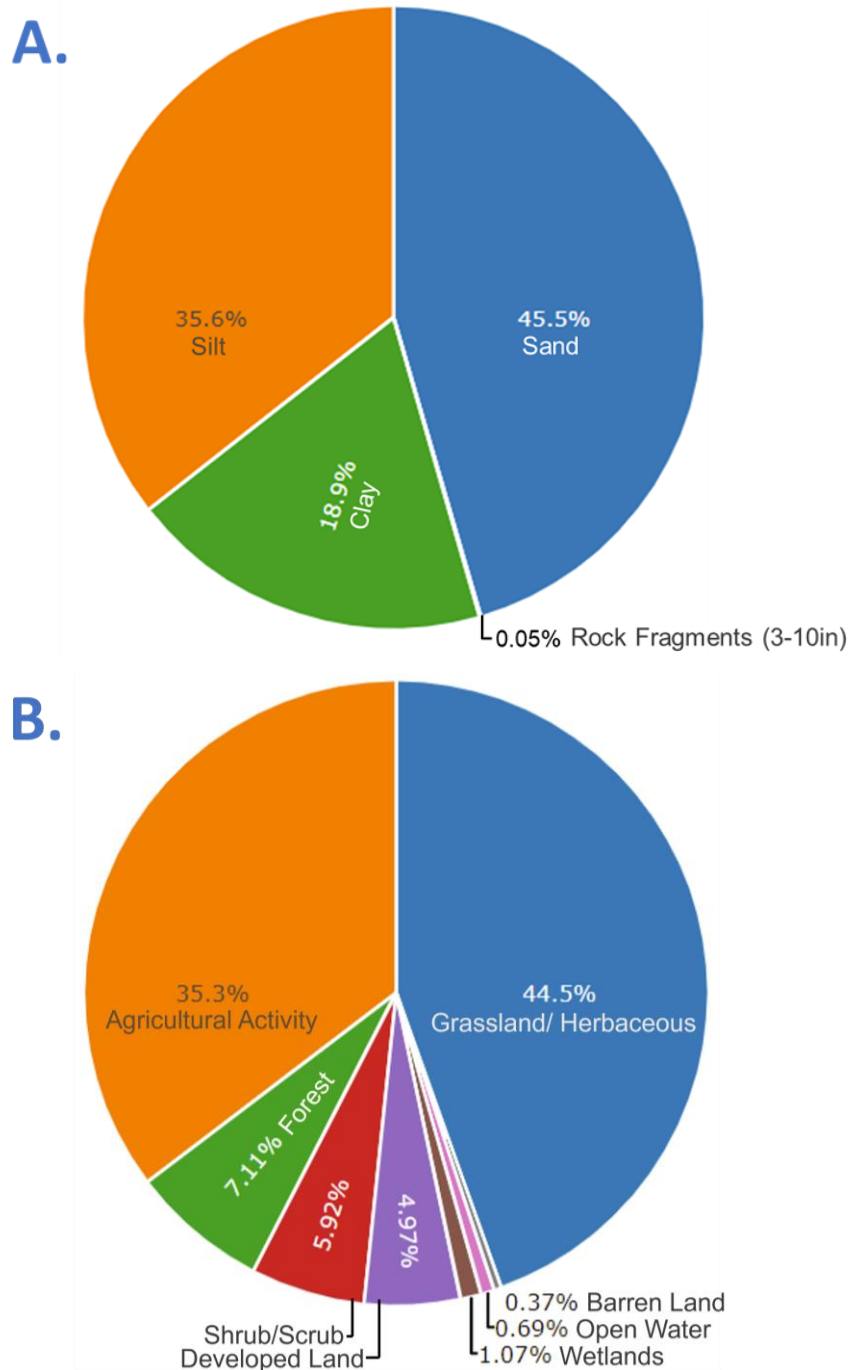


**Figure 1.7.** Boxplots of the distributions of substrate metrics (A-O) at sites where Emerald Shiner are present or absent. Shown are median (thick black bar), quartiles (white box), and minimum and maximum (individual points). (A-C) measure clay substrates at the (A) catchment, (B) flowline, and (C) point scale. (D-F) measure rock fragment (3-10 in) substrates at the (D) catchment, (E) flowline, and (F) point scales. (G-I) measure sand substrates at the (G) catchment, (H) flowline, and (I) point scales. (J-L) measure silt substrates at the (J) catchment, (K) flowline, and (L) point scales. (M-O) measure soil erodibilities at the (M) catchment, (N) flowline, and (O) point scales. Minimal overlap between presence and absence bars indicates that a specific metric-scale differs for sites where Emerald Shiner is present or absent.

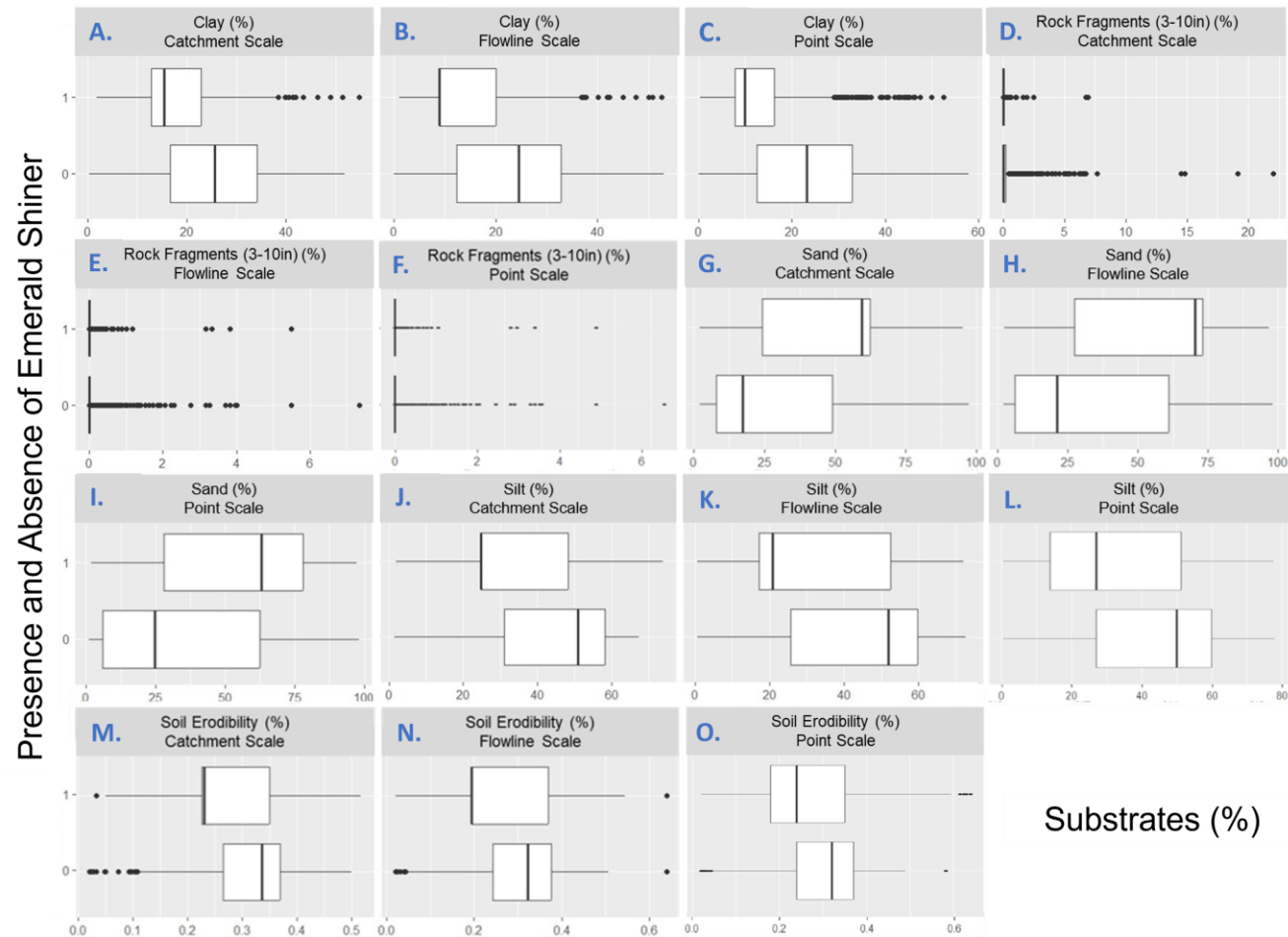


**Figure 1.8.** Boxplots of the distributions of natural land use metrics (A-J) at sites where Emerald Shiner are present or absent. Shown are median (thick black bar), quartiles (white box), and minimum and maximum (individual points). (A-D) use National Landcover Database (NLCD, USGS) and measure grassland cover at the (A) flowline, (B) catchment, (C) network flowline, and (D) network catchment scale. (E-J) are from the Cropland Data Layer (CDL, USDA) and measure grassland (E-G) and natural land (H-J) covers (grassland, forest, wetland, shrub) at the (E, H) point scale, (F, I) flowline, and (G, J) catchment scales. Minimal overlap between presence and absence bars indicates that a specific metric-scale differs for sites where Emerald Shiner is present or absent.

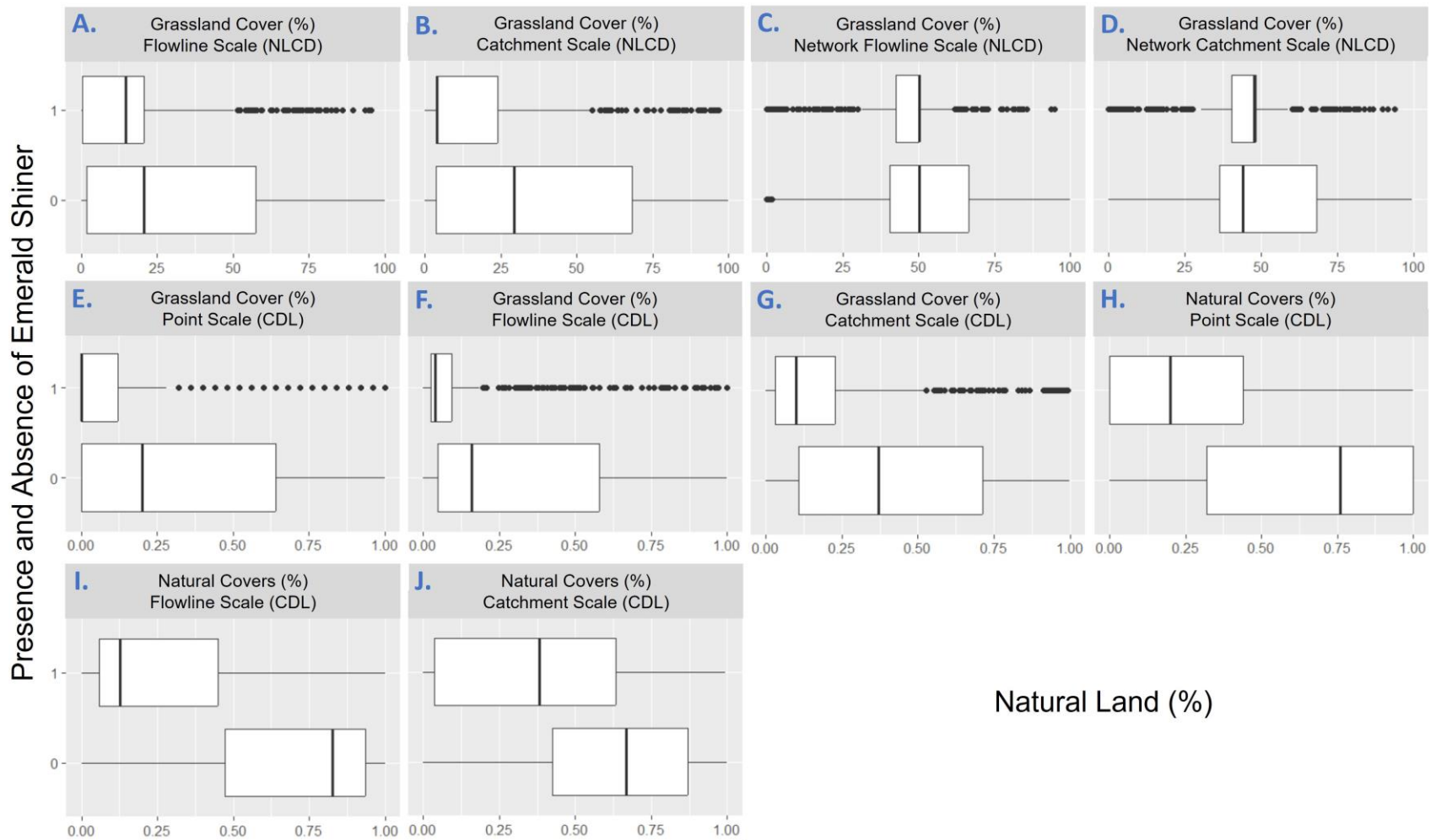


**Figure 1.9.** (A) Frequency of silt substrates where Emerald Shiner are present and absent. Some overlap occurs across all silt conditions. (B) Sand substrate frequencies where Emerald Shiner are present and absent. Overlap occurs across the majority of sand conditions. (C) Frequency of stream orders where Emerald Shiner are present and absent. There is some overlap at each order. Red sites (ridges) are where Emerald Shiner are present, and purple sites (ridges) are where Emerald Shiner are absent.

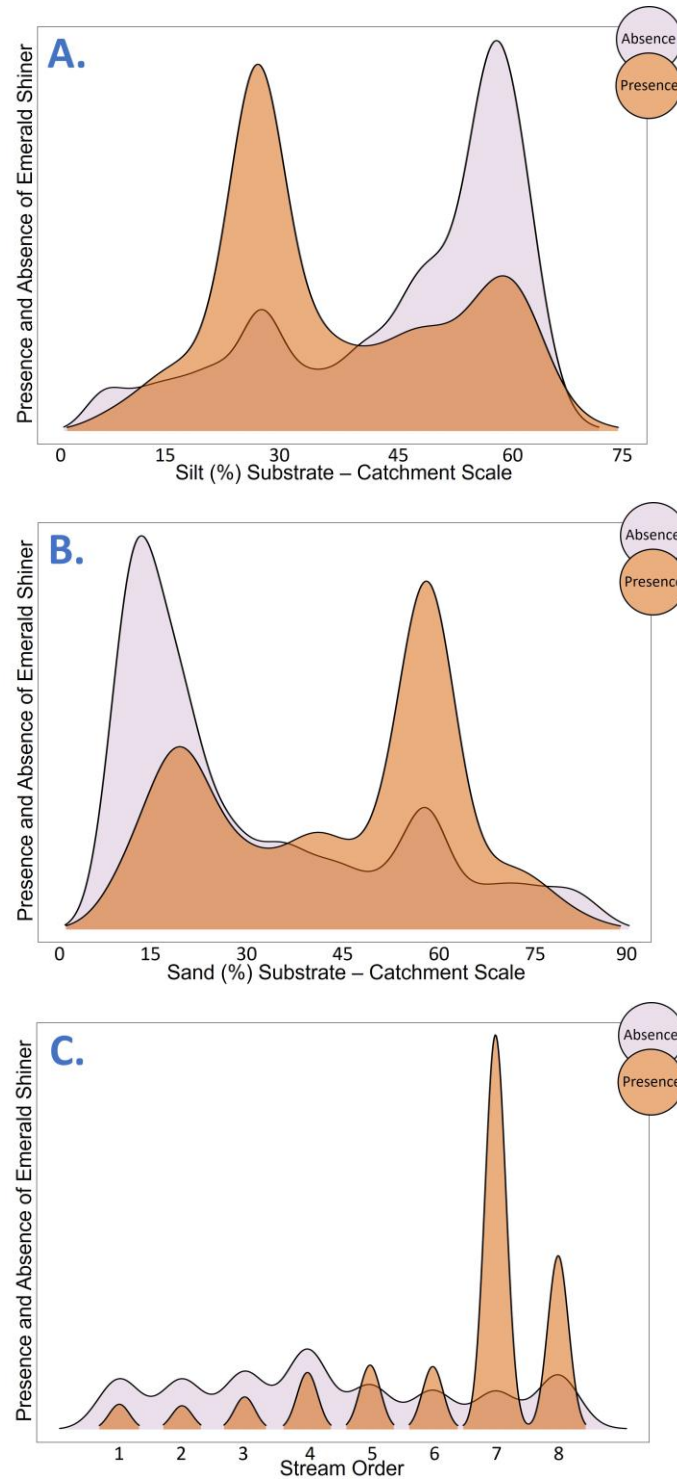
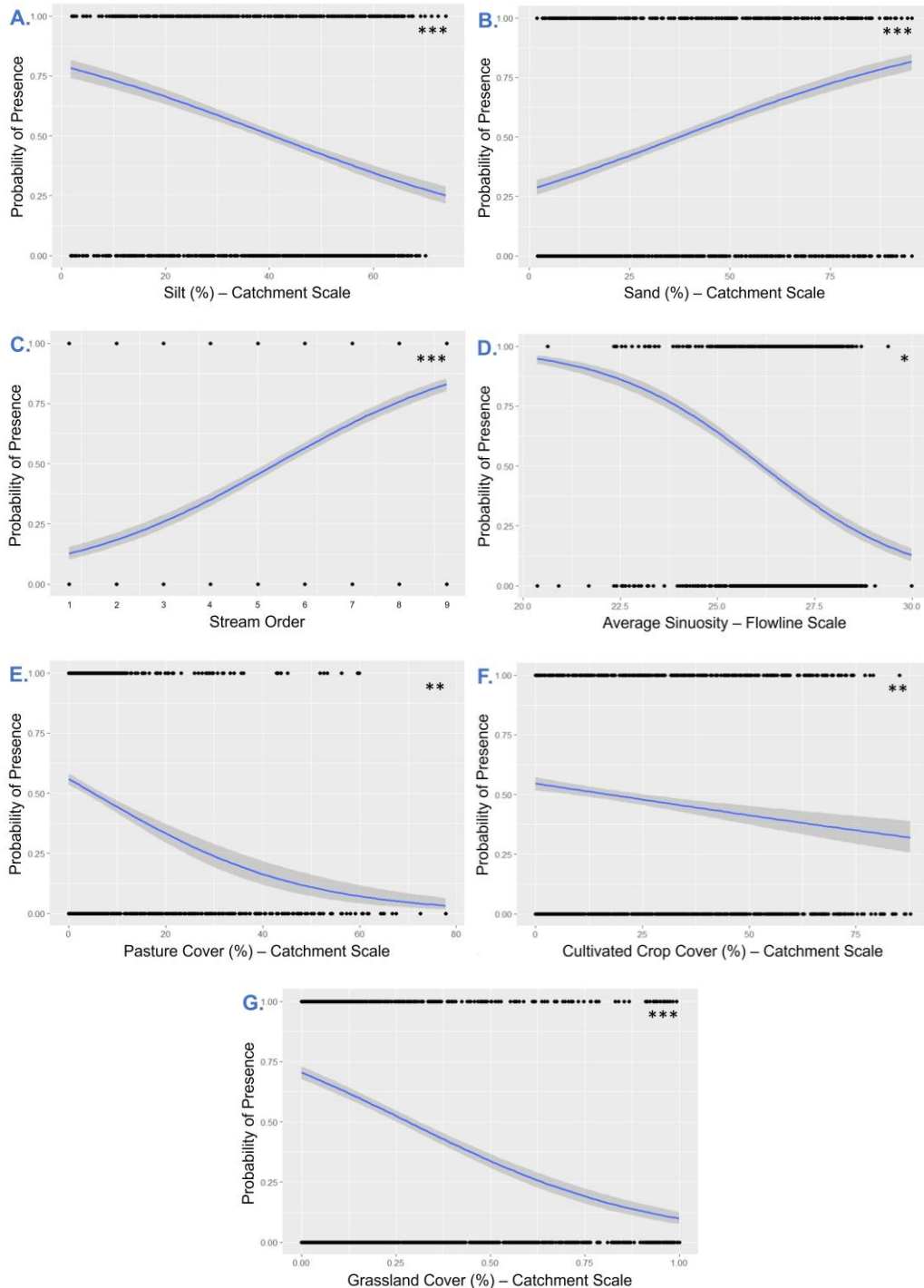


**Figure 1.10.** Correlation plot for all prioritized variables in Emerald Shiner multiple logistic regression model. Variables with correlations > 0.7 were excluded from final models [i.e., velocity types (3 metrics), stream width (1 metric), and natural land (1 metric)]. Substrates (3 metrics) and agricultural land use types (2 metrics) were used in separate models.



**Figure 1.11.** Probability plots for all metrics ( $P < 0.05$ ) included within the top model(s) for Emerald Shiner. (A) Silt (%) – Catchment Scale, (B) Sand (%) – Catchment Scale, (C) Stream Order, (D) Sinuosity – Flowline Scale, (E) Pasture Cover (%) – Catchment Scale, (F) Crop Cover (%) – Catchment Scale, (G) Grassland Cover (%) – Catchment Scale. The metrics level of significance can be viewed in the top left corner (Significance Codes: '\*\*\*',  $P < 0.001$ ; '\*\*',  $0.001 < P < 0.01$ ; '\*',  $0.01 < P < 0.05$ ).



## **Chapter 2 - A tale of three fish: how a monitoring dataset, an adaptive management framework, and the comparison of thoughtfully-selected fish groups can guide stream fish conservation planning, future data collections, and management actions**

Olivia Rode, Martha Mather, Devon Oliver, Suyash Pratap, Kate Nelson, Trisha Moore

### **Abstract**

Conserving and restoring threatened and endangered fish at state, regional, and national scales is challenging because of complexities associated with planning, data collection, analysis, interpretation, and synthesis. Without data on where rare and declining fish are located and what habitat and impact variables reduce their distribution, researchers and managers have difficulty constructing plans for restoration. Our purpose is to illustrate how an adaptive management framework and monitoring data for thoughtfully chosen groups of common and uncommon fish can assist conservation and guide restoration planning. Our adaptive management framework was comprised of an iterative 10-step cycle within which a six statistical step subloop was embedded. To compare two common fish (Emerald Shiner, Central Stoneroller) and one uncommon fish (Plains Minnow), we combined visualization tools (i.e., fish maps, proportional resource maps, ridgeline plots, box plots, histograms, pies diagrams) with multiple logistic regression and related probability plots. Data analysis of groups of fish enhanced and expanded conservation insights compared to a single species analysis (e.g., regional distribution patterns). Our pretty good, but not perfect, multiple logistic regression models consistently identified priority regressors (e.g., system size, substrate, sinuosity). Our weight of evidence approach clarified ambiguous regression trends (e.g., substrate). Prediction maps (paired with visualization

tools) identified promising regions and sites for future restoration. Our framework is an example of an implementable adaptive management approach. Our methodology relies heavily on the collaborative efforts among teams of conservation professionals for data analysis, interpretation of data trends, identification of testable predictions, and targeted data collections across iterations.

## **Introduction**

### **A Difficult Problem**

A common mission of many fisheries agency professionals is to be good stewards of natural ecosystems, often with a special emphasis on protecting declining and rare native fish. Conserving and restoring threatened and endangered fish at state, regional, and national scales is challenging because of complexities associated with planning, data collection, analysis, interpretation, and synthesis (Craig et al. 2017; Dey et al. 2021). As one example, data on rare fish are difficult to collect (because their rarity makes them hard to sample), which slows the process of gaining information on how to protect and restore them (Lindenmeyer et al. 2012; Robinson et al. 2018). Without data on where rare and declining fish are located and what habitat and impact variables reduce their distribution, researchers and managers have difficulty constructing a justifiable plan for conservation and restoration actions. Our purpose is to assess if the fisheries profession (e.g. managers, researchers, or manager - research teams) can more effectively and systematically analyze, synthesize, and interpret existing monitoring data on native taxa using an adaptive management framework with comparable groups of common and uncommon fish.

### **Adaptive Management**



Adaptive management is a scientific concept that was first proposed in the mid-1970s (Hollings 1978; Walters 1986) about which much has been written (e.g., Millennium Ecosystem Assessment 2005; Reever et al. 2006; Stern et al. 2012; Rist et al. 2013, Williams and Brown 2014). Although variable definitions of adaptive management have been developed over time (e.g., Gunderson 1999; McFadden et al. 2011; Kingsford et al. 2017; Nicol et al. 2022), common components of this common concept include (i) utilizing a structured process, or framework, to stimulate (ii) active-learning for the purpose of (iii) enhanced decision-making (Mather and Dettmers 2022). Although adaptive management is widely invoked as a popular approach, implementation guidance for adaptive management plans for specific natural resource problems are often lacking. For example, in a comprehensive 5-year study of 51 state wildlife action plans, almost all (98%) mention adaptive management, but only a quarter of these detailed and thoughtful plans describe how to integrate this approach at the project-level (Fontaine 2011). Implementing adaptive management plans is problematic for all fisheries professionals (researchers, managers, administrators) because of the complexity of this challenge. Providing a detailed framework for this “*learn while doing*” process for one conservation problem, conservation and restoration of native fish, is what we address here.

### **Using Monitoring Data to Increase Conservation Insights**

The coupling of our adaptive management framework (Rode et al. 2023 - Chapter 1) with existing monitoring data can extract useful conservation insights. Monitoring data have great value for providing a big picture of status and trends and are often the only opportunity for obtaining this geographically and temporarily broad view (Magurran et al. 2010; Vihervaara et al. 2013, Nieman et al. 2021). However, monitoring data have challenges that make analysis and interpretation difficult (Olsen et al. 1999, Biber 2013). Unlike well-planned, hypothesis-testing

research, monitoring data rarely reveal unambiguous and significant trends through a single analysis (Milliken and Johnson 1989, 2001; Flather 1997; Fischer et al. 2021). Using monitoring data in an interactive, iterative, structured process, guided by the weight of evidence approach from multiple analyses (as we do here) is a different way to assess trends, identify gaps, and propose future actions (Lindenmeyer and Likens 2009; Mather and Dettmers 2022).

### **Our Adaptive Management Framework**

Elsewhere (Rode et al. 2023 - Chapter 1), we describe an iterative 10-step cycle (Figure 2.1A) within which a six statistical step loop is embedded (Fig. 2.1B). As a brief review of our adaptive management framework, each iteration of this framework prioritizes a tractable focused question of interest (Step 1), identifies a thoughtfully and realistically chosen taxa and scale (Step 2), uses a directed literature review to provide context (Step 3), applies data cleaning and evaluation procedures to fish and habitat-impact data (Steps 4, 7). selects appropriate fish-relevant data variables as identified in the literature (Step 5), then wrangles appropriate data (GIS or empirical; Step 6) at each location for which fish data exists. Our previous development of the adaptive management framework addressed the overarching question of “Using monitoring data, what habitat and impact variables affect the probability of specific fish presence at a statewide scale, and why? Here we add a new step to this framework (Step 9.5) that asks, “How can the comparative analysis of thoughtfully grouped fish taxa be incorporated into our adaptive management framework?” (Step 9.5: Fig. 2.1C). Next, the multi-step statistical subloop partitions the broader overarching question of interest into specific questions (Step 8) that each can be addressed by a single data analysis or visualization procedure. The resulting weight of evidence approach (Steps 9A-F) systematically combines accumulated insights from organismal distribution maps, histograms for conditions sampled, exploratory box and ridgeline plots,

proportional symbol resource maps, multiple logistic regression models with accuracy validation, probability plots, and maps of model predictions). In our final step (Step 10), results of the first iteration (Steps 1-9A-F) are synthesized to identify specific data/analysis needs for future collection efforts and to make predictions. Thus, results of iteration 1 - Step 10 can be tested in the field and incorporated into data analysis and modeling in Iteration 2 - Step 1. This iterative process, which accumulates insights and links past and present monitoring data to future data collection needs, is repeated until researcher-manager teams are satisfied they have adequate knowledge for sampling, restoration, or regulations.

### **Kansas Fish**

Kansas has a diverse native stream fish community that is vulnerable to anthropogenic and climate threats (e.g., Distler et al. 2014; Rohweder 2022). In 2005, experts suggested that almost half (47%) of Kansas *native* fish species merit special conservation status because of declines or small present population sizes (Haslouer et al. 2005). Many native Kansas fish are small bodied, short-lived fish that reproduce only a few times and can be easily decimated by disturbances (Distler et al. 2014). Many native prairie stream fish were adapted to naturally occurring extreme prairies conditions that have been altered by humans (e.g., fluctuations in temperature, seasonal flood peaks, high turbidity; Dodds et al. 2004; Distler et al. 2014; Krentz et al. 2020). In addition, other anthropogenic threats such as human-induced flood control (large dams), water withdrawals for municipal development and agriculture, introduction of sport fish predators, small dams, climate change, and a megadrought have further altered conditions to which these native prairie fish evolved (e.g., Vörösmarty et al. 2000; Baron et al. 2002; Dudgeon et al. 2006; Roni et al. 2014; Dudgeon 2019). In 2022, experts in the state of Kansas identified and prioritized native fish that were of greatest conservation need (SGCN;  $n=70$ ) in their detailed

Kansas State Wildlife Action Plan (SWAP; Rohweder 2022). These Kansas native species of conservation interest included state and federal endangered species ( $n=5$ ), state and federal threatened species ( $n=10$ ), state species in need of conservation (SINC;  $n=32$ ), and other state species of greatest conservation need (SGCN;  $n=23$ ) (SGCN Ranking Criteria; Rohweder 2022) (Appendix Table 2.1). The KS SWAP (Rohweder 2022) also identifies eleven statewide conservation issues impacting biodiversity, including eight direct impacts [(1) residential and commercial development, (2) agriculture, (3) energy production, (4) modification of natural systems, (5) invasive species, (6) pollution, (7) climate change, and (8) compliance and enforcement of wildlife laws and regulation], and three indirect threats to biodiversity [(9) existing data gaps and lack of knowledge, (10) inadequate coordination between government agencies, and (11) lack of outreach and education]. Our adaptive management framework seeks to use monitoring data to understand patterns of these native fish.

## **Objectives**

Here we address five objectives. First, via what decision criteria, can fish be grouped to yield meaningful ecological and conservation comparisons? Second, using maps of monitoring data, how are taxa in the chosen group distributed statewide? Third, using a variety of quantitative analyses and visualization tools (i.e., ridgeline plots, box plots, histograms, pies, multiple logistic regression, probability plots), what habitat and impact variables are most influential for the distribution of fish taxa in our select groups? Fourth, what insights are gained by comparing and contrasting the results across taxa within the chosen group compared to single taxon analysis? Finally, what guidance can this approach provide for restoration planning and future data collection for an uncommon fish?

## **Methods**

### **Methods: Objective 1 – Via what decision criteria, can fish taxa be grouped to yield meaningful ecological and conservation comparisons?**

#### **Approach**

For the first objective, we identify then use a middle-complexity decision tree for grouping native prairie stream fish that will allow researchers and managers to accumulate useful insights from comparing and contrasting framework-based data analyses for common and uncommon fish taxa (Figure 2.2). Our decision tree uses three types of ecological and life history characteristics to select comparable fish taxa. These three types of characteristics are: 1. Goal characteristics; 2. Matching characteristics; and 3. Option characteristics. For objective 1 (Steps A-D), we used literature on Kansas fish (e.g., Distler et al. 2014) or resources that are otherwise cited.

#### **Objective 1: Step A. Goal Characteristics**

We first determined which characteristic best reflected the pattern that we sought to explain. Because we wanted to use patterns of common fish to guide restoration of uncommon fish, the linked goal characteristics we chose were patterns of abundance of presence sites (common vs. uncommon) and site distribution (statewide vs. regional) (Step A: Fig. 2.2).

#### **Objective 1: Step B. Matching Characteristics**

Second, we judged that certain characteristics need to be matched for meaningful across-taxa comparisons that have broad applications to restoration. Body size, life span, and age at first reproduction influence many aspects of a fish ecology, life history, and demographic processes (e.g., Mims et al. 2010). Thus, in our framework we only wanted to compare common and uncommon native fish taxa that were small bodied, short-lived with early and infrequent

reproduction (Step B: Fig. 2.2). Foraging behavior can affect abundance and distribution of common and uncommon taxa (Gebrekiros 2016; Fehlmann et al. 2020). Because most small-bodied stream fish have largely generalist and opportunistic diets that include some animal (inverts), plant (algae), and detrital items, many small native prairie stream fish have comparable matched diets (Step B: Fig. 2.2).

### **Objective 1 - Step C. Option Characteristics**

Many important life history and ecological characteristics will vary across taxa in a way that is beyond control when selecting taxa to compare [e.g., ecosystem type, size (Walters et al. 2003), substrate use (Mueller and Pyron 2010; Gebrekiros 2016; Roberts 2020; Faucheux et al. 2023), specific spawning behaviors - early life history traits (Balon 1975, Simon 1998)]. Although these characteristics cannot be controlled systematically across groups, these option characteristics can be documented and explicitly considered in data interpretation. The first option characteristic that we document is ecosystem type, or specialization [i.e., fish that only occur in flowing water (lotic only) versus those that can survive and reproduce in lakes and reservoirs (both lotic and lentic); Step C: Fig. 2.2]. The second option characteristic that we document is ecosystem size used [are fish taxa more common in small streams (S) vs middle-large rivers (M-L); Step C: Fig. 2.2]. The third and fourth option characteristics that we document for fish groups are substrate specialization (a single substrate used vs many substrates generally used) and substrate size (small vs medium-large; Step C: Fig. 2.2). For option characteristics five and six, we document locations in the water column where adults spawn (water column vs benthic), and locations in the water column where eggs hatch and larvae develop (water column vs benthic) (Step C: Fig. 2.2).

### **Objective 1 - Step D. Comparing and Contrasting Fish Group**

For the next three objectives, we consider comparisons and contrasts in our data interpretations for three fish (one uncommon and two common fish taxa; Step D: Fig. 2.2) based on the criteria reviewed above.

**Methods: Objective 2 – Second, using maps of monitoring data, how are taxa in the chosen group distributed statewide?**

**Data for Site Presence Number and Site Distribution Maps**

For objectives 2-5, we used presence-absence fish sampling data from a large Kansas statewide monitoring stream and river sampling program in (Kansas Department of Wildlife and Parks Stream Team). This monitoring program reported 100+ fish species across all 12 major river Kansas basins (<https://www.kdhe.ks.gov/368/Kansas-River-Basin-Map>) at 8,844 unique site-times at 7,872 unique sites. Using these survey data, we created geographic maps (Step 9A: Fig. 2.1B) and their associated summaries for presence and absence site abundance (for common vs uncommon taxa) and site distribution (statewide vs regional) across presence-absent sites using ggplot2 (Wickham 2016).

**Methods: Objective 3 - Third, using a variety of quantitative analyses and visualization tools (i.e., ridgeline plots, box plots, histograms, pies, multiple logistic regression, probability plots), what habitat and impact variables are most influential for the distribution of fish taxa in our select groups?**

**Primary Regression Approach**

To assess what habitat and impact variables might be influential in determining patterns of probability of taxa-specific presence or absence, we used GIS metrics representing 11 standard ecological categories of habitat and impact data: (1) NHDPlus flow, (2) substrate, (3)

stream order, (4) reach measures (width, depth), (5) catchment area, (6) sinuosity, (7) agricultural land use, (8) developed land use, (9) natural land, (10) dam characteristics, and (11) gradient. Within each ecological category, multiple GIS metrics were included from various GIS datasets for a variety of scales (see Rode et al. Chapter 1: Appendix Table 1.2). Specifically, to select the best metric and scale in each ecological category for each taxa, we reviewed the ecological literature, examined box plots of presence and absence for each metric for each taxa, and ran best subsets regressions within ecological categories (Steps 9B-D: Fig. 2.1B). One uncorrelated metric from each ecological category was then used in a single regression for a single taxon. These “best-species-specific-metric unstandardized” (BSSM-U) regressions used unstandardized data from the same ecological categories for each fish taxon, but the specific metric and scale representing the category could differ across taxa (e.g., grassland vs all natural land; all development types vs developed open space). Our intensive investigation of metrics within each ecological category and across scales provided valuable exploratory information about similarity and differences in metrics, afforded the best chance of identifying relevant taxa-specific information from a messy monitoring dataset, and allowed us to make thoughtful metric choices in our first framework iteration. Of course, other metrics and scales that we did not select can also be influential under select conditions. This BSSM-U approach was our primary approach for data analysis and interpretation and is reported below in detail. To put this approach in perspective, however, we also ran regressions with “best-species specific metric” on standardized data (BSSM-S) and regressions using the exact same metrics within each ecological category for all species for unstandardized and standardized data (same species-specific metric, SSSM-U, SSSM-S - see below).

## **Regression Steps**



We used the following seven steps to create and evaluate our models for each fish taxa (Step 9E: Fig. 2.1B). All analyses described were performed in R Version 2022.12.0 (R Core Team 2022). First, for each model, we balanced our data classes (presence and absence), by randomly removing samples from the larger data class (usually absence) to equal the number of the smaller class (usually presence). Second, correlations among model-specific regressors were identified, and one of any highly correlated ( $P > 0.7$ ) pair was removed or assessed separately (corrplot, Wei and Simko 2021). Third, we fitted a multiple logistic regression model to metrics belonging to one of 11 ecological categories (*MuMIn*, Bartoń 2022). Fourth, models with  $\Delta AIC < 2$  were further evaluated by examining the size and direction of the parameter estimates, error size, and parameter-specific P-values. Fifth, for regressors with  $P < 0.05$  in the top set of taxa-specific models ( $\Delta AIC < 2$ ), we visually examined the relationship between significant regressors and fish presence and absence using probability plots (Step 9F: Fig. 2.1B; *ggplot2*, Wickham 2016). Although P-values do not have exact meaning for complex field data, here we use them to prioritize variables that are likely to be the most influential (Murtaugh 2014). Next, we applied 10-K fold cross validation to evaluate the accuracy of the model(s). This training and test classification approach produces a confusion matrix that identifies what proportion of classifications made for both data classes were correct or incorrect (*caret* and *tidyverse*, Kuhn 2022; Wickham et al. 2019) (Brownlee 2019, 2020). Finally, the D2 statistic for each top model was calculated to observe the amount of variance that the model explained (*stats*, R Core Team 2022). Here we only report and discuss significant variables ( $P < 0.05$ ) from the top models ( $\Delta AIC < 2$ ).

### **Assumptions**

We addressed assumptions of the multiple logistic regressions (McDonald 2014). We used histograms to examine the distribution of regressors. We used box plots to examine heterogeneity across presence and absence categories for each regressor variable. Because of the large numbers of sites used (hundreds to thousands), many variables approximated a normal distribution with similar heterogeneity across presence-absence data. When distributions were skewed, we compared plots and outputs using transformed and untransformed data. Correlations among regressors were examined before running the logistic regression, and no highly correlated variables ( $>0.7$ ) were used in the same model. To further test for multicollinearity, we examined variable inflation factors (VIF) (*car*, Fox and Weisberg 2019) and condition indices (CN) (*klaR*, Weihs et al. 2005). A  $VIF < 10$  is considered an acceptable rule of thumb for detecting collinearity (Vittinghoff et al. 2005; James et al. 2014) although some suggest investigating lower values ( $VIF < 5-10$ ; Menard 2002). A  $CN < 30$  is considered an upper level for acceptable multicollinearity (Freund and Littell 2000; Salmeron and Garcia 2022; Roever et al. 2023) although again some suggest investigating lower values ( $CN < 10-30$ ). In our best-  
unstandardized top models, 96% of variables exhibited VIF values  $< 5$ , and 100% exhibited values  $< 6$  (Appendix Table 2.2). Further, 82% of variables had CN values  $< 10$ , and 100% exhibited values  $< 20$  (Appendix Table 2.2). We acknowledge that monitoring data, like most field data, violates many statistical assumptions, which can alter the interpretation of P-values and parameter estimates. However, in this analysis we are looking for general trends, and, as noted above, we only use statistical cutoffs to prioritize variables (i.e., identify a place to start), and we interpret the regression coefficients as general estimates of direction not as specific effect sizes. Furthermore, because we are investigating trends in messy data, we are also not concerned

about accumulating family-wide or experiment-wide errors from multiple analyses and do not make Bonferroni corrections.

### **Other Visualizations**

We used five additional types of exploratory data plots to further interpret the regression output. Histograms and box plots assessed regressor conditions sampled (*ggplot2*, Wickham 2016). Data pie charts quantified land use patterns at sites used and not used by specific fish taxa (*plotly*, Sievert 2020). Ridgeline plots visualized conditions of different variables where a fish taxon was present or absent (*ggridges*, Wilke 2022). Finally, proportional symbol resource maps, for which the size of the symbol reflected the magnitude of the regressor, assessed geographic patterns in the regressors (*ggplot2*, Wickham 2016).

### **Regression Comparison**

We compared the results of the above-described “best-species specific metric” on unstandardized data (BSSM-U) with “best-species specific metric” on standardized data (BSSM-S). We include standardized regressions as comparable coefficients to highlight the important role of many metrics in driving this species distribution. Model standardization was completed using the *sqr*t function (R Core Team 2022). As another added feature to our framework, we created and evaluated regression models that used the same metrics within each ecological category for all taxa (same-species-specific metric; SSSM) for unstandardized and standardized data (SSSM-U, SSSM-S). In our same-metric models, all selected metrics were consistent within each ecological category for all three fish. As the results will show, using the same metrics for all taxa does not always make ecological sense. These same-metric models were constructed following the same procedures described previously for best-metric models. In following this

process, we were able to assess information gaps, recommend future sampling, and propose field tests that could be implemented in future data collections (Step 10: Fig. 2.1A)

**Methods: Objective 4 - Fourth, what insights are gained by comparing and contrasting the results across taxa within the chosen group compared to single taxon analysis?**

We compared and contrasted results from all three taxa to expand our understanding of patterns. For this objective, analysis methods were the same as described above, but we integrated data analysis and visualizations across fish taxa in the interpretation.

**Methods: Objective 5 - What guidance can our framework approach provide for restoration planning and future data collection?**

To visualize regions within our study area that are could be targets for sampling or may be viable for restocking efforts for the uncommon taxa in our above-described analyses, we calculated likelihood of occurrence (probability) for each site using the top model (*ggplot2*, Wickham 2016; *predict* function, R Core Team 2022). On this fish probability map, we identified regions where the uncommon species had been found recently, might be found now, and was found historically. These three regions were superimposed on proportional symbol resource maps and compared resource-specific conditions in areas of high probability for fish presence that might be promising for restoration. The range of conditions at sites with the highest (>99%) and lowest probability (<1%) of occurrence were also calculated and mapped to visualize specific patterns that separated the best and worst sites.

## Results

### **Results: Objective 1 - Via what decision criteria, can appropriate fish groups be identified for meaningful ecological and conservation comparisons?**

#### **What Fish Do We Group?**

We identified three comparable native Kansas stream fish: Emerald Shiner (*Notropis atherinoides*), Central Stoneroller (*Camptostoma anomalum*), and Plains Minnow (*Hybognathus placitus*) (Figure 2.3; Table 2.1). Emerald Shiner is a common and stable fish, currently receives no special protection, and occurs in 27 other states (Step A: Table 2.1; Rohweder 2022; NatureServe 2023). Central Stoneroller is also a common fish, receives no special conservation protection, and occurs in 32 other states (Step A: Table 2.1; Rohweder 2022; Fuller 2023). In contrast, our third taxon, Plains Minnow is an uncommon fish, is listed as threatened within the state of Kansas, and occurs in 16 other states (Step A: Table 2.1; Rohweder 2022; NatureServe 2023).

These three native prairie stream fish taxa have small body sizes (89-127mm, 122-239mm, < 127mm), short life spans (0-4 yrs.), reproduce early and infrequently (1-2 yrs.), and consume some algae, detritus, and invertebrates in varying proportions (Step B: Table 2.1; Flittner 1964; Becker 1983; Fowler and Taber 1985; Taylor and Miller 1990; Jenkins and Burkhead 1994; Rohde 1994; Pflieger 1997; Rees et al. 2005). Related to ecosystem preference, Emerald Shiner is an ecosystem generalist that occurs in both rivers and reservoirs/lakes, whereas Central Stoneroller and Plains Minnow are ecosystem specialists that occur only in lotic systems (Lee et al. 1980; Robison and Buchanan 1988; Sublette et al. 1990; Page and Burr 2011). Related to ecosystem size, Emerald Shiner and Plains Minnow inhabit medium to large rivers, whereas Central Stoneroller is a small stream taxon (Cross 1967; Matthews et al. 1986;

Cross and Moss 1987). Related to substrate specialization and size, Emerald Shiner is a substrate generalist associated with many substrate types, and Central Stoneroller and Plains Minnow are substrate specialists that use specific substrate types (Crevecœur 1907; Eberle et al. 1997; Ross 2001; Bonner and Wilde 2002; Boschung and Mayden 2004). In Kansas, Emerald Shiner and Plains Minnow are associated with small substrate (e.g., sand), whereas Central Stoneroller needs larger, hard substrates (gravel, pebble, small cobble) to reproduce (Metcalf 1966; Cross 1967; Eberle et al. 2002). Related to spawning location, both Emerald Shiner and Plains Minnow adults spawn in the water column, whereas Central Stoneroller spawns in benthic nests (Crevecœur 1907; Flittner 1964; Cross 1967; Lehtinen and Layzer 1988; Simon, 1998). The eggs of Emerald Shiner and Central Stoneroller develop on the stream bottom, whereas Plains Minnow eggs develop suspended in the water column (Step C: Table 2.1; Flittner 1964; Pflieger 1997; Platania and Altenbach 1998). Using insights from the literature, the above criteria produced four groupings of these taxa that can provide context for interpreting empirical trends (Figure 2.4). In our grouping approach 1, Emerald Shiner differed from Central Stoneroller and Plains Minnow based on ecosystem and substrate specializations. In grouping approach 2, Central Stoneroller differed from Emerald Shiner and Plains Minnow based on ecosystem size, substrate size, and water column location of spawning adults. In grouping approach 3, Plains Minnow differed from Emerald Shiner and Central Stoneroller based on presence site abundance and water column location of eggs and larval development. In grouping approach 4, all three fish were comparable based on body size, life span, age at first reproduction, and diet (Fig. 2.4).

**Results: Objective 2 - Second, using maps of monitoring data, how are taxa in the chosen group distributed statewide?**

**Emerald Shiner**

Using our statewide database, Emerald Shiner was commonly collected across sites in Kansas, but the distribution of this taxon differed across river basins. Emerald Shiner was collected in 1,131 samples from 903 unique locations and absent from a total of 7,713 samples collected at 7,076 unique locations (Figure 2.5A). Emerald Shiner was captured at the seventh highest number of sites of the 15 native Kansas fish that we included in our analyses (Rode et al. 2023 - Chapter 1; Table 1.1). Although this taxon was collected in 11 of the 12 major river basins, over 93% of sample sites at which this taxon was present occurred in only two Kansas river basins ( $n=1,050$  of 1,131 samples): the Lower Arkansas ( $n=696$  samples) and Kansas-Lower Republican ( $n=354$  samples) river basins (Figure 2.6A). Emerald Shiner presence was uncommon in the Missouri ( $n=27$  samples), Marais Des Cygnes ( $n=16$  samples), Walnut ( $n=11$  samples), Cimarron ( $n=8$  samples), Neosho ( $n=8$  samples) and Smoky Hill-Saline ( $n=8$  samples) river basins. There was only one record of occurrence in the Upper Arkansas, Solomon, and Verdigris river basins, and Emerald Shiner was completely absent from the Upper Republican river basin (Fig. 2.6A).

### **Central Stoneroller**

Central Stoneroller was commonly collected across sites in all Kansas river basins. Central Stoneroller was present in a total of 3,251 samples from 3,017 unique locations and was absent from a total of 5,594 samples taken at 4,888 unique locations (Fig. 2.5B). Central Stoneroller was captured at the second highest number of sites of all of 15 native Kansas fish that we targeted for analysis (Table 1.1). Within Kansas, Central Stoneroller was captured at many sites in all 12 river basins (Fig. 2.6B) and site presence was most common in the Neosho ( $n=987$  samples), Kansas-Lower Republican ( $n=722$  samples), Lower Arkansas ( $n=514$  samples), and Smoky Hill-Saline ( $n=220$  samples) river basins. Central Stoneroller was infrequently captured

at sites within the Upper Arkansas ( $n=40$  samples) and Walnut ( $n=38$  samples) river basins (Fig. 2.6B).

### **Plains Minnow**

Plains Minnow was an uncommon fish that had a patchy distribution across Kansas river basins. Plains Minnow was caught a total of 750 times, at 736 unique locations and was absent from 8,095 collections at 7,132 unique locations (Fig. 2.5C). Plains Minnow was captured in the sixth lowest number of sites of the suite of 15 native Kansas fish that we targeted (Table 1.1). Within Kansas, Plains Minnow was captured regionally at sites in only 6 of 15 river basins (Fig. 2.6C). The basins in which Plains Minnow was most commonly present included the Lower Arkansas ( $n=447$  samples), Cimarron ( $n=251$  samples), and Kansas-Lower Republican ( $n=31$  samples) river basins. This taxon was rarely collected in the Missouri ( $n=11$  samples), Smoky Hill-Saline ( $n=9$  samples) and Upper Republican ( $n=1$  sample) river basins and was absent entirely from the six remaining river basins (Fig. 2.6C).

**Results: Objective 3 - Third, using a variety of quantitative analyses and visualization tools (i.e., ridgeline plots, box plots, histograms, pies, multiple logistic regression, probability plots), what habitat and impact variables are most influential for the distribution of fish taxa in our select groups?**

### **Emerald Shiner**

**Summary of BSSM-U Models (Best-Species-Specific Metric Regression using Unstandardized Data).** Of the metrics prioritized for Emerald Shiner from 11 ecological categories, annual velocity, natural land use, and width were removed from the analyses because they were highly correlated with other variables (Appendix Figure 2.1A). Of the remaining regressors, we ran separate models for three correlated substrate variables (silt, sand, clay) and



two correlated agricultural land use types (pasture, cropping). Of all the multiple logistic regression models that combined one uncorrelated metric from each of 11 ecological categories, two models had a  $\Delta AIC < 2$  (Table 2.2). Each of these top models had a prediction accuracy of 74% (correctly predicted 809 of 1067 presences) and explained 23% of the variation between the balanced sample classes ( $D^2$ ; Table 2.2). The two top models ( $\Delta AIC < 2$ ) each had five significant regressors that represented the same five ecological categories: substrate, stream order, sinuosity, agricultural land use, and natural land use (Table 2.2).

**Substrate.** Probability of Emerald Shiner presence was not positively correlated with any single substrate type in top models, suggesting that this taxon was a substrate generalist. Surprisingly, the best substrate predictor for Emerald Shiner was silt, for which probability of occurrence decreased as silt increased (Table 2.2; Figure 2.7D). Sand and silt were inversely correlated (Appendix Fig. 2.1A). Emerald Shiner probability of occurrence increased significantly with sand in models with  $\Delta AIC > 2$  (Table 2.2). Ridgeline plots showed that Emerald Shiner was more often present when sand was common (Figure 2.8A) and when silt was limited (Fig. 2.8D). Examining proportional symbol resource maps, river basins in which Emerald Shiner was common (Lower Arkansas and Kansas-Lower Republican river basins) had high percentages of sand (Figure 2.9B) but could also have high silt (Fig. 2.9C).

**Stream Order and Sinuosity.** As expected, the probability of Emerald Shiner presence increased with stream order (Table 2.2; Fig. 2.7G). Ridgeline plots showed that Emerald Shiner occurred most often in higher order ( $> 7$ ) rivers (Figure 2.10A). In viewing proportional symbol resource maps, river basins in which Emerald Shiner was common (Lower Arkansas and Kansas-Lower Republican river basins) contained large rivers (Figure 2.11A). The probability of Emerald Shiner presence decreased as sinuosity increased (Table 2.2; Fig. 2.7M). Ridgeline plots

showed that Emerald Shiner was present at sites with the lowest sinuosities within our study area and largely absent from sites with the highest sinuosity values (Fig. 2.10G). In viewing proportional symbol resource maps, low sinuosity sites occurred in all basins (Lower Arkansas and Kansas-Lower Republican river basins) where Emerald Shiner was common (Fig. 2.11C).

**Agricultural Land Use.** The probability of Emerald Shiner presence decreased as both types of agricultural land use increased (Table 2.2; Fig. 2.7P, S). When both types of agriculture were considered together (pasture, cropping), land-use pie charts showed that Emerald Shiner could maintain presences at sites with higher levels of agricultural activity [site-specific average = 35.3% (range: 0-89%); Figure 2.12A]. Ridgeline plots showed that Emerald Shiner was more common at sites with low amounts of pasture (Figure 2.13A) and low levels of cropping (Fig. 2.13D). The proportional symbol resource map illustrated very low proportions of pasture in basins with sites where Emerald Shiner was common (Lower Arkansas and Kansas-Lower Republican river basins) (Figure 2.14A), and low to medium proportions of cropping in the same two basins (Fig. 2.14B). Combining data visualizations illustrated how this somewhat tolerant fish can survive at disturbed conditions. Specifically, because of tolerance, Emerald Shiner presence was maintained at high levels of cropping (Fig. 2.12A; pies), but the negative relationship (Fig. 2.7S) suggests that taxon does not necessarily thrive when this agricultural disturbance is present (i.e., this fish is more often present at low-medium proportions of cropping).

**Natural Grassland.** Surprisingly, the probability of Emerald Shiner presence decreased as natural grassland cover increased (Table 2.2; Fig. 2.7Y). Ridgeline plots showed that Emerald Shiner was present at more sites with low proportions of grassland (Figure 2.15A). Proportional symbol resource maps illustrated that river basins where Emerald Shiner was commonly present

(Lower Arkansas and Kansas-Lower Republican river basins) had moderate proportions of agriculture (Fig. 2.14A-B), higher proportions of development (Fig. 2.14C), and necessarily lower proportions of grassland (Fig. 2.14F), as a result of the complementary relationship of land use percentages.

**BSSM-S Regression Models (Best-Species-Specific Metric Regression using Standardized Data).** For Emerald Shiner, size and direction of coefficients for natural grassland ( $n=-0.92$ ), silt substrate ( $n=-0.63$ ), and stream order ( $n=0.42$ ), mirrored the significant variables described above (Appendix Table 2.3B). Thus, regression on best-standardized data reinforced the important but complex role of land use, substrate, and river size for this species in both sets of regressions (Appendix Table 2.3A).

**SSSM-U and SSSM-S Regression Models (Same-Species-Specific Metric Regression using Unstandardized and Standardized Data).** For unstandardized data that utilized the same metrics for all three taxa (Appendix Table 2.4), three similar, regressors, described in detail above, were significant (natural land cover,  $\beta=-1.90$ ; stream order,  $\beta=0.31$ ; sinuosity,  $\beta=-0.16$ ). In addition, sand was positively correlated with probability of Emerald Shiner presence ( $\beta=0.02$ ), when silt was not included in the regression model as a substrate option. Two other variables were significant in same-metric unstandardized models (average April discharge,  $\beta=-0.00$ ; local catchment area,  $\beta=-0.02$ ). For reasons described in the Central Stoneroller results section below, these two new significant metrics were likely related to system size. For the same-metric standardized models (Appendix Table 2.5), trends for Emerald Shiner were consistent with the results described above for same-metric unstandardized models.

### **Central Stoneroller**

**Summary of BSSM-U Models (Best-Species-Specific Metric Regression using Unstandardized Data).** For Central Stoneroller, highly correlated metrics were removed (catchment size) or run in separate models (annual vs June discharges; stream depth vs order) for Central Stoneroller (Appendix Fig. 2.1B). Two multiple logistic models had  $\Delta\text{AIC} < 2$  (Table 2.2). Each top model had a prediction accuracy of 76% (correctly predicted 2,690 of 3,218 presences) and explained about 31% of the variation between the balanced sample classes ( $D^2$ ; Table 2.2). In these two top models ( $\Delta\text{AIC} < 2$ ), the coefficients of the same six regressors from five ecological categories were significantly different from zero. These significant regressors were substrate, depth, sinuosity, two types of agricultural land, and developed land (Table 2.2). In one model [Model (A)], NHDPlus discharge was also significant (Table 2.2).

**NHDPlus Discharge.** The probability of Central Stoneroller presence declined with increasing average June NHDPlus discharge (Table 2.2; Fig. 2.7B). NHDPlus flow metrics, which measure total water movement through a system at larger geographic and temporal scales, exhibit lower values as distance to mainstem grows. Thus, the decreasing June discharge trend was indicative of conditions in the small streams which this taxon inhabits. The proportional map for June discharge illustrated this relationship between small streams and low NHDPlus flows (Fig. 2.9A).

**Substrate.** The probability of Central Stoneroller presence increased with increasing percentages of rock fragments (Table 2.2; Fig. 2.7E). Ridgeline plots showed that Central Stoneroller was not present in areas with high sand (Fig. 2.8B) but was present when rock fragment substrate was more common (Fig. 2.8G). Proportional symbol resource maps illustrated geographically this relationship between a higher proportion of rock fragments and basins at

which Central Stoneroller was present [Neosho and Kansas-Lower Republican (southern-border) river basins; Fig. 2.9D)].

**Stream Depth.** The probability of Central Stoneroller presence decreased with increasing stream depth (Table 2.2; Fig. 2.7K). Ridgeline plots showed that this taxon was more common in smaller, shallower streams (Fig. 2.10E). Proportional symbol resource maps illustrated that the distribution of Central Stoneroller [Neosho (northern half) and Kansas-Lower Republican (southern border, north-central region) river basins] overlapped with low order streams (Fig. 2.11A) and shallow depths (Fig. 2.11B).

**Sinuosity.** The probability of Central Stoneroller presence increased with increasing stream sinuosity (Table 2.2; Fig. 2.7N). Ridgeline plots showed that Central Stoneroller was only present at sites with higher sinuosities (Fig. 2.10H). Highly sinuous sites were distributed widely across all basins [Neosho (northern half) and Kansas-Lower Republican (southern border, north-central region) river basins] where Central Stoneroller was common (Fig. 2.11C).

**Agricultural Land Use.** The probability of Central Stoneroller presence increased with increasing pasture (Table 2.2; Fig. 2.7Q). Ridgeline plots showed that sites at which Central Stoneroller was present very often had lower levels of pasture, but also persisted in lower numbers across higher proportions of pasture (Fig. 2.13B). Proportional symbol resource maps provided an insight into this pattern; specifically, Central Stoneroller occurrence was highest within basins in eastern Kansas (Neosho and Kansas-Lower Republican river basins), an area that had many sites with high proportions of pasture (Fig. 2.14A). Central Stoneroller presence decreased with increasing agricultural cropping (Table 2.2; Fig. 2.7T). Like Emerald Shiner, Central Stoneroller occurred, on average, at locations that could have higher proportions of

agricultural activity [site-specific average = 33.9% (range = 0-94%); Fig. 2.12B], setting the stage for a negative relationship between this tolerant fish and this adverse stressor.

**Developed Land Use.** The probability of Central Stoneroller presence decreased with increasing high intensity development (Table 2.2; Fig. 2.7W). In ridgeline plots, Central Stoneroller was only present at sites where high intensity development was low (Fig. 2.13H). Proportional symbol resource maps illustrated that Central Stoneroller was present at sites with lower percentages of developed land [Neosho, Kansas-Lower Republican (northern half) and Lower Arkansas (western half) river basins; Fig. 2.14D].

**BSSM-S Regression Models (Best-Species-Specific Metric Regression using Standardized Data).** Using standardized data for best-species-specific metric regression (Appendix Table 2.3A), similar trends emerged as described above. For Central Stoneroller, stream depth ( $\beta=-1.30$ ) was an important metric for predicting probability of presence, followed by high intensity developed land use ( $\beta=-0.53$ ), average June discharge ( $\beta=-0.25$ ), agricultural cropping ( $\beta=-0.22$ ), sinuosity ( $\beta=-0.20$ ), agricultural pasture ( $\beta=0.14$ ), and rock fragment substrate ( $\beta=0.12$ ) (Appendix Table 2.3B).

**SSSM-U and SSSM-S Regression Models (Same-Species-Specific Metric Regression using Unstandardized and Standardized Data).** One same-metric unstandardized model had an  $\Delta AIC < 2$  (Appendix Table 2.4). This top model had five significant regressors that represented five ecological categories. Of these, two regressors were the same as the significant regressors reported above: stream width ( $\beta=-0.04$ ) and sinuosity ( $\beta=0.11$ ). An inverse relationship with sand was consistent with previously described trends when rock fragments was not a substrate variable in the model (sand,  $\beta=-0.01$ ). Two new variables emerged as significant (natural land cover,  $\beta=1.17$ , gradient  $\beta=21.87$ ), which require further examination. However, in

general, trends in same-metric unstandardized models were consistent with those in same-metric unstandardized regression models (Appendix Table 2.5).

## **Plains Minnow**

**Summary of BSSM-U Models (Best-Species-Specific Metric Regression using Unstandardized Data).** For Plains Minnow, highly correlated variables were removed (catchment size) or run in separate models (May vs August discharges, silt vs sand substrates, stream depth vs order; Appendix Fig. 2.1C). Two top multiple logistic regression models had a  $\Delta AIC < 2$  (Table 2.2). Each of these top models had a prediction accuracy of 89% (correctly predicted 504 of 556 presences) and explained 55% of the variation between the balanced sample classes for Plains Minnow ( $D^2$ ; Table 2.2). Top models ( $\Delta AIC < 2$ ) included significant regressors that represented the same seven ecological categories. In both models, coefficients were significantly different from zero for variables in the ecological classes representing substrate, depth, sinuosity, developed land, natural land, dam effects, gradient (Table 2.2).

**Substrate.** Plains Minnow presence probability increased as percentages of sand increased (Table 2.2; Fig 2.7F). Ridgeline plots showed that Plains Minnow most often occurred at sites where percentages of sand were relatively high (Fig. 2.8C) and where presence of silt was low (Fig. 2.8F). Proportional maps illustrated that basins in which Plains Minnow was most often present had high levels of sand (Lower Arkansas, Cimarron, and Kansas-Lower Republican river basins), but this taxa in need of restoration was not present at all sites where high percentages of sand occurred (Fig 2.9B).

**Stream Depth.** The probability of Plains Minnow presence increased with increasing stream depth (Table 2.2; Fig. 2.7L). Ridgeline plots showed that Plains Minnow was not in the shallowest areas, nor the deepest (Fig. 2.10F). Proportional symbol resource maps illustrated that

appropriately sized streams were common in the south-central portion of our study area where most Plains Minnow presence had been recorded (Lower Arkansas and Cimarron river basins), as well as elsewhere throughout the state (Fig. 2.11B).

**Sinuosity.** Plains Minnow presence decreased with increasing stream sinuosity (Table 2.2; Fig 2.7O). Ridgeline plots showed that Plains Minnow was present at sites with intermediate sinuosities (Fig. 2.10I). Proportional symbol resource maps illustrated that appropriate moderate sinuosity values were present in the south-central portion of the state, where Plains Minnows was found, as well as elsewhere (Fig. 2.11C).

**Developed Land Use.** The probability of Plains Minnow presence decreased with increasing developed open space (Table 2.2; Fig. 2.7X). Ridgeline plots showed that Plains Minnow occurred at sites that had lower proportions of developed open space (Fig. 2.13I). Using proportional symbol resource maps, we observed that sites where Plains Minnow was present [Lower Arkansas, Cimarron, and Kansas-Lower Republican (northern portion), and Missouri river basins], had low developed open space (Fig. 2.14E). However, this species did not occur at all locations with low developed open space.

**Natural Grassland.** The probability of Plains Minnow presence increased with increasing grassland cover (Table 2.2; Fig. 2.7AA). Ridgeline plots showed that Plains Minnow was only present at sites with high percentages of this natural land use type (Fig. 2.15C). Additionally, land use pies showed that Plains Minnow was associated with sites that had very high proportions of grassland cover [site-specific average = 63.4% (range = 1-95%); Fig. 2.12C], which illustrates that this taxon neither tolerates nor thrives in disturbed locations. Proportional symbol resource maps showed that the patchy distribution of Plains Minnow (Lower Arkansas, Cimarron river basins) overlapped with sites that had high proportions of grassland, but this



species of greatest conservation concern did not occur at all sites with high grassland (Fig. 2.14F).

**Dams.** As the proportion of upstream mainstem open water (UMO) from a given sample site increased (i.e., distance from dam), so did the probability of Plains Minnow presence (Table 2.2; Fig. 2.7DD). Ridgeline plots showed that Plains Minnow only occurred at sites away from dams (high UMO) and was almost entirely absent from sites with little to moderate proportions of upstream mainstem open water (i.e., close to dams; Fig 2.15F). Proportional symbol resource maps illustrated that the basins in which Plains Minnow was present had sites away from dams (Lower Arkansas, Cimarron, and Missouri river basins), but again this Kansas threatened species did not occur at all locations away from dams (Figures 2.16A-B).

**Gradient.** The probability of Plains Minnow presence decreased as stream gradient increased (Table 2.2; Fig. 2.7GG). Proportional symbol resource maps showed that in the regions of Kansas where Plains Minnow presence was clustered (Lower Arkansas and Cimarron river basins), gradients were low (Fig. 2.16C).

**BSSM-S Regression Models (Best-Species-Specific Metric Regression using Standardized Data).** Using standardized data for best-metric regressions (Appendix Tables 2.3A-B), trends were similar to those described above. Open proportion of undammed upstream (UMO) was the best metric for predicting probability of Plains Minnow presence ( $\beta=1.42$ ), followed by stream depth ( $\beta=1.20$ ), natural grassland land cover ( $\beta=1.10$ ), sand substrate ( $\beta=1.04$ ), developed open space land use ( $\beta=-0.47$ ), gradient ( $\beta=-0.39$ ), and sinuosity ( $\beta=-0.29$ ).

**SSSM-U and SSSM-S Regression Models (Same-Species-Specific Metric Regression using Unstandardized and Standardized Data).** For Plains Minnow, one unstandardized model using the same metrics for all three fish taxa had  $\Delta AIC < 2$  (Appendix Table 2.4). This

model had six significant regressors that represented six ecological categories. Of these, five were the same as seen in the models described above in detail [sand ( $\beta=0.06$ ), developed land ( $\beta=-1.94$ ), natural land cover ( $\beta=1.29$ ), distance to dams ( $\beta=0.04$ ), gradient ( $\beta=-182.24$ )]. One significant variable, width ( $\beta=-0.02$ ), differed because this variable, not depth, was utilized in all same-metric regressions. Once again, standardizing the same-metric regressions resulted in consistent findings for Plains Minnow (Appendix Table 2.5).

**Results: Objective 4 - Fourth, what insights are gained by comparing and contrasting the results across taxa within the chosen group compared to single taxon analysis?**

**Grouping 1. Emerald Shiner vs. Central Stoneroller and Plains Minnow**

Emerald Shiner showed a broader, more general response than the other two taxa for two metrics (substrate specialization and developed land use (Figure 2.17 – Group 1). Emerald Shiner was a substrate generalist, and unlike Central Stoneroller and Plains Minnow was not positively related to a single substrate type (Fig. 2.7D vs Fig. 2.7E, F). Emerald Shiner tolerated a wide range of development, unlike Central Stoneroller and Plains Minnow (Fig. 2.7V vs Fig. 2.7W, X) which were most often present at sites with the lowest values of development.

**Grouping 2. Central Stoneroller vs. Emerald Shiner and Plains Minnow**

Central Stoneroller responded differently than the other two taxa in response to five metrics (Fig. 2.17 – Group 2). First, the widely distributed Central Stoneroller that occurred throughout Kansas contrasted with the patchily distributed Emerald Shiner and Plains Minnow, which were concentrated in the northeast and south-central regions (Fig. 2.6B vs Fig. 2.6A, C). Second, Central Stoneroller was associated with a larger gravel-cobble substrate (Fig. 2.7E vs Fig. 2.7D, F). Third, Central Stoneroller responded differently than the other taxa to three

additional metrics that largely reflected the consistent and important role played by system size. Central Stoneroller was associated with smaller streams (Fig. 2.7K vs Fig. 2.7G, L), a small-system NHDPlus flow (Fig. 2.7B vs Fig. 2.7A, C), and a small stream sinuosity (Fig. 2.7N vs Fig. 2.7M, O).

### **Grouping 3. Plains Minnow vs. Emerald Shiner and Central Stoneroller**

Plains Minnow differed from Emerald Shiner and Central Stoneroller relative to four metrics (presence site abundance, response to agricultural land use – crops, response to dams, and gradients at which they were present; Fig. 2.17 – Group 3). First, the relatively common Emerald Shiner and Central Stoneroller contrasted with the declining Plains Minnow relative to the number of sites at which they were present. Emerald Shiner was moderately common, Central Stoneroller was very common, and Plains Minnow was uncommon within our study area (Fig. 2.5C vs Fig. 2.5A, B). Second, Plains Minnow was less affected by agriculture than the other two taxa (Fig. 2.7R, U vs Fig. 2.7P, Q, S, T) possibly because the less tolerant Plains Minnow only occurred at sites with a relatively low incidence of agricultural activity overall [site-specific average = 26.6% (0=87%); Fig. 2.12C]. Third, unlike the other two taxa, Plains Minnow was the only taxa to be statistically and negatively affected by dams (Fig. 2.7DD vs Fig. 2.7BB, CC). Fourth, gradient was significant only for Plains Minnow (Fig. 2.7GG vs Fig. 2.7EE, FF), possibly because of region-specific gradients that occurred in the restricted areas that Plains Minnow was caught.

### **Grouping 4**

All three fish that we examined here were small, short-lived, reproduced early and infrequently, and ate a generally omnivorous diet.

### **Grouping 5. Emerald Shiner vs. Central Stoneroller vs. Plains Minnow**

In our habitat-impact regression analyses, all three fish responded differently to two variables: pastureland (agriculture land use) and natural land cover (natural land) (Fig. 2.17 – Group 5). First, the probability of Emerald Shiner and Central Stoneroller presences were significantly associated with pasture cover, but in opposing ways whereas pasture did not affect the probability of Plains Minnow presence (Fig. 2.7P vs Fig. 2.7Q vs Fig. 2.7R). Second, all three fish were unique in their responses to natural land metrics. Natural land cover significantly affected the presence probability of both Emerald Shiner and Plains Minnow, but in opposing ways, but did not significantly affect Central Stoneroller in top models (Fig. 2.7Y vs Fig. 2.7Z vs Fig. 2.7AA).

## **Results: Objective 5 - What guidance can our framework approach provide for restoration planning and future data collection?**

### **Locations Promising for Restoration of Plains Minnow**

When the relative probability of Plains Minnow occurrence resulting from our top model is mapped (Figure 2.18), several insights emerged that can aid on-the-ground restoration activities (e.g., sampling, reintroduction, trap and transfer). In addition to many areas where this taxon is unlikely to ever occur (dark blue points, Fig. 2.18A), our model probability map confirms likely areas of occurrence (red points, Fig. 2.18A) where this fish has been caught in recent samples (orange shapes, areas I-II; Fig. 2.18B). Additionally, these maps suggest likely areas of occurrence where this fish has not yet been caught in samples (light blue shapes, areas III-VIII; Fig. 2.18B), and notes areas where they were historically found, that now exhibit unlikely occurrence probabilities (gray shapes; areas IX-XI; Fig. 2.18B).

### **Considerations for Restoration**

When the three areas where Plains Minnow had been found, might be found, and historically was found are overlaid on proportional symbol habitat and impact maps, several patterns emerged that may aid fisheries managers in deciding where to concentrate restoration efforts (Figure 2.19A-F). First, areas with sand substrate and without silt substrate correspond with potentially favorable areas for Plains Minnow restoration (Fig. 2.19A-B). Second, a higher probability of Plains Minnow presence occurred in bigger deeper rivers (Fig. 2.19C). However, not all locations with adequate depth had a high probability of occurrence for Plains Minnow. Third, little is known about how sinuosity might affect instream habitat, but our probability map provides a guide for site identification where sinuosities might be appropriate for Plains Minnow (Fig. 2.19D). Lastly, Plains Minnow had a positive relationship with proportion of upstream undammed open water, indicating an association with undammed streams (Fig. 2.19E). A large total distance (both upstream and downstream, km) to a mainstem dam, (TM2D; Fig. 2.19F), also reinforced the belief that Plains Minnow required open stretches of undammed stream.

#### **Parameter Estimates at the Best and Worst Locations for Plains Minnow**

When conditions at the 10 best and 10 worst locations were compared (Tables 2.3 A-B), an even clearer picture emerges of promising areas to focus or avoid future restoration efforts. Reinforcing the important role that river size plays, mean stream order and depth at the best locations are 6X and 4X the mean values at the worst locations (Order: 6 vs 1, Depth: 5.61 vs 1.33m; Tables 2.3A-B). In addition, the mean percentage of sand at the best locations is 12X that of the worst locations (85.65 vs 6.57%) and the percentage of open water at the best locations is 5X that of the worst locations (100 vs 20%) (Tables 2.3A-B).

## Discussion

### Overview

Here we review six take home messages that interpret the results of our analyses, summarize the insights gained, and discuss possible management directions. First, we review the value of comparing thoughtfully grouped fish taxa. Second, we discuss influential regressors. Third, we explain how our assessment was aided by a weight of evidence approach. Fourth we interpret complex and ambiguous variables. Fifth, we provide examples for how our approach may guide restorative action for a state threatened species. Finally, we review how our framework advances the goals of adaptive management. Throughout we choose a single regressor as an example, but many of our take home messages apply to many regressors.

### Take Home Message 1: Value of Examining Groups of Taxa

Data analysis of groups of fish can enhance and expand conservation insights compared to the analysis of a single taxon. As an example, a single species focus on uncommon fish taxa (threatened, endangered, or species in need of conservation) can be derailed by small, ambiguous datasets (Milliken and Johnson 1989, 2001; Austen et al. 1994), whereas a comparative analyses of multiple uncommon and common fish taxa can identify new trends. By comparing the across basin distribution of Central Stoneroller, Emerald Shiner and Plains Minnow, we identified that common fish (Emerald Shiner and Central Stoneroller) can be either ubiquitous throughout the state (Central Stoneroller) or regionally heterogeneous (Emerald Shiner). Overall commonness within Kansas, has been well established (Distler et al. 2014), but distributional similarities between Emerald Shiner and Plains Minnow have not. Using the common but heterogeneous Emerald Shiner distribution to guide restoration of the uncommon but regionally distributed

Plains Minnow is a potential direction that would not have been obvious without our three fish comparison (Fig. 2.1A - Step 10 – information gap and testable hypothesis).

Our grouping approach provided opportunities to make additional use of existing resources (i.e. monitoring data, literature). Of course, fish groupings need to reflect the specifics of the fish and the study objective. Elsewhere, individual taxa have been grouped by taxonomy (Sánchez-Hernández 2020), statistical patterns (Smith et al. 2013, 2014; Hitchman et al. 2018a, b), or functional groups (Austen et al. 1994; Welcomme et al. 2006; Benoit et al. 2021) in ways that may or may not be useful for clarifying ecological patterns. Even though our three fish grouped differently depending on which optional characteristic was considered, our comparisons still provided guidance. In our objective 1, we were able to group characteristics to justify a comparative analysis. In objectives 2-3, we were able to compare empirical patterns of those three fish in a standardized way that showed generalities, recognized differences, provided sidebars to bound interpretation, and identified data needs. Although assignment of mechanisms for uncommonness (e.g., reproductive mode) would be premature, our fish taxa comparisons provided a larger context for interpretation of data for individual taxa (objective 4). With these insights, we were able to focus place-based recommendations for restoration of a Kansas threatened fish (objective 5).

### **Take Home Message 2: Consistent Priority Regressors**

Our pretty good, but not perfect, multiple logistic regression models identified consistently important regressors. As an example, one or more stream size metrics (order, width, depth, catchment size, sinuosity and the related NHDPlus flow) were significant for all three taxa, but told different stories for each fish. Central Stoneroller was a small system fish, Emerald Shiner was a large system fish, and Plains Minnow, which historically was found in

large rivers (Cross and Collins 1995), is presently limited to moderately large sized rivers and is overall absent from very large and very small systems. This trend, a KS threatened fish (Plains Minnow) occupying some but not all moderate sized rivers, and being absent from historically-occupied large streams, raises testable questions for future sampling (Fig. 2.1A – Step 10). For example, do Plains Minnow no longer occupy large rivers because changes in habitat have made them suitable? What habitat attributes do the currently occupied moderate sized streams share compared to those that are not occupied? The comparison of similarities and differences in system size across taxa painted a detailed picture of how size might be used more specifically to guide restoration activities.

Sinuosity, measured as the ratio of thalweg length to valley length (Fitzpatrick et al. 1998; Wilzbach and Cummins 2008), was significant for all three taxa and reflected a consistent association with system size. In our study, small stream fish (Central Stoneroller) were associated with higher sinuosity values and larger system fish (Emerald Shiner and Plains Minnow) were associated with smaller sinuosities. Complex geomorphic relationships related to channel geomorphology (width vs depth by order), channel units (pool vs riffle vs run; Hitchman et al. 2018a, b) or aquatic network characteristics (Taylor et al. 2019, 2021) play a role in shaping fish habitat use and behavior, but often require on-site measurements. Sinuosity, which can be calculated remotely for all fish sites, may be linked to local instream habitat requirements of specific taxa. Our findings about the consistent role that sinuosity plays raises the testable question of whether remotely-senses sinuosity can predict local instream channel conditions relevant to specific taxa (width to depth ratios, channel types, sand bars, bend habitat)(Fig. 2.1A – Step 10).

### **Take Home Message 3: Weight of evidence approach**



Individual analyses and visualizations are useful, but a weight of evidence approach, which integrates fish and resource maps, exploratory plots, and regressions, can provide new insights (Regoli et al. 2019). For example, some attributes of substrate were statistically significant for all three fish taxa, but the trends within and across taxa were initially ambiguous based on the regressions alone. Histograms identified the erratic distribution of different substrates. Ridgeline plots showed that both Emerald Shiner and Plains Minnow used sand, whereas Central Stoneroller used rock fragments. From the literature we know that Emerald Shiner can use many different substrates (Ross 2001), whereas the Central Stoneroller and Plains Minnow display specialist tendencies (Cross 1967; Pflieger 1997; Platania and Altenbach 1998). Although Emerald Shiner and Plains Minnow both used sand, proportional symbol resource maps clarified how these two taxa responded differently to silt. Our analyses showed that although Emerald Shiner can be tolerant of silt levels (Pflieger 1997), there is a limit to the amount of silt that even tolerant fish can withstand. Finally, probability maps illustrated geographically where probability of occurrence was high for our uncommon fish, Plains Minnow, (i.e., high sand and low silt). Demonstrated silt tolerances for both common fish (Central Stoneroller and Emerald Shiner) identified a potentially important role that silt may play in restricting the distribution of the uncommon and intolerant Plains Minnow. For Kansas fish restoration, the establishment of substrate thresholds (not just averages, percentages, or dominant size/type) could help focus future Plains Minnow restoration (Fig. 2.1A - Step 10).

#### **Take Home Message 4: Complex and Ambiguous Variables**

Regressions on natural system monitoring data can be useful, but these natural variable associations can be extremely challenging to interpret. Some variables were difficult for us to interpret (land use, gradient, dams) even with our adaptive management framework and weight

of evidence approach. We used five different approaches to interpretations of regression patterns.

The first interpretation of a natural variable regression was one that potentially identifies the direct influence of an independent (X) variable (habitat or impact) on fish probability of presence. This is often what we expect to test in a regression analysis for deliberately chosen field sites or experimental manipulations. Here, we observed five examples in which potential direct effects of regressors on fish presence occurred as predicted from the general fish literature. First, negative responses to agricultural cropping (Emerald Shiner, Central Stoneroller) and agricultural pasture (Emerald Shiner) were consistent with trends expected from the literature. Second, negative responses to high levels of developed land (Central Stoneroller, Plains Minnow) were also expected from the literature. Third, the lack of a relationship between developed land and the relatively tolerant Emerald Shiner was not surprising based on literature expectations. Fourth, a positive relation between natural grassland and Plains Minnow is the relationship that many researchers expect between native species and historic land use conditions. Fifth, the adverse relationship between dams and Plains Minnow was consistent with general predictions about fragmentation on fish habitat. For this first interpretation, analysts need to acknowledge that correlation does not mean causation and even significant trends need to be tested more rigorously,

A second interpretation of a natural variable regression is required when multiple fish species are analyzed across different ranges of land use (X variable). For example, if one taxon occurs across a wide distribution of a variable, like agriculture, and another taxon occurs where there is little agriculture, a somewhat tolerant fish with a wide distribution may have a significant negative relationship with the variable and a potentially less tolerant fish with a narrow

distribution may show no effects. In our data, the negative relation between agriculture and tolerant Emerald Shiner and the lack of a strong relationship between agriculture and the state threatened Plains Minnow may reflect this scenario. In this interpretation, different ranges of conditions can provide different statistical trends that can in fact represent similar ecological responses. Multiple pieces of data are required to understand then devise additional statistical tests.

A third interpretation of natural data regressions patterns occurs when a taxon has a limited distribution that cooccurs with specific geographic conditions when there is undetectable statistical correlation or autocorrelation. The positive relationship between agriculture pasture and Central Stoneroller is an example of this interpretation. Proportional symbol maps illustrated that the areas where this fish is most common (Neosho and Kansas-Lower Republican river basins) overlapped with the high level of pasture in eastern part of the state. As a second example, Plains Minnow exhibited a negative relationship with gradient, potentially because it largely occurs in a region with consistently lower gradients (Lower Arkansas and Cimarron river basins). These associations represent fish-habitat trends or accidental associations. For the third interpretation, data analysts need to acknowledge that both spatial and non-spatial analyses need to be integrated even if this cannot be done in a single analysis. Other data visualizations (e.g., proportional symbol maps for habitat characteristics) are needed.

A fourth interpretation for regressions relates to the complementarity of some natural variables (again not related to detectable statistical correlation, autocorrelation, or multicollinearity). For example, negative or no relationship with natural grassland by the more common and tolerant Emerald Shiner was not expected. However, when this fish cooccurred with higher agriculture and higher development, a negative relationship emerged with the

remaining types of land use. A fifth interpretation of natural pattern regression can simply identify that a group of variables requires additional attention. The effect of dams on fish that are pelagic spawners is not surprising (Dudley and Platania 2007; Perkin and Gido 2011), but further analyzing the full suite of GIS dam variables (Ostroff et al. 2013) may reveal substantial insights into how different dam metrics affect different taxa.

In many of the above described interpretations, natural system regressions may reveal useful information, but interpretations of fish-impact relation need to be tempered. For all interpretations, presence of a fish at a specific condition does not necessarily mean that the condition is preferred or has a positive effect. Of course, conditions like system size and substrate may in fact represent conditions under which different taxa thrive. For all interpretations, more sophisticated regression tools may be needed. Outside of ecology, disciplines such as psychology and epidemiology, have advanced the development of statistical methods for teasing apart relationships among natural variables including mediation (connections among variables), moderation of variables, and the role of confounding, shared, and lurking variables (MacKinnon et al. 2007; Jung 2021; Bhandari 2023). We don't use advanced mediation analysis here, but we do observe some of the trends that these techniques address.

### **Take-home Message 5: Advantages for restoration**

Our three-taxa analysis of monitoring data, paired with our framework approach, provided specific tractable tools for restoration planning. Restoration of native fish is a priority among conservation professionals. Common fish restoration strategies include: the establishment of nongame fish hatcheries (rearing and stocking native fish), trap and transfer efforts, identifying locations for further collection (Trushenski et al. 2011; Harris et al. 2019; Valencia-Rodríguez et al. 2022, and targeting locations for release of restoration taxa. A difficulty

associated with these activities is often not knowing where to stock, where to transplant, where to release hatchery fish, and where to collect further samples and habitat data. Thus, many of our fish conservation strategy needs are location-based (Maire et al. 2017). What we provide here is one way to prioritize future locations to assess.

Our species-specific multiple logistic regressions allowed us to map fish occurrence probability across our study area using thoughtfully prioritized habitat metrics. Of course, much is unknown, and no statistical framework will provide exact locations for restoration success. This caveat is especially true when data on a rare taxon are limited. Nevertheless, our maps can identify promising regions and sites for future examination by a team of conservation professionals. Exploratory analyses, maps, regressions, probability plots, visualization of the probability of occurrence model and related proportional symbol maps for specific variables are part of the multi-step process that can facilitate a multi-way information exchange among teams on where to sample next. We showed how our framework can help with the Kansas threatened Plains Minnow. Our general approach for providing restoration guidance can be applied to other taxa even those with limited data. For example, using the exact steps identified here, we proposed a series of locations and variables that may aid additional capture of Blue Sucker (*Cycleptus elongatus*).

### **Take Home Message 6: Adaptive Management**

Our framework is an example of an implementable adaptive management approach that can compare distributional patterns of thoughtfully chosen fish taxa to aid restoration. Adaptive management is widely seen as a useful approach for conservation (e.g., Franklin et al. 2007; Williams 2011; Kingsford et al. 2017). However, implementable plans for problem-specific adaptive management for a specific problem are limited. Our methodology relies heavily on the

collaborative efforts between conservation professionals through data analysis and targeted data collections across iterations. Our comparative analyses of multiple taxa through our AM framework can help plan, identify gaps, and effectively connect datasets to make efficient use of existing resources.

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## Tables

**Table 2.1.** Objective 1 literature results for decision-tree characteristics (Steps A-C; Figure 2.2). Column 1 (white) displays our comparative taxa (1-3). The next columns (gray) display literature results related to our goal characteristics (status in Kansas and U.S. distribution). The following columns (blue) display literature results related to our matching characteristics (body size, life span, age of 1st reproduction and overall diet). The final columns (green) display literature results related to our optional characteristics (ecosystem type, size, and substrate and locations of spawning and egg development). This information is from the literature. Empirical trends from the monitoring data are explored in objectives 2-4.

| TAXA                   | Step A: GOAL CHARACTERISTICS |                          | Step B. MATCH CHARACTERISTICS |                 |                        |                          | Step C: OPTION CHARACTERISTICS |              |                       |                                |                |                                           |
|------------------------|------------------------------|--------------------------|-------------------------------|-----------------|------------------------|--------------------------|--------------------------------|--------------|-----------------------|--------------------------------|----------------|-------------------------------------------|
|                        |                              |                          |                               |                 |                        |                          | Ecosystem                      |              |                       | Spawning                       |                |                                           |
|                        | KS Status                    | US Distribution (states) | Body Size                     | Life Span       | 1st Reproduction (Age) | Diet                     | Type                           | Size         | Substrate Association | Substrate Size                 | Spawn Location | Egg Location                              |
| 1. Emerald Shiner      | Stable                       | 27                       | Small                         | Short (0-2 yr.) | 1 or 2                 | Inverts, Algae, Rotifers | Rivers, lakes                  | Medium-Large | Generalist            | Small (sand)                   | Water column   | Benthic (non-adhesive)                    |
| 2. Central Stoneroller | Stable                       | 32                       | Small                         | Short (3-4 yr.) | 1 or 2                 | Diatoms, Algae, Inverts  | Rivers                         | Small        | Specialist            | Large (cobble, pebble, gravel) | Benthic nest   | Benthic (nest)                            |
| 3. Plains Minnow       | Threatened (KS)              | 16                       | Small                         | Short (0-2 yr.) | Mostly 1               | Detritus, Inverts, Algae | Rivers                         | Medium       | Specialist            | Small (sand)                   | Water column   | Water Column (semi-buoyant, non-adhesive) |

**Table 2.2.** Unstandardized, multiple logistic regression models for all three fish using our Best-Species-Specific Metric (BSSM-U) approach. Each model includes 1 non-correlated, prioritized variable from each ecological category. Exceptions include if a metric is removed entirely due to correlations [NA (corr)], or if metrics within the same category are not correlated and thus do not need to be separated (Central Stoneroller, agricultural land). Column sections include (1) model identifier, (2) parameter estimates ( $\beta$ ) and standard errors (SE) for metrics within each of the 11 ecological categories, and (3) model evaluation statistics including:  $\Delta$  AIC, model accuracy (%), and D2 (%). For each fish, models are listed in order of descending AIC. Models A, B have a  $\Delta$  AIC < 2 and are considered top models (above the thick, dark gray dividing line). Metrics that were significant ( $P < 0.5$ ) are bolded and underlined. Regressor names and scale (if relevant are abbreviated as P: point, F: flowline, C: catchment, N: network catchment).

| Best Species-Specific Metric – Unstandardized Regression (BSSM-U) |                             |                |          |  |          |                  |                    |                      |                   |                           |          |  |               |                        |                  |      |                |  |               |  |               |  |           |  |              |              |                    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| Models                                                            | Ecological Categories       |                |          |  |          |                  |                    |                      |                   |                           |          |  |               |                        |                  |      |                |  |               |  |               |  |           |  | Δ AIC        | Accuracy (%) | D <sup>2</sup> (%) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|                                                                   | NHDPlus Flow (CFS or FPS)   | Substrates (%) |          |  |          | Stream Order (#) | Reach Measures (m) | Catchment Area (km²) | Average Sinuosity | Agricultural Land Use (%) |          |  |               | Developed Land Use (%) | Natural Land (%) | Dams | Gradient (m/m) |  |               |  |               |  |           |  |              |              |                    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|                                                                   | Emerald Shiner              |                |          |  |          |                  |                    |                      |                   |                           |          |  |               |                        |                  |      |                |  |               |  |               |  |           |  |              |              |                    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|                                                                   | Prioritized Metrics (Scale) |                |          |  |          |                  |                    |                      |                   |                           |          |  |               |                        |                  |      |                |  |               |  |               |  |           |  |              |              |                    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|                                                                   |                             |                | Silt (C) |  | Sand (C) |                  | Clay (C)           |                      | Order             |                           | Area (N) |  | Sinuosity (F) |                        | Pasture (C)      |      | Crop (C)       |  | All Types (C) |  | Grassland (C) |  | TM2D (km) |  | Gradient (F) |              |                    |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

**Table 2.3.** Habitat and impact conditions at the (A) top 10 highest (> 99%) and (B) top 10 lowest (<1%) probability sites for Plains Minnow occurrence. The first column is the site identifier. The second through 10th columns include the site conditions for each metric that exhibited significance in Plains Minnow models [From left to right: August discharge, sand substrate, silt substrate, stream order, stream depth, sinuosity, developed open space, grassland, Upstream open water distance to dam (UMO), and gradient]. Range and mean values for metric conditions can be found in the bottom two rows.

| <b>A. 10 Highest Probability Sites (&gt;99%) – Top Model/Of Interest Metrics – Plains Minnow</b> |                                                             |                 |                 |                     |                  |                  |                                    |                                    |                                           |                       |
|--------------------------------------------------------------------------------------------------|-------------------------------------------------------------|-----------------|-----------------|---------------------|------------------|------------------|------------------------------------|------------------------------------|-------------------------------------------|-----------------------|
| Site Numbers:                                                                                    | NHDPlus Flow: Average August Discharge (ft <sup>3</sup> /s) | <u>Sand (%)</u> | <u>Silt (%)</u> | <u>Stream Order</u> | <u>Depth (m)</u> | <u>Sinuosity</u> | <u>Development: Open Space (%)</u> | <u>Natural Land: Grassland (%)</u> | <u>Open Upstream Proportion [UMO] (%)</u> | <u>Gradient (m/m)</u> |
| 2989                                                                                             | 246.31                                                      | 75.02           | 9.05            | 6                   | 5.22             | 20.29            | 1.08                               | 92.05                              | 100                                       | 0.00                  |
| 3599                                                                                             | 453.95                                                      | 83.65           | 1.50            | 6                   | 5.65             | 21.88            | 2.56                               | 95.14                              | 100                                       | 0.00                  |
| 3601                                                                                             | 453.95                                                      | 83.65           | 1.50            | 6                   | 5.65             | 21.88            | 2.56                               | 95.14                              | 100                                       | 0.00                  |
| 3602                                                                                             | 453.95                                                      | 83.65           | 1.50            | 6                   | 5.65             | 21.88            | 2.56                               | 95.14                              | 100                                       | 0.00                  |
| 3603                                                                                             | 453.95                                                      | 83.65           | 1.50            | 6                   | 5.65             | 21.88            | 2.56                               | 95.14                              | 100                                       | 0.00                  |
| 3606                                                                                             | 453.95                                                      | 83.65           | 1.50            | 6                   | 5.65             | 21.88            | 2.56                               | 95.14                              | 100                                       | 0.00                  |
| 2841                                                                                             | 447.57                                                      | 91.27           | 1.39            | 6                   | 5.65             | 26.15            | 0.00                               | 90.08                              | 100                                       | 0.00                  |
| 2837                                                                                             | 447.57                                                      | 91.27           | 2.10            | 6                   | 5.65             | 26.58            | 0.00                               | 90.08                              | 100                                       | 0.00                  |
| 3524                                                                                             | 447.01                                                      | 79.45           | 2.10            | 6                   | 5.65             | 24.31            | 0.35                               | 90.75                              | 100                                       | 0.00                  |
| 2838                                                                                             | 447.57                                                      | 91.27           | 2.09            | 6                   | 5.65             | 26.97            | 0.00                               | 90.08                              | 100                                       | 0.00                  |
| Range                                                                                            | <b>246-453</b>                                              | <b>75-91</b>    | <b>1-9</b>      | <b>6</b>            | <b>5.22-5.65</b> | <b>20-26</b>     | <b>0-2</b>                         | <b>90-95</b>                       | <b>100</b>                                | <b>0.00-0.00</b>      |
| Mean                                                                                             | <b>430.6</b>                                                | <b>84.65</b>    | <b>2.42</b>     | <b>6</b>            | <b>5.61</b>      | <b>23.37</b>     | <b>1.43</b>                        | <b>92.87</b>                       | <b>100</b>                                | <b>0.00</b>           |
| <b>B. 10 Lowest Probability Sites (&lt;1%) – Top Model/Of Interest Metrics – Plains Minnow</b>   |                                                             |                 |                 |                     |                  |                  |                                    |                                    |                                           |                       |
| Site Numbers:                                                                                    | NHDPlus Flow: Average August Discharge (ft <sup>3</sup> /s) | <u>Sand (%)</u> | <u>Silt (%)</u> | <u>Stream Order</u> | <u>Depth (m)</u> | <u>Sinuosity</u> | <u>Development: Open Space (%)</u> | <u>Natural Land: Grassland (%)</u> | <u>Open Upstream Proportion [UMO] (%)</u> | <u>Gradient (m/m)</u> |
| 7044                                                                                             | 70.94                                                       | 8.95            | 47.47           | 5                   | 3.08             | 24.59            | 61.04                              | 3.96                               | 0                                         | 0.01                  |
| 7166                                                                                             | 1.07                                                        | 5.50            | 62.13           | 1                   | 1.15             | 28.34            | 35.98                              | 1.04                               | 0                                         | 0.01                  |
| 7588                                                                                             | 2.02                                                        | 10.01           | 61.06           | 2                   | 1.34             | 27.56            | 16.89                              | 0.00                               | 0                                         | 0.03                  |
| 79                                                                                               | 0.30                                                        | 6.31            | 52.80           | 1                   | 0.85             | 28.10            | 87.60                              | 0.47                               | 100                                       | 0.00                  |
| 6512                                                                                             | 0.92                                                        | 5.70            | 54.08           | 1                   | 1.11             | 27.84            | 62.74                              | 0.00                               | 100                                       | 0.01                  |
| 7128                                                                                             | 1.08                                                        | 5.85            | 62.67           | 1                   | 1.16             | 28.70            | 12.21                              | 1.22                               | 0                                         | 0.01                  |
| 7127                                                                                             | 1.08                                                        | 5.85            | 64.84           | 1                   | 1.16             | 28.22            | 12.21                              | 1.22                               | 0                                         | 0.01                  |
| 7129                                                                                             | 1.08                                                        | 5.85            | 68.56           | 1                   | 1.16             | 28.11            | 12.21                              | 1.22                               | 0                                         | 0.01                  |
| 7126                                                                                             | 1.08                                                        | 5.85            | 52.04           | 1                   | 1.16             | 27.67            | 12.21                              | 1.22                               | 0                                         | 0.01                  |
| 7132                                                                                             | 1.08                                                        | 5.85            | 52.21           | 1                   | 1.16             | 27.64            | 12.21                              | 1.22                               | 0                                         | 0.01                  |
| Range                                                                                            | <b>0-70</b>                                                 | <b>5-10</b>     | <b>47-68</b>    | <b>1-5</b>          | <b>0.85-3</b>    | <b>24-28</b>     | <b>12-87</b>                       | <b>0-3</b>                         | <b>0-100</b>                              | <b>0.00-0.03</b>      |
| Mean                                                                                             | <b>8.06</b>                                                 | <b>6.57</b>     | <b>57.79</b>    | <b>2</b>            | <b>1.33</b>      | <b>27.67</b>     | <b>32.53</b>                       | <b>1.16</b>                        | <b>20</b>                                 | <b>0.01</b>           |

## Figures

**Figure 2.1.** (A) Our 10-step iterative, adaptive management framework and (B) our statistical subloop with six additional steps. Our framework and statistical loop are described in Chapter 1 (Rode et al. 2023). (C) In this chapter, we add Step 9.5, which uses the framework to compare and contrast three fish to inform conservation decisions. Small red circles with arrows in A and C indicate opportunities for additional iterations of the framework.

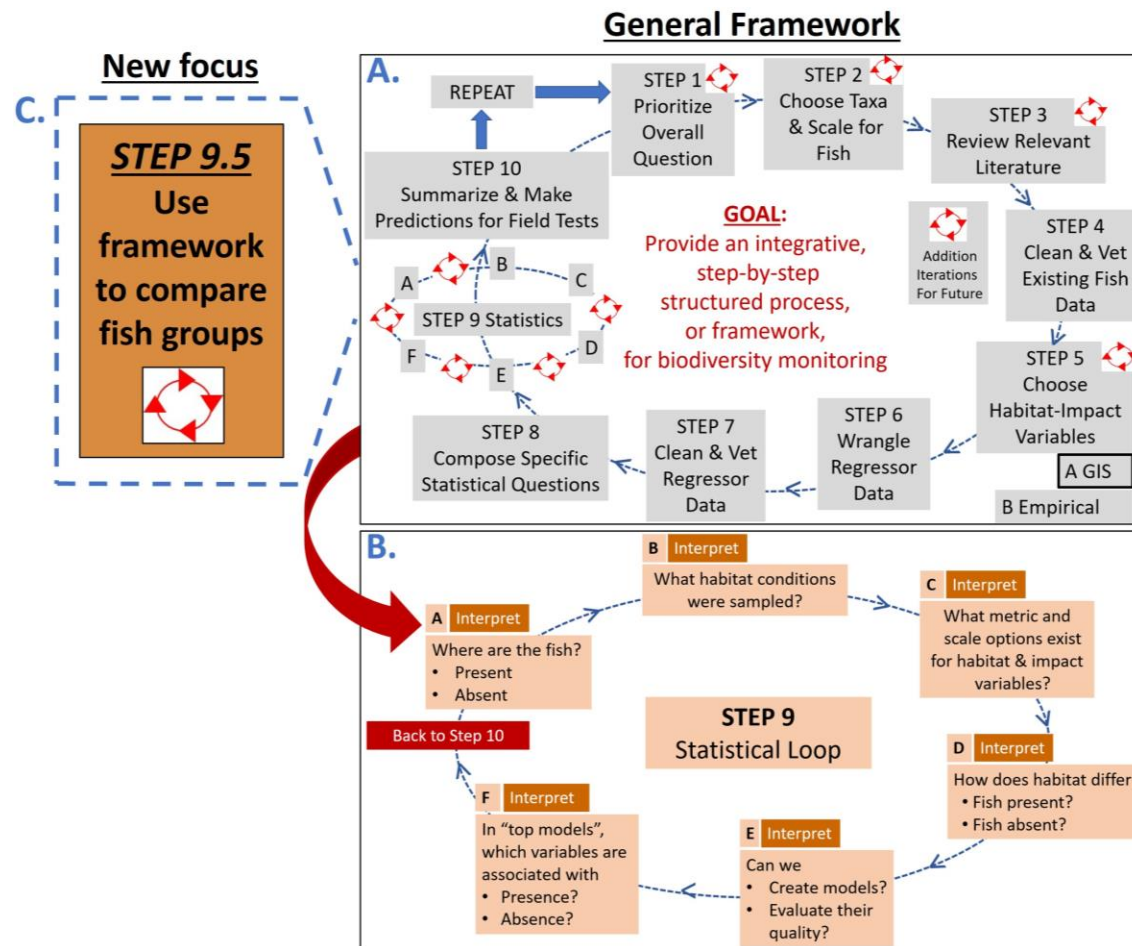


**Figure 2.2.** Our Objective 1, middle-complexity decision tree for grouping native fish. Insights may be accumulated from comparing and contrasting framework-based data for common and uncommon fish taxa. Three types of ecological and life history characteristics are used to select comparable fish taxa: Step A. Goal characteristics (presence site abundance and distribution); Step B. Matching characteristics (size, age, and diet); and Step C (ecosystem type, size, substrate and spawning locations). The literature (e. g. Distler et al. 2014, or any otherwise cited sources) is then assessed to form groupings (Step D).

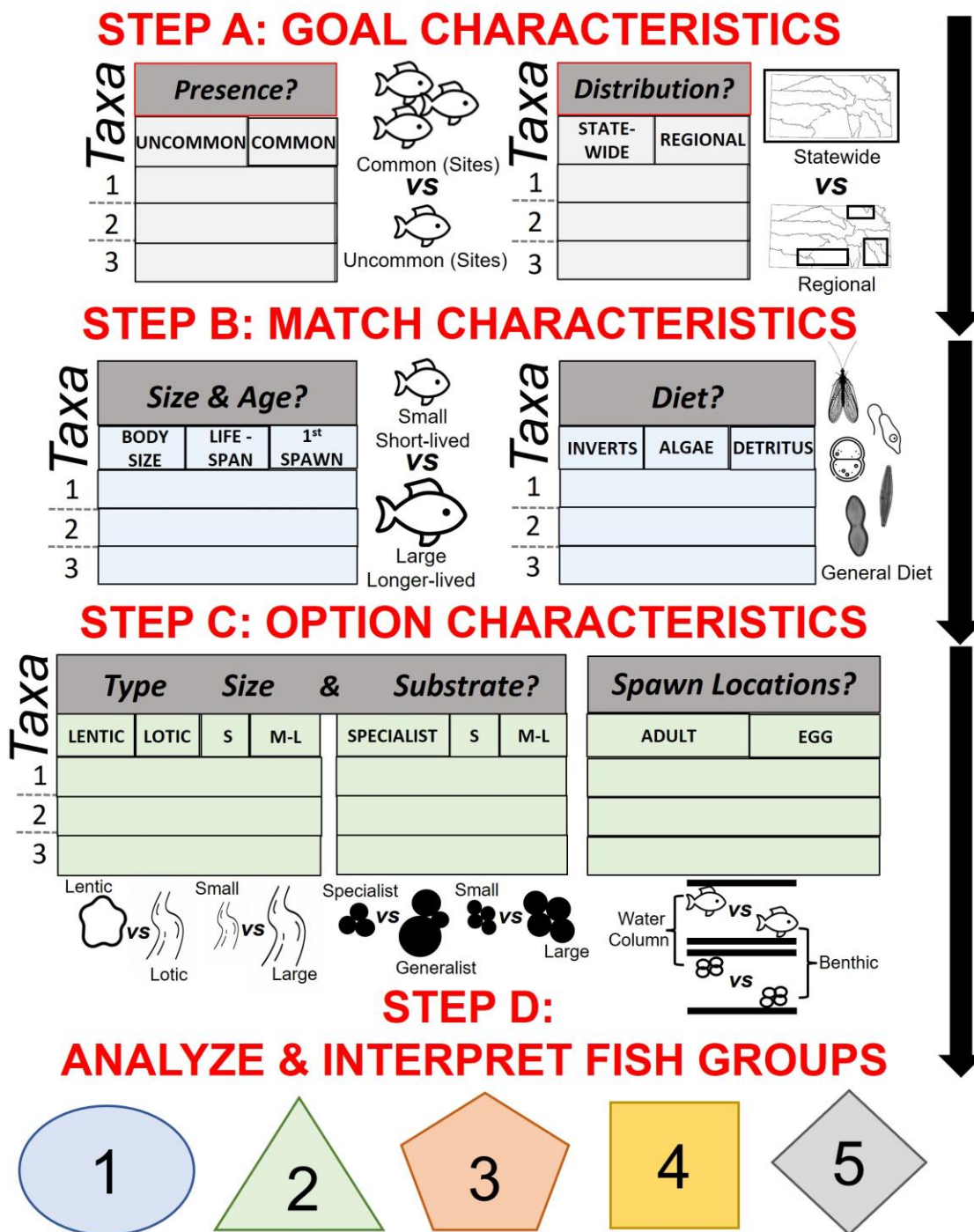


**Figure 2.3.** Our three comparable native Kansas stream fish: (Taxa 1) Emerald Shiner (*Notropis atherinoides*), (Taxa 2) Central Stoneroller (*Campostoma anomalum*), and (Taxa 3) Plains Minnow (*Hybognathus placitus*). Using our decision tree (Figure 2.2), these taxa are comparable as they exhibit contrasting presence site abundances (See Sample Number) – our goal characteristic (Step A). They also share matching characteristics (Step B): small body size, short lifespan, and a generalist diet. Thus, we are able to gain useful insight using framework data for this grouping.

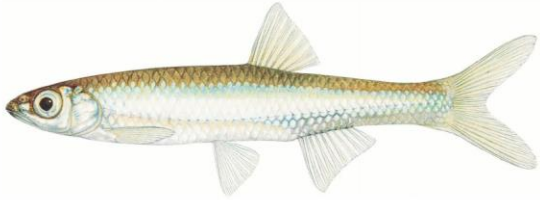
| Taxa 1                                                                            | Taxa 2                                                                              | Taxa 3                                                                              |
|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|  |   |  |
| <p>Emerald Shiner<br/> <i>Notropis atherinoides</i><br/> Sample Number: 1131</p>  | <p>Central Stoneroller<br/> <i>Campostoma anomalum</i><br/> Sample Number: 3251</p> | <p>Plains Minnow<br/> <i>Hybognathus placitus</i><br/> Sample Number: 750</p>       |



**Figure 2.4.** Four groupings were formed as a result of comparing life histories and traits of our three taxa using our decision tree and the literature (Figure 2.2). Grouping 1: Emerald Shiner contrasts with Central Stoneroller and Plains Minnow. Grouping 2: Central Stoneroller contrasts with Emerald Shiner and Plains Minnow. Grouping 3: Plains Minnow contrasts with Emerald Shiner and Central Stoneroller. Grouping 4: All three fish were comparable. Grouping 5: All fish differed (no traits met this criteria for the literature based objective 1).

## Objective 1: Types of Fish Groups

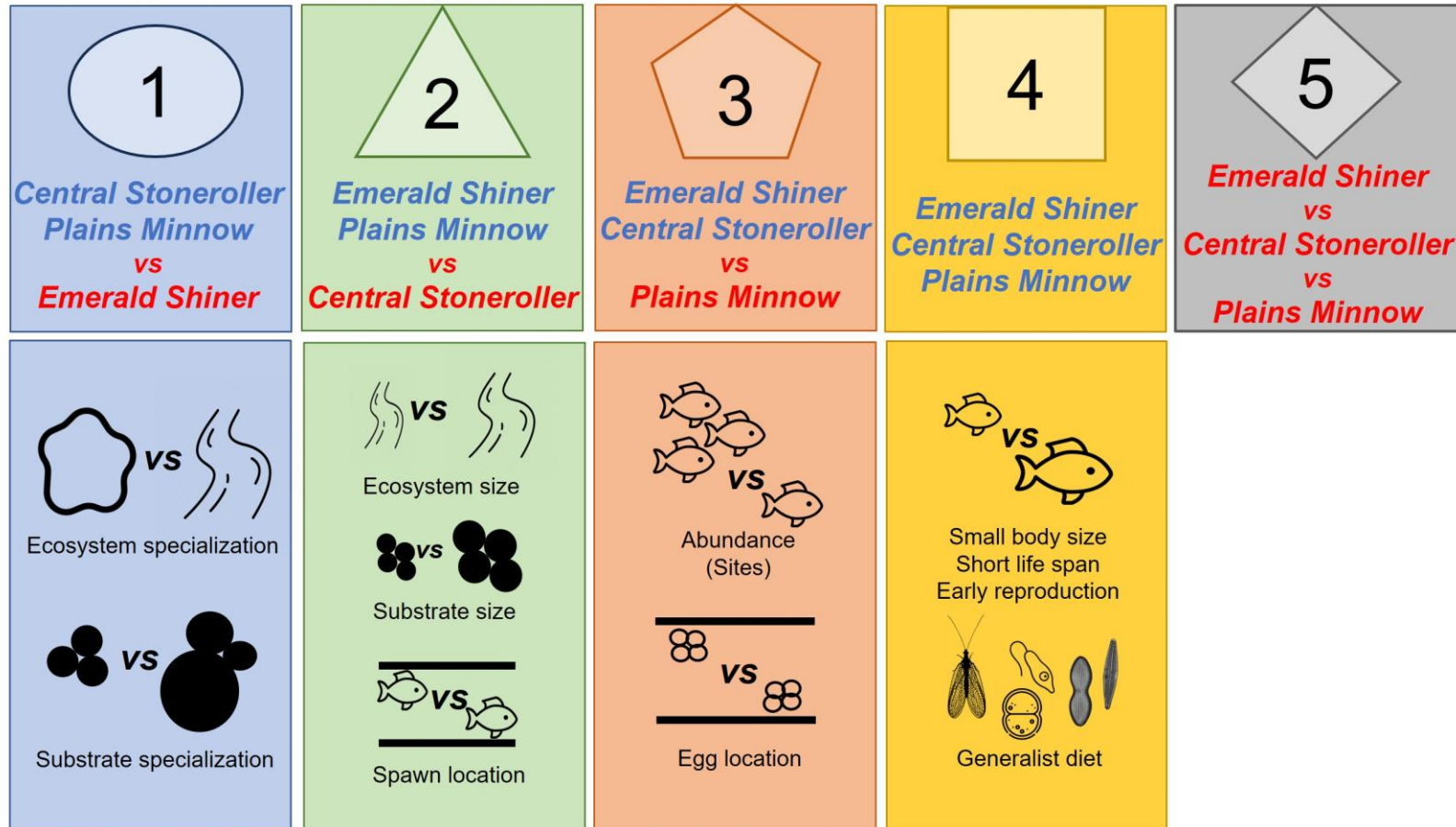


**Figure 2.5.** (A) Fish sample sites at which Emerald Shiner is present ( $n=1131$  total presences at 903 unique locations) and absent ( $n=7713$  total absences at 7076 unique locations). (B) Fish sample sites at which Central Stoneroller is present ( $n=3251$  total presences at 3017 unique locations) and absent ( $n=5594$  total absences at 4888 unique locations). (C) Fish sample sites at which Plains Minnow is present ( $n=750$  total presences at 736 unique locations) and absent ( $n=8095$  total absences at 7132 unique locations). Presences are marked by gold points and absence points are in blue. Major river basins in Kansas are indicated.

## Objective 2: Comparing Distributions

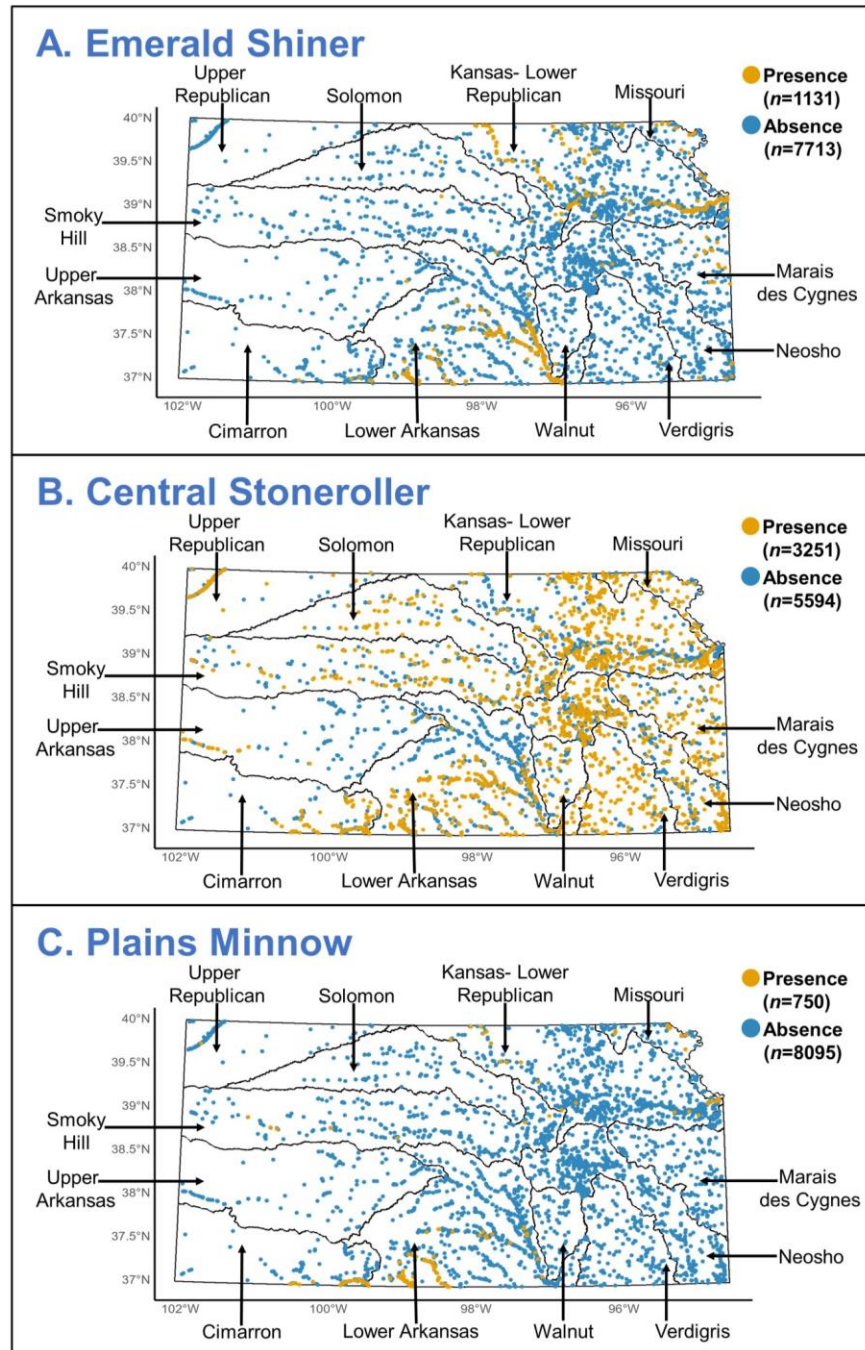




**Figure 2.6.** (A-C) Presence-absence maps with regions of concentrated presence for each fish within the state of Kansas indicated. (A) For Emerald Shiner, purple shapes highlight presence regions. (B) For Central Stoneroller, navy shapes highlight presence regions. (C) For Plains Minnow orange shapes highlight presence regions. Focusing on regions where the majority of presences lie for a given taxon allows for useful interpretation of distribution patterns. Major river basins in Kansas are indicated.

## Objective 2: Comparing Distributions

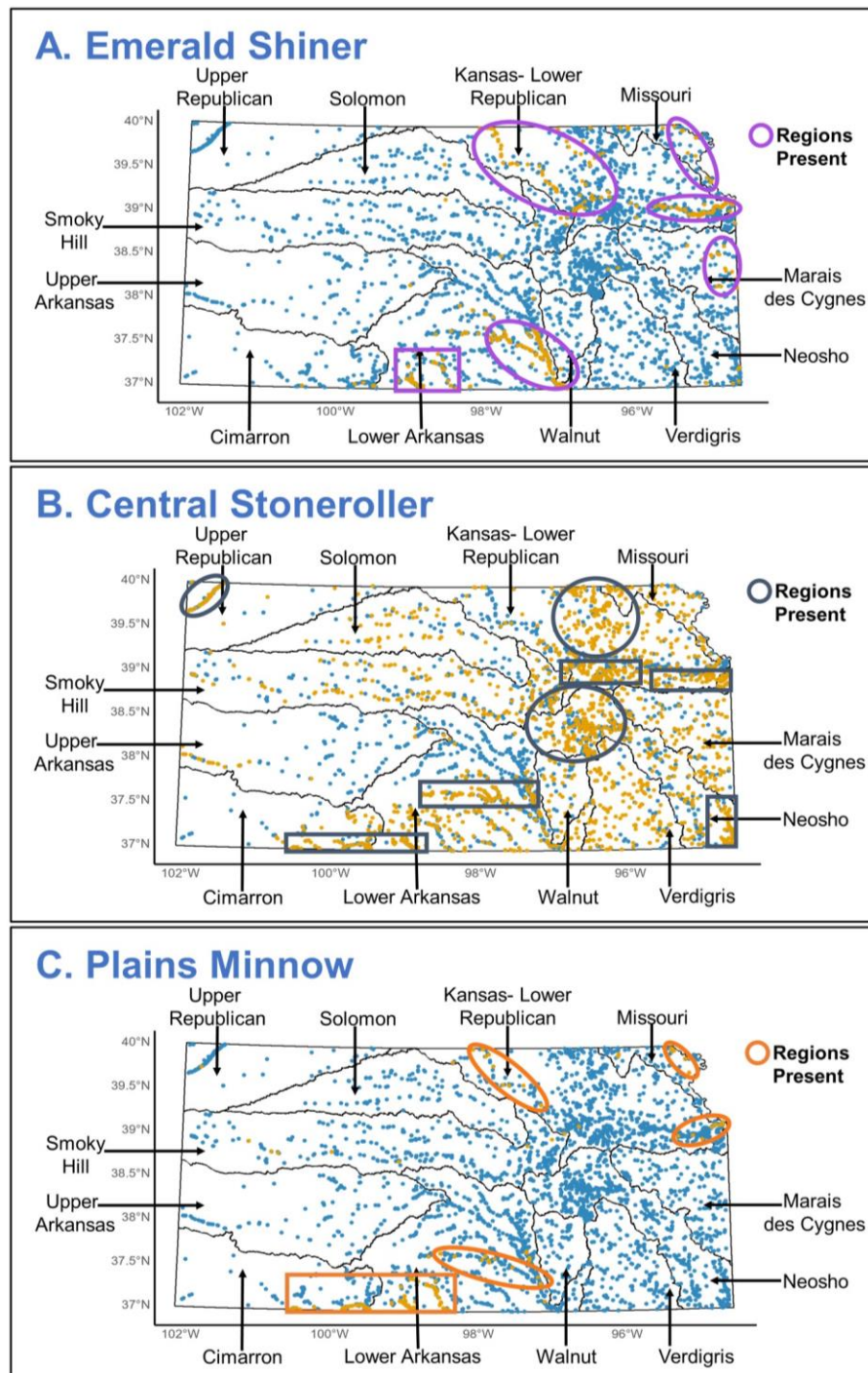
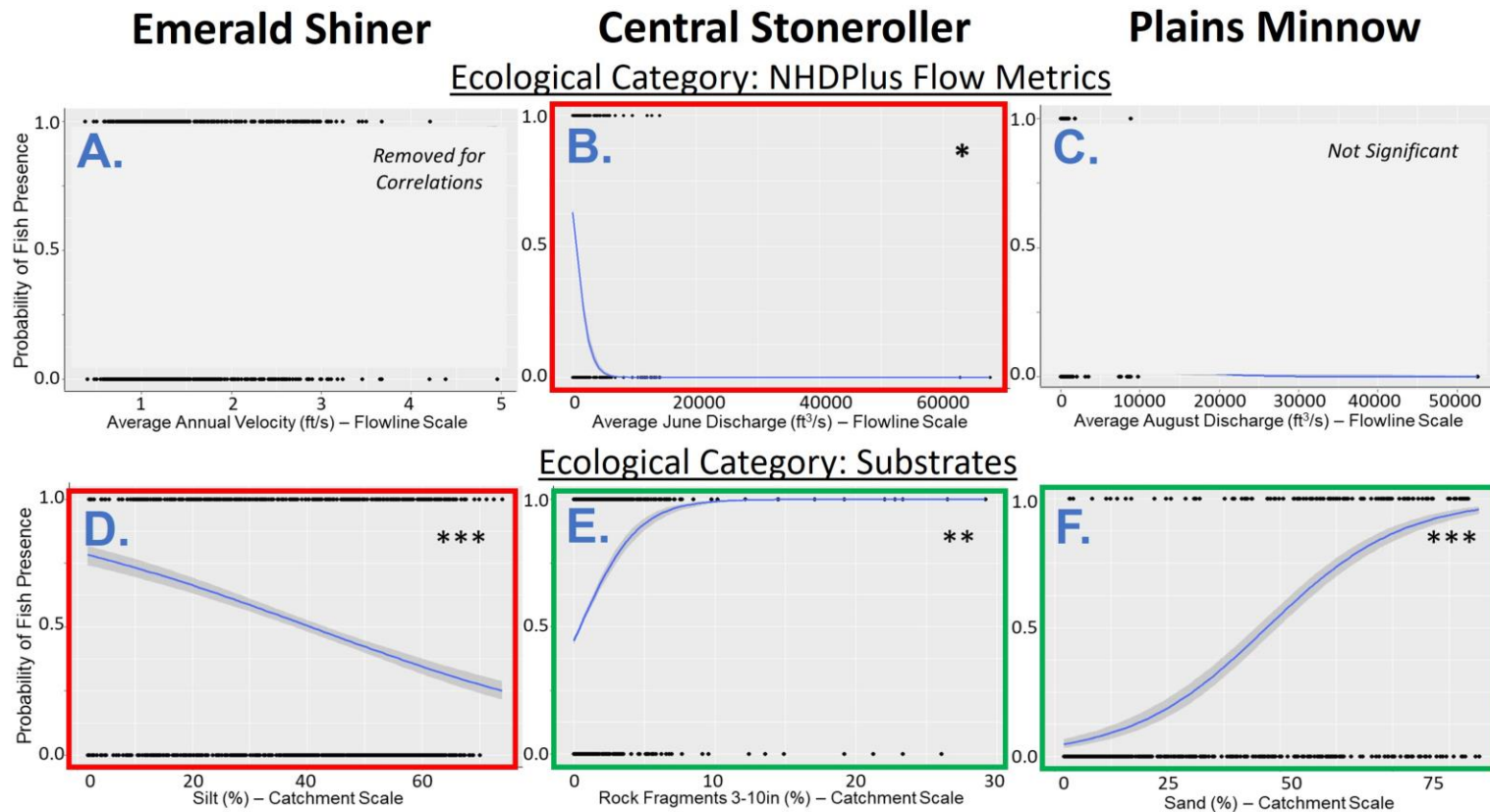
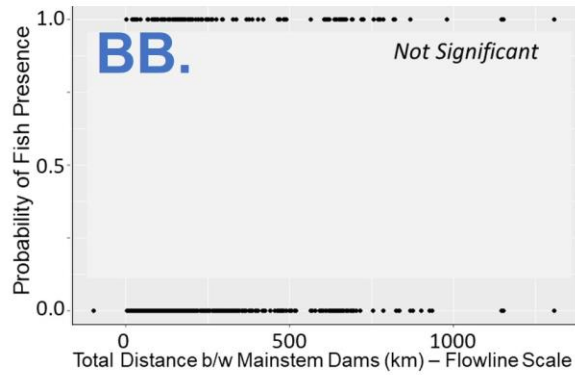


**Figure 2.7.** Probability plots from the regression models for all three fish by ecological category. (A-C) show NHDPlus flow metrics. (D-F) show substrate metrics. (G-I) show stream order. (J-L) show reach measures (depth). (M-O) show sinuosity. (P-R) show pasture cover (agricultural land use). (S-U) show crop cover (agricultural land use). (V-X) show developed land uses. (Y-AA) show natural land uses. (BB-DD) show dam metrics. (EE-GG) show gradient. The left column (A, D, G, J, M, P, S, V, Y, BB, EE) always depicts Emerald Shiner trends. The middle column (B, E, H, K, N, Q, T, W, Z, CC, FF) always depicts Central Stoneroller trends. The right column (C, F, I, L, O, R, U, X, AA, DD, GG) always depicts Plains Minnow trends. Ecological categories included had a metric that exhibited significance ( $P < 0.05$ ) in top models for at least one taxon. If a trend is not shown, the purpose is stated in the top right corner (i.e. not significant, correlations, not in top model, not prioritized). The metrics level of significance can be viewed in the top left corner (Significance Codes: '\*\*\*',  $P < 0.001$ ; '\*\*',  $0.001 < P < 0.01$ ; '\*',  $0.01 < P < 0.05$ ).

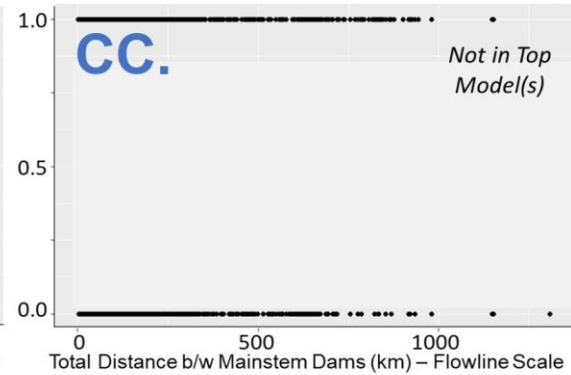


## Emerald Shiner

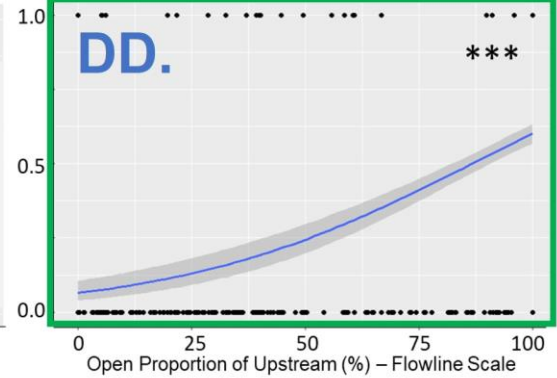


## Central Stoneroller

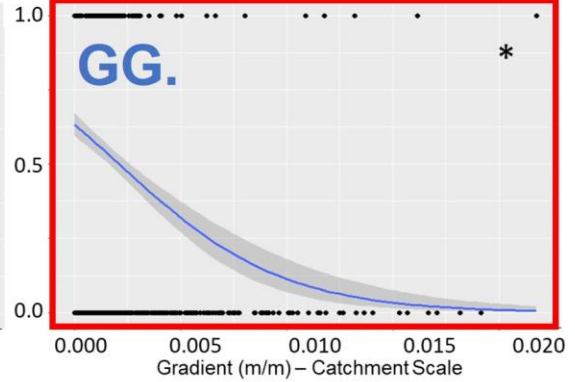
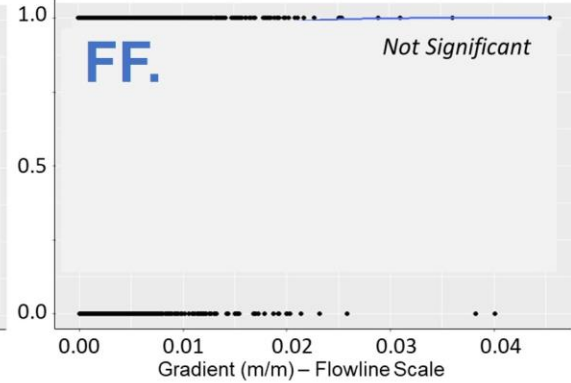
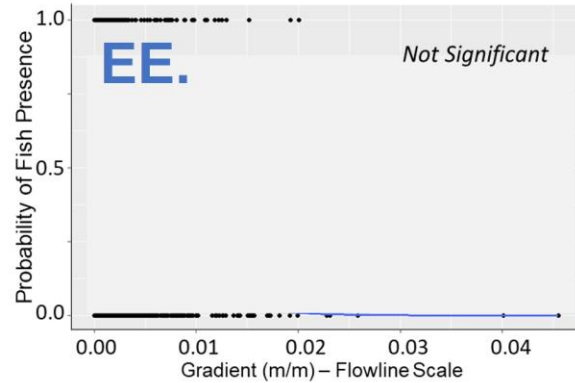
Ecological Category: Dams



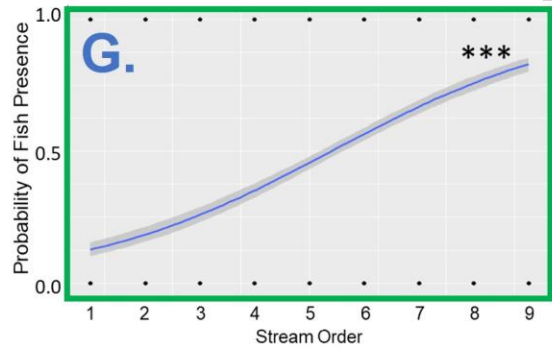
## Plains Minnow



Ecological Category: Gradient



## Emerald Shiner

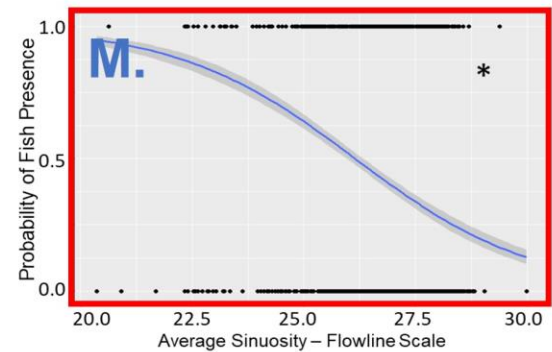
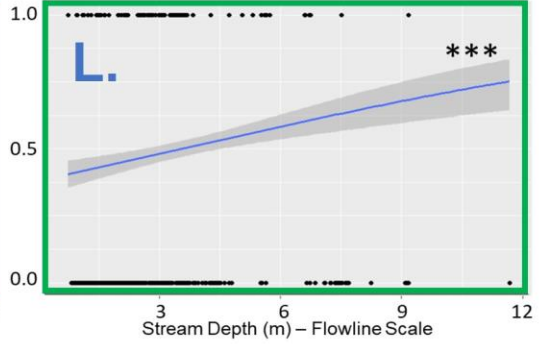
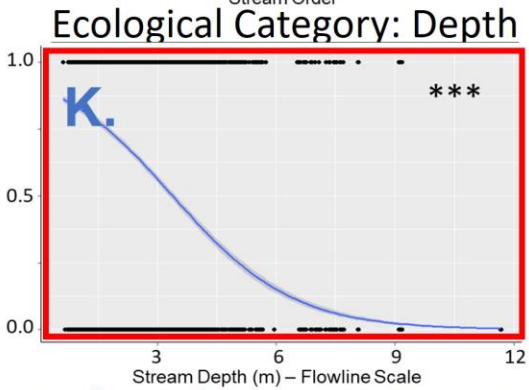
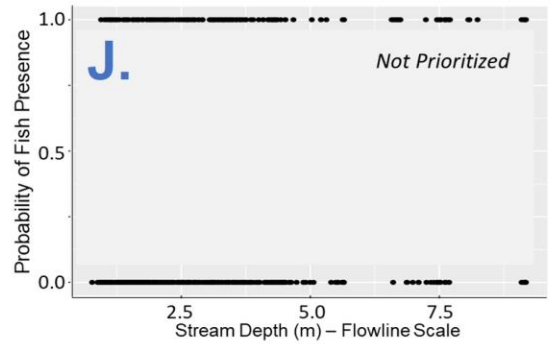
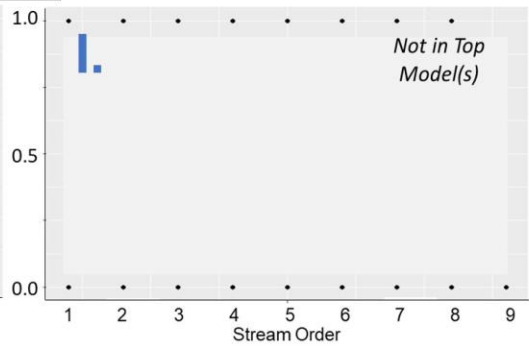


## Central Stoneroller

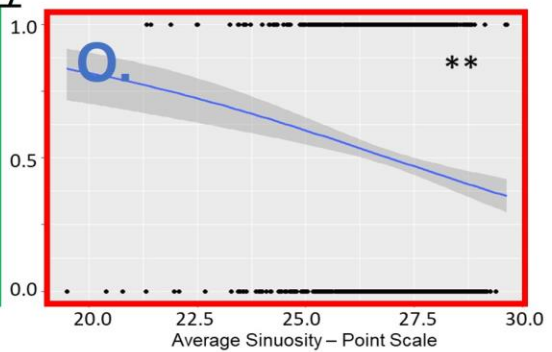
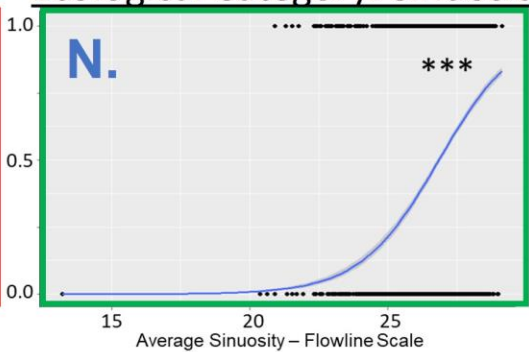
Ecological Category: Stream Order



## Plains Minnow



## Ecological Category: Sinuosity



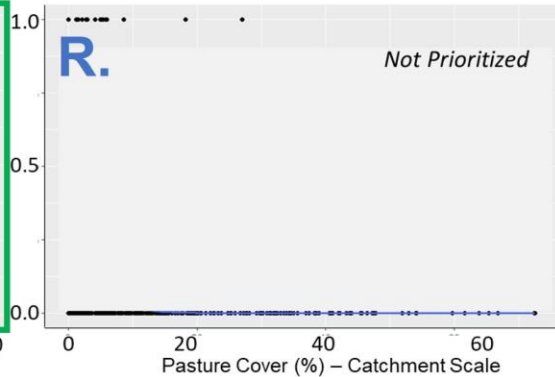
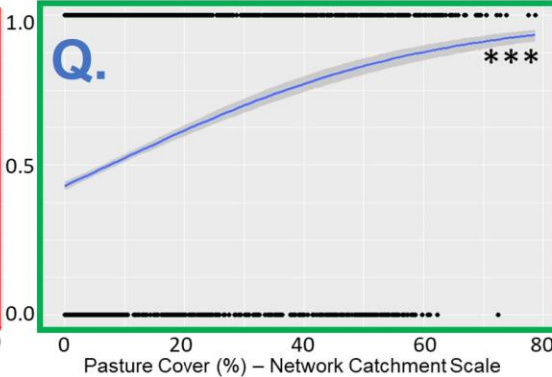
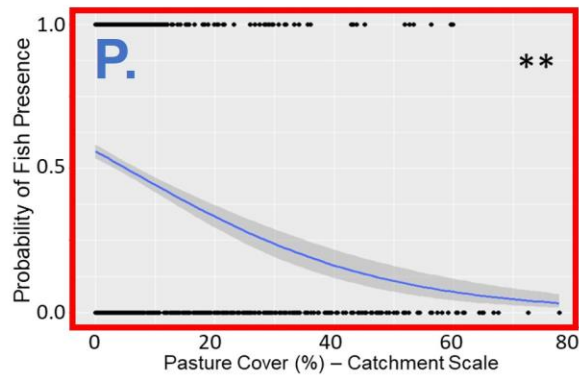


## Emerald Shiner

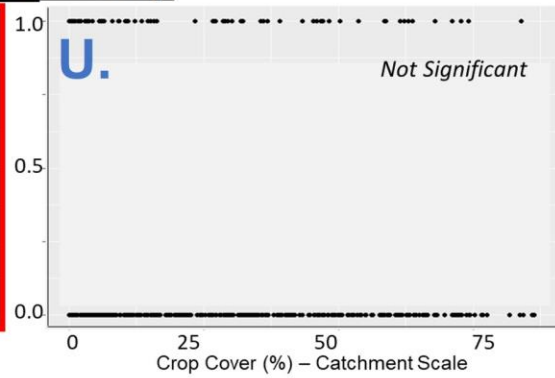
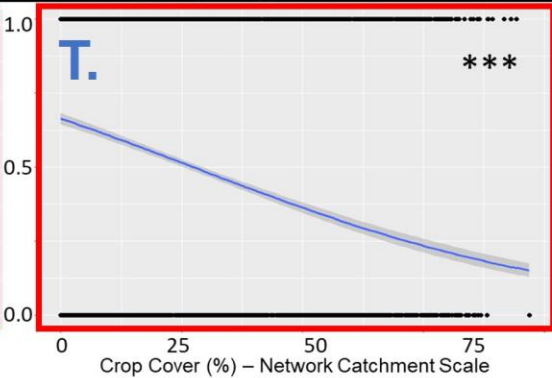
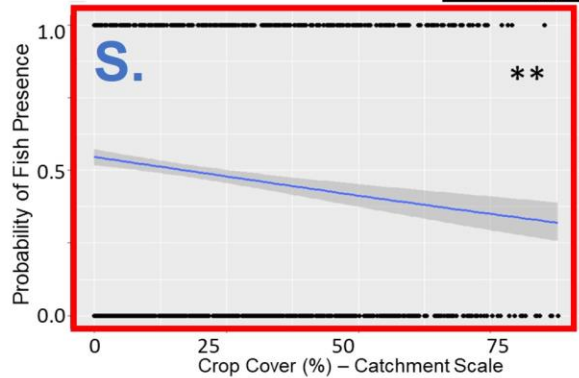
## Central Stoneroller

## Plains Minnow

### Ecological Category: Agricultural Land Use - Pasture



### Ecological Category: Agricultural Land Use - Crop

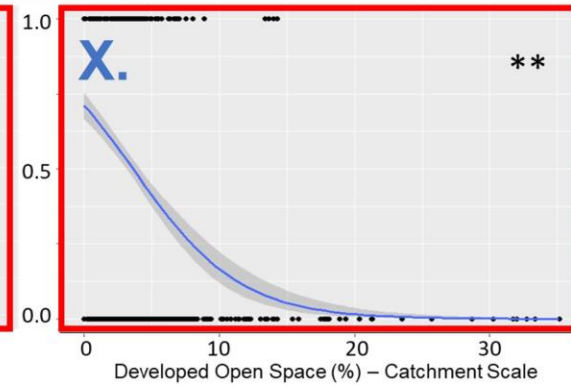
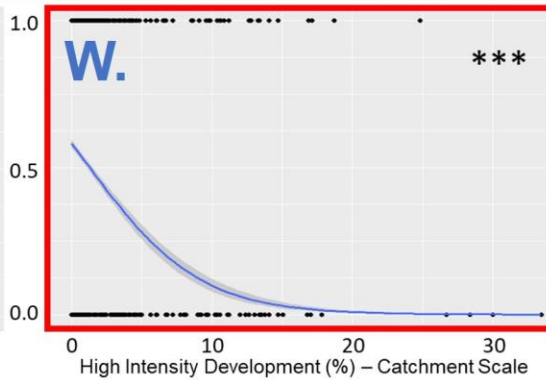
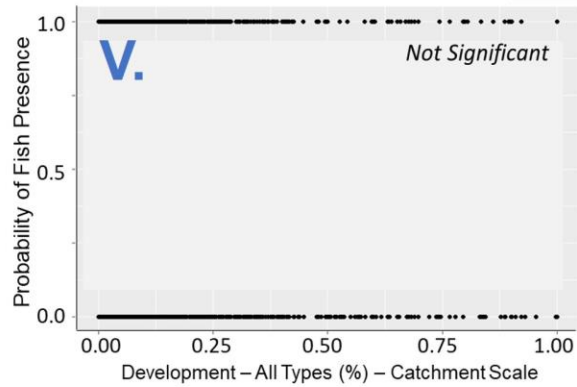


## Emerald Shiner

## Central Stoneroller

## Plains Minnow

### Ecological Category: Developed Land Use



### Ecological Category: Natural Land

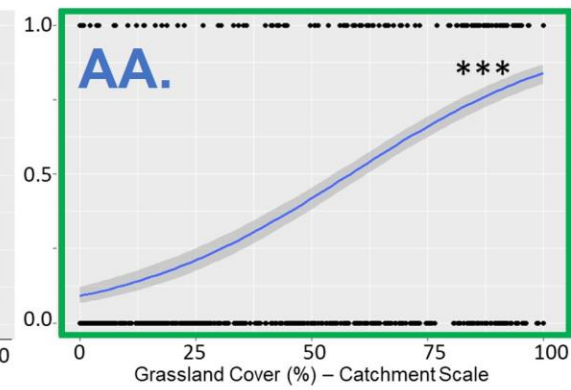
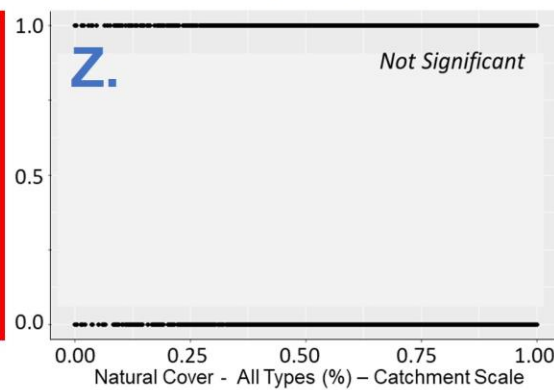
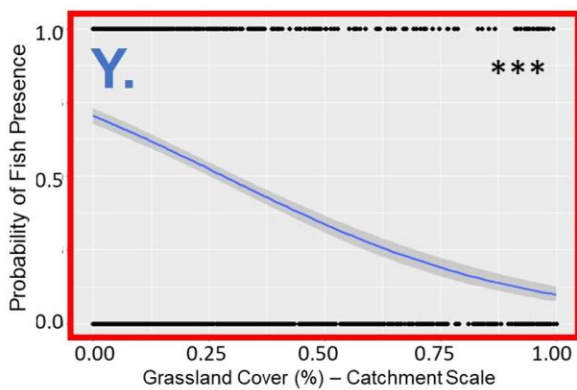


**Figure 2.8.** Three fish ridgeline response to ecological category: substrate. (A-C) are for sand substrate for all three fish; (D-F) are for silt substrates for all three fish; (G) is for rock fragment substrate. (A, D) are for Emerald Shiner. (B, E, G) are for Central Stoneroller. (C, F) are for Plains Minnow. On the X-axis is the metric value distribution, and on the Y-axis is the presence or absence frequency of the fish. Red = fish presence. Purple = fish absence. The format shows all three fish systematically because the comparison of fish groups is one of the priorities of the project. Rock fragments panels were left empty for Emerald Shiner and Plains Minnow because they were not significant or relevant to these fish. These ridgelines plots represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

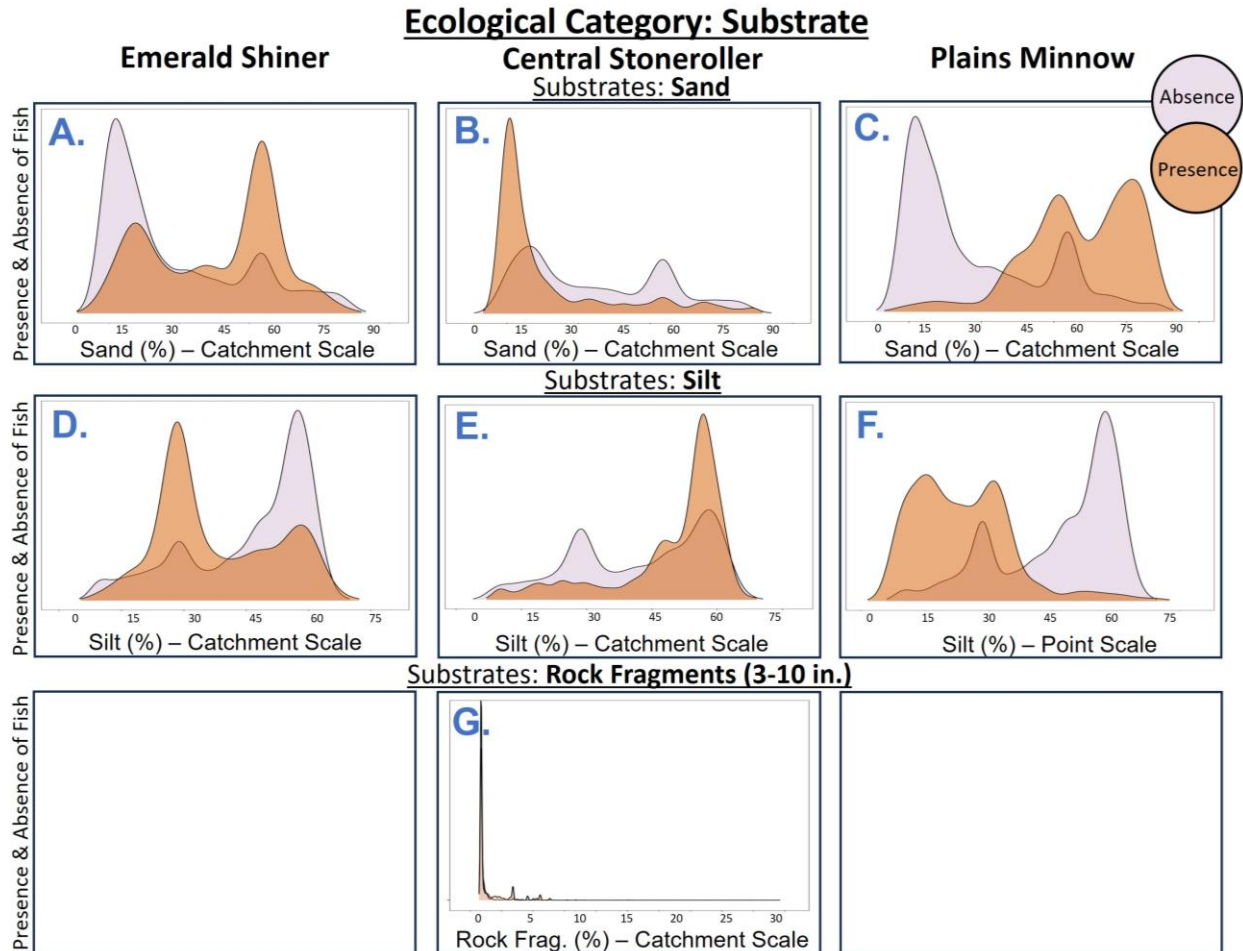


**Figure 2.9.** Statewide proportional maps for prioritized metrics in ecological categories: (A) depicts average June discharge patterns statewide. (B) depicts sand percentages statewide. (C) depicts silt percentages statewide. (D) depicts rock fragment percentages statewide. Dot size and color both indicate the metric's proportion, or value, at that site (Ex: A large, light blue dot indicates higher proportions, while a small, dark blue dot indicates lower proportions). Dots represent all unique locations sampled within our study area. Major river basins are indicated. These proportional maps represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

### Ecological Categories: NHDPlus Flow & Substrates

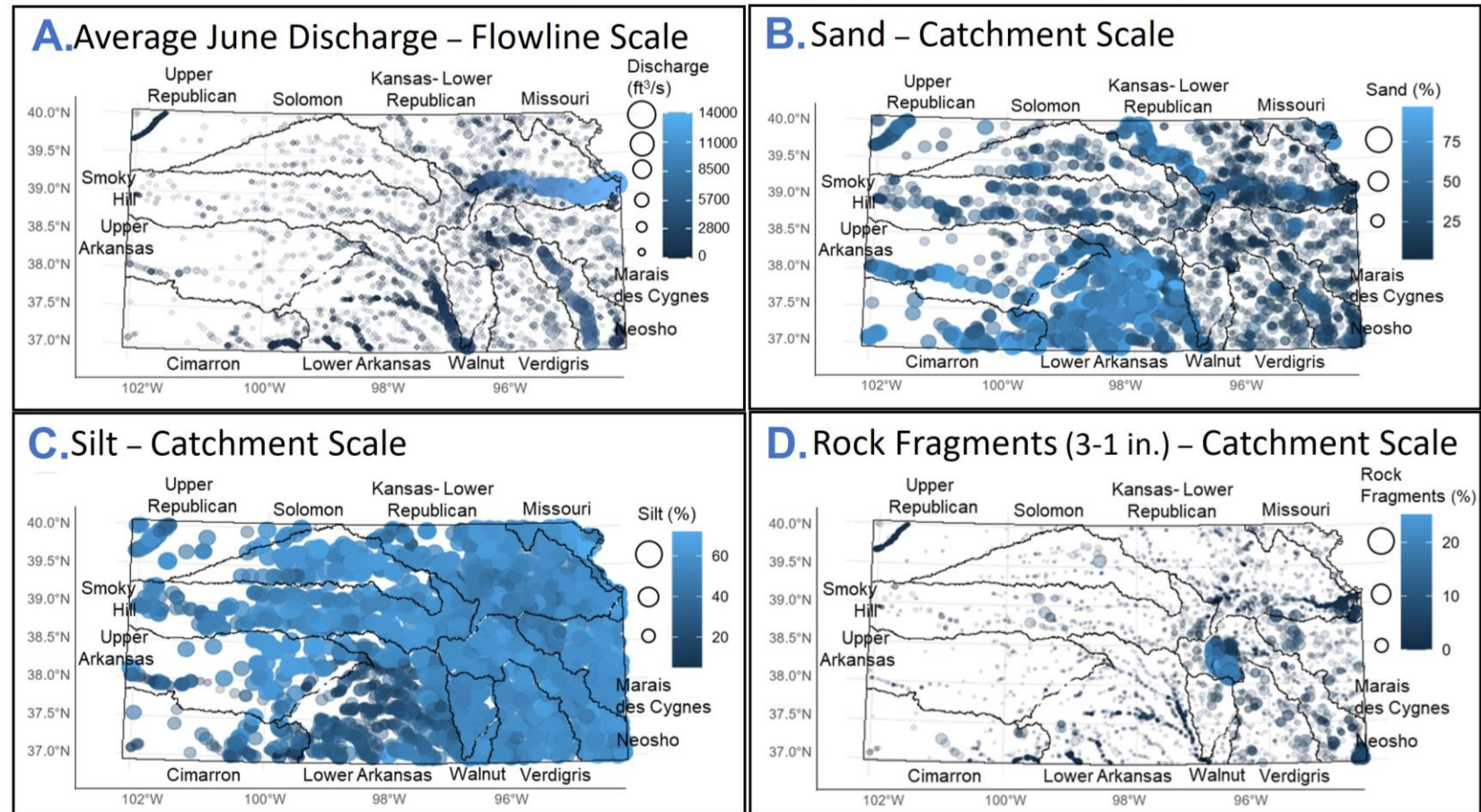




**Figure 2.10.** Three fish ridgeline response to ecological category: system size related metrics. (A-C) are for stream order for all three fish; (D-F) are for stream depth for all three fish; (G-I) are for sinuosity for all three fish. (A, D, G) are for Emerald Shiner. (B, E, H) are for Central Stoneroller. (C, F, I) are for Plains Minnow. On the X-axis is the metric value distribution, and on the Y-axis is the presence or absence frequency of the fish. Red = fish presence. Purple = fish absence. The format shows all three fish systematically because the comparison of fish groups is one of the priorities of the project. These ridgelines plots represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

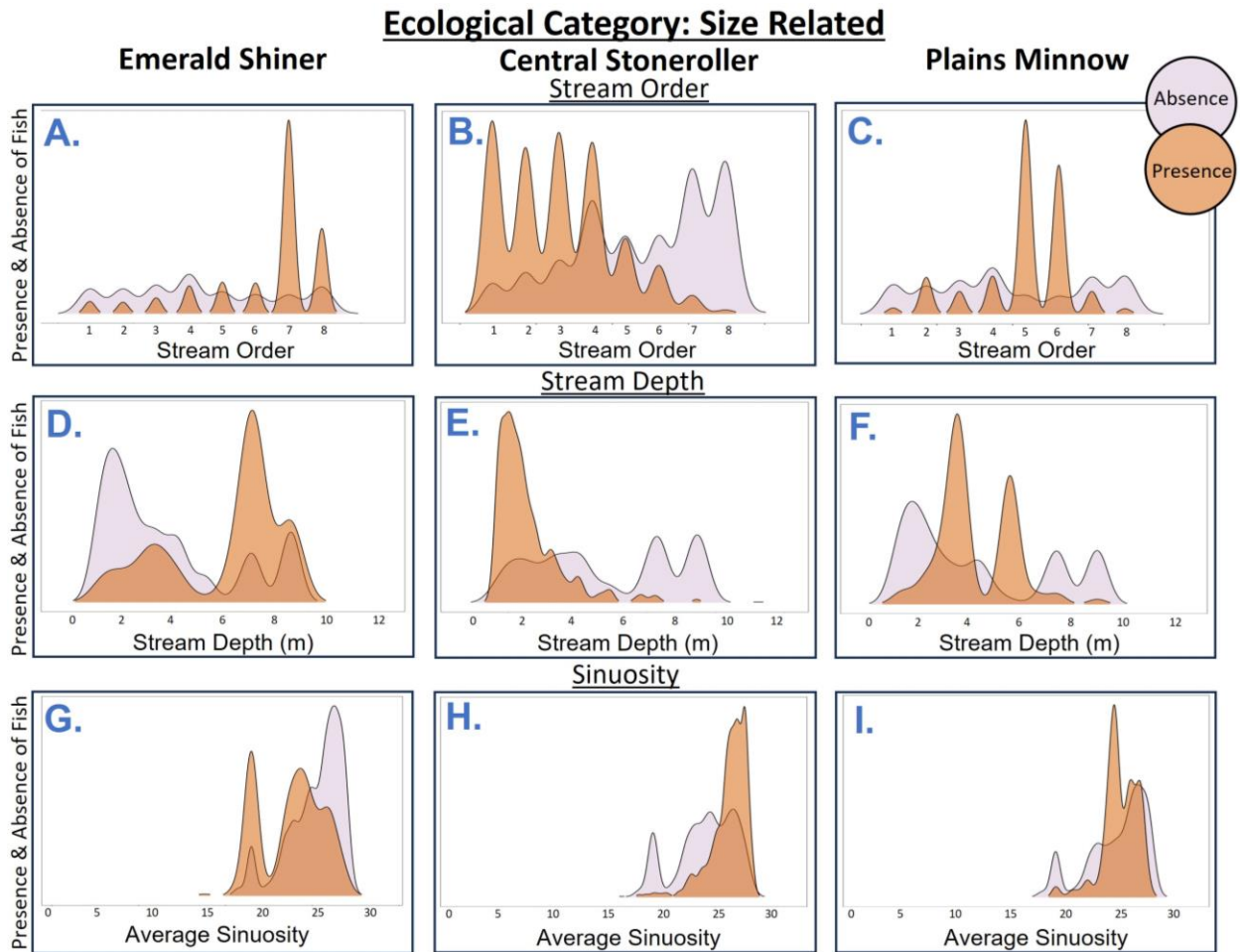


**Figure 2.11.** Statewide proportional maps for prioritized metrics for system size related metrics. (A) depicts stream orders statewide. (B) depicts stream depths statewide. (C) depicts sinuosities statewide. Dot size and color both indicate the metric's proportion, or value, at that site (Ex: A large, light blue dot indicates higher proportions, while a small, dark blue dot indicates lower proportions). Dots represent all unique locations sampled within our study area. Major river basins are indicated. These proportional maps represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

### Ecological Category: Size Related

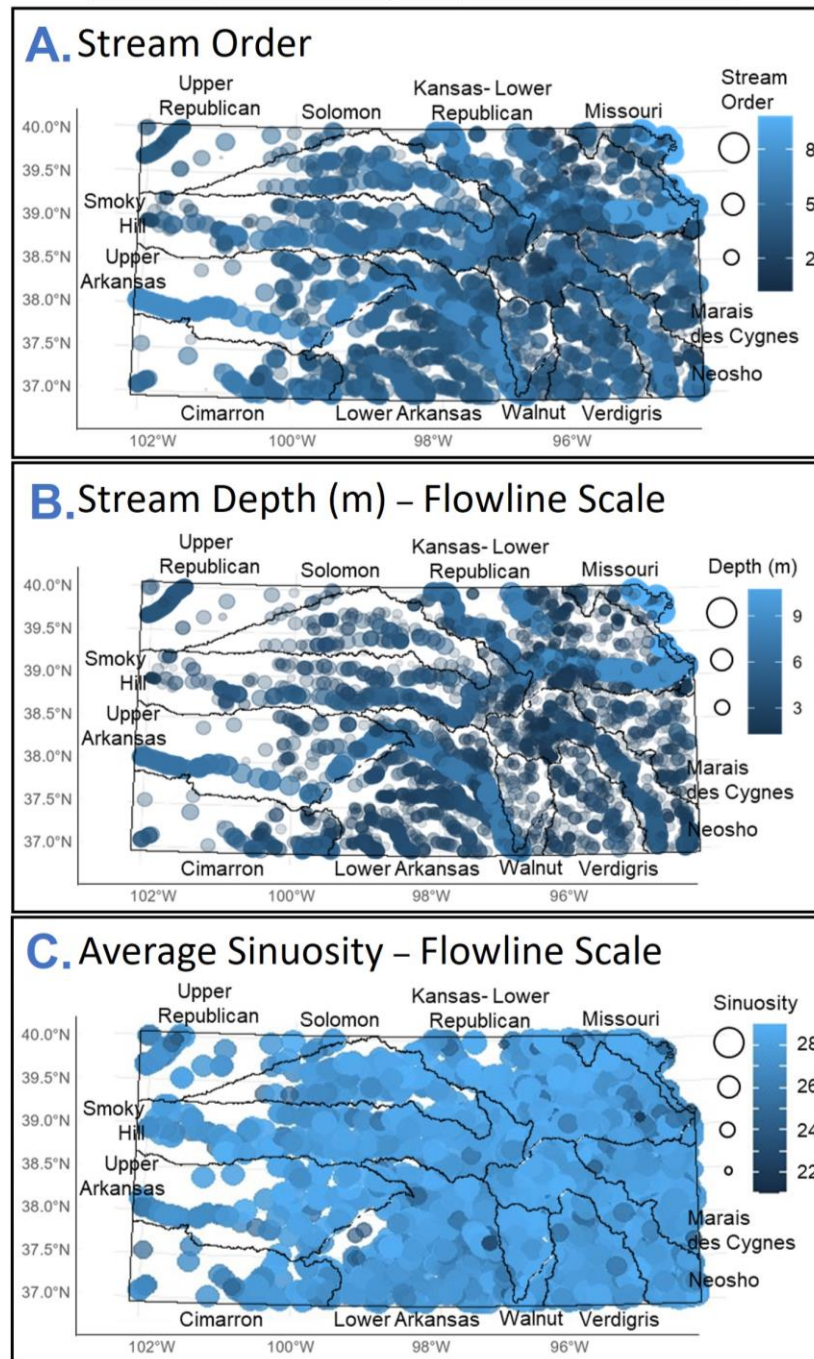


**Figure 2.12.** The average percent of entire network catchment scale land use metrics for all sample sites where (A) Emerald Shiner, (B) Central Stoneroller, and (C) Plains Minnow were present. Land uses are labeled.

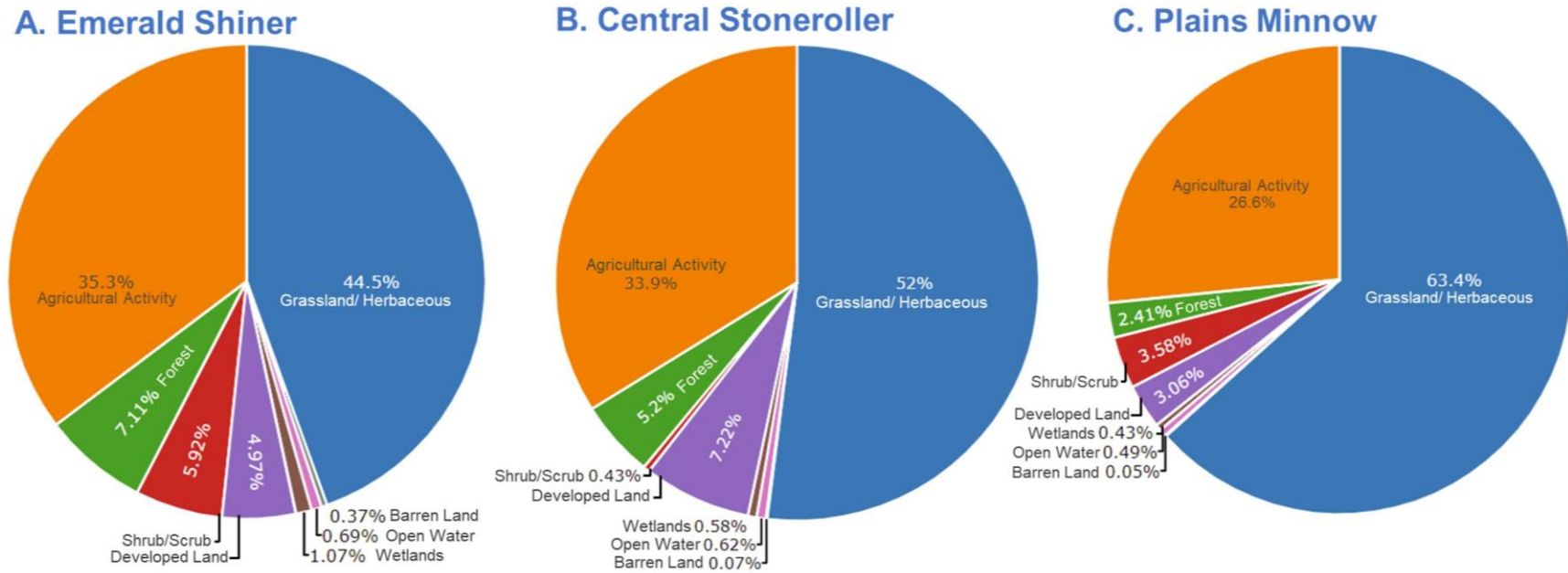


**Figure 2.13.** Three fish ridgeline response to ecological category: land uses (anthropogenic). (A-C) are for pasture cover (agriculture) for all three fish; (D-F) are for crop cover (agriculture) for all three fish; (G-I) are for developed land use types. (A, D, G) are for Emerald Shiner. (B, E, H) are for Central Stoneroller. (C, F, I) are for Plains Minnow. On the X-axis is the metric value distribution, and on the Y-axis is the presence or absence frequency of the fish. Red = fish presence. Purple = fish absence. The format shows all three fish systematically because the comparison of fish groups is one of the priorities of the project. These ridgelines plots represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

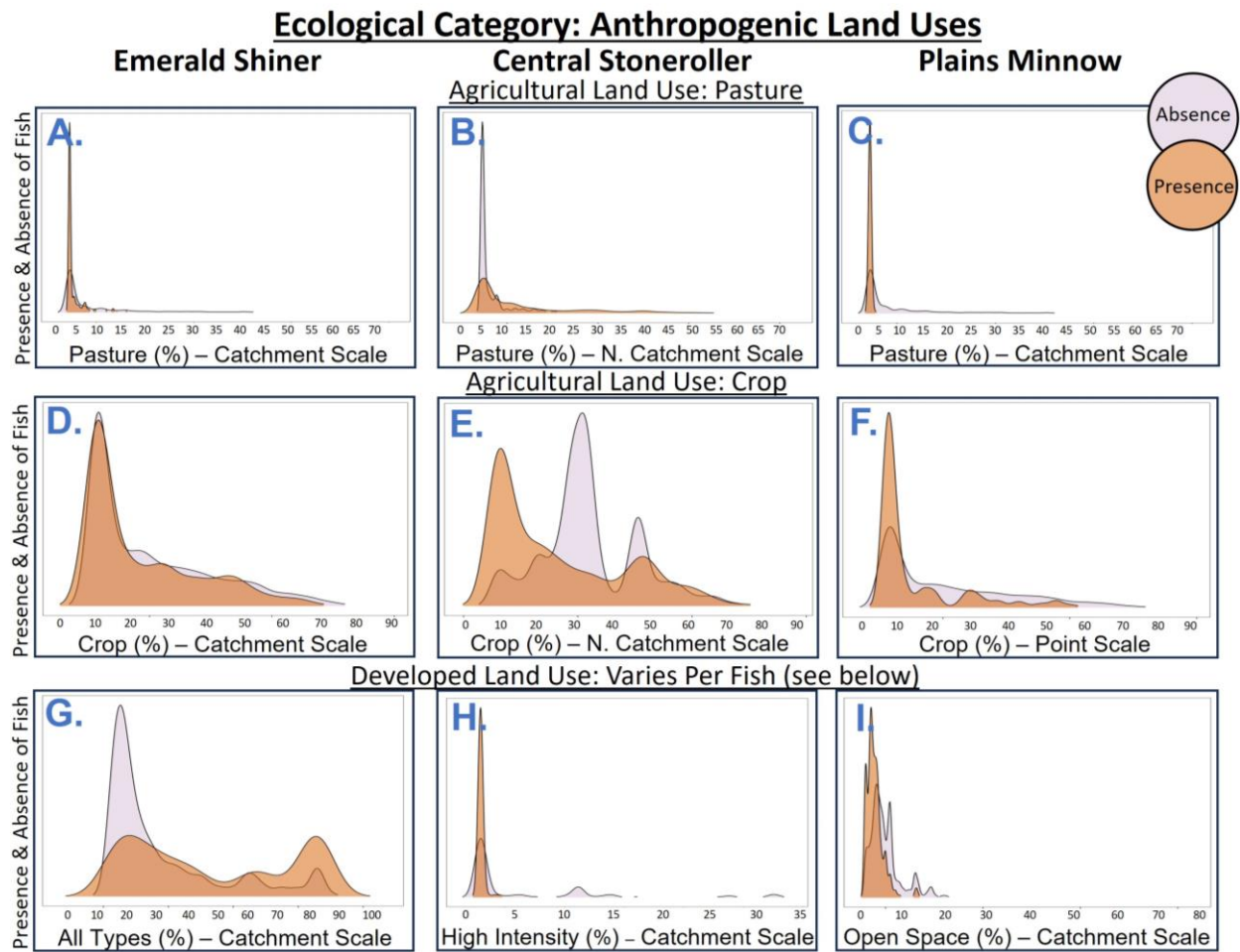




**Figure 2.14.** Statewide proportional maps for prioritized metrics in ecological category: land use. (A-B) depict percentages of agricultural cover (pasture and crop) statewide. (C-E) depict percentages of developed land use types statewide. (F) depicts percentages of grassland (natural) statewide. Dot size and color both indicate the metric's proportion, or value, at that site (Ex: A large, light blue dot indicates higher proportions, while a small, dark blue dot indicates lower proportions). Dots represent all unique locations sampled within our study area. Major river basins are indicated. These proportional maps represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

### Ecological Category: Land Uses

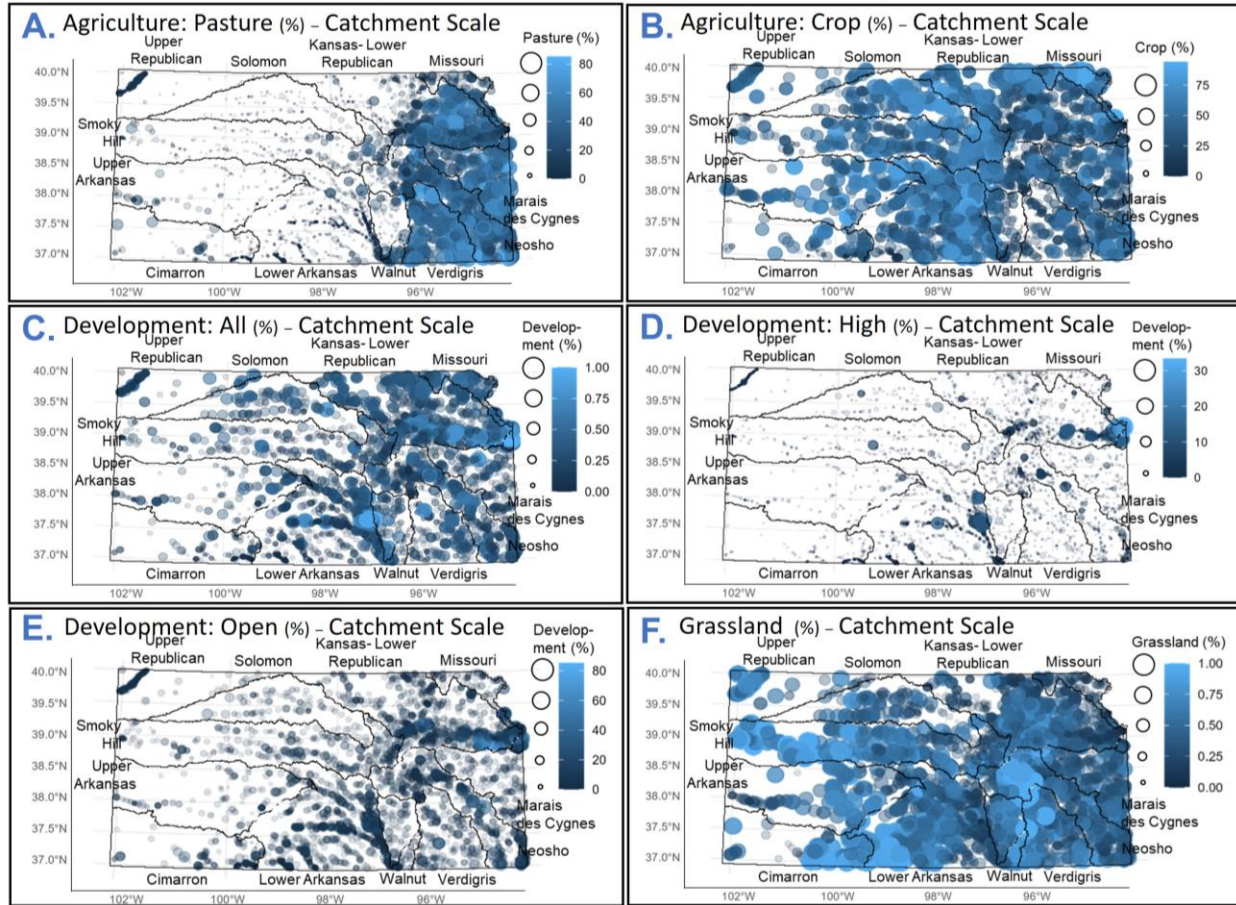


**Figure 2.15.** Three fish ridgeline response to ecological categories: natural land and dams. (A-C) are for grassland (a natural land use) for all three fish; (D-F) are for priority dam metrics for all three fish. (A, D) are for Emerald Shiner. (B, E) are for Central Stoneroller. (C, F) are for Plains Minnow. On the X-axis is the metric value distribution, and on the Y-axis is the presence or absence frequency of the fish. Red = fish presence. Purple = fish absence. The format shows all three fish systematically because the comparison of fish groups is one of the priorities of the project. These ridgelines plots represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

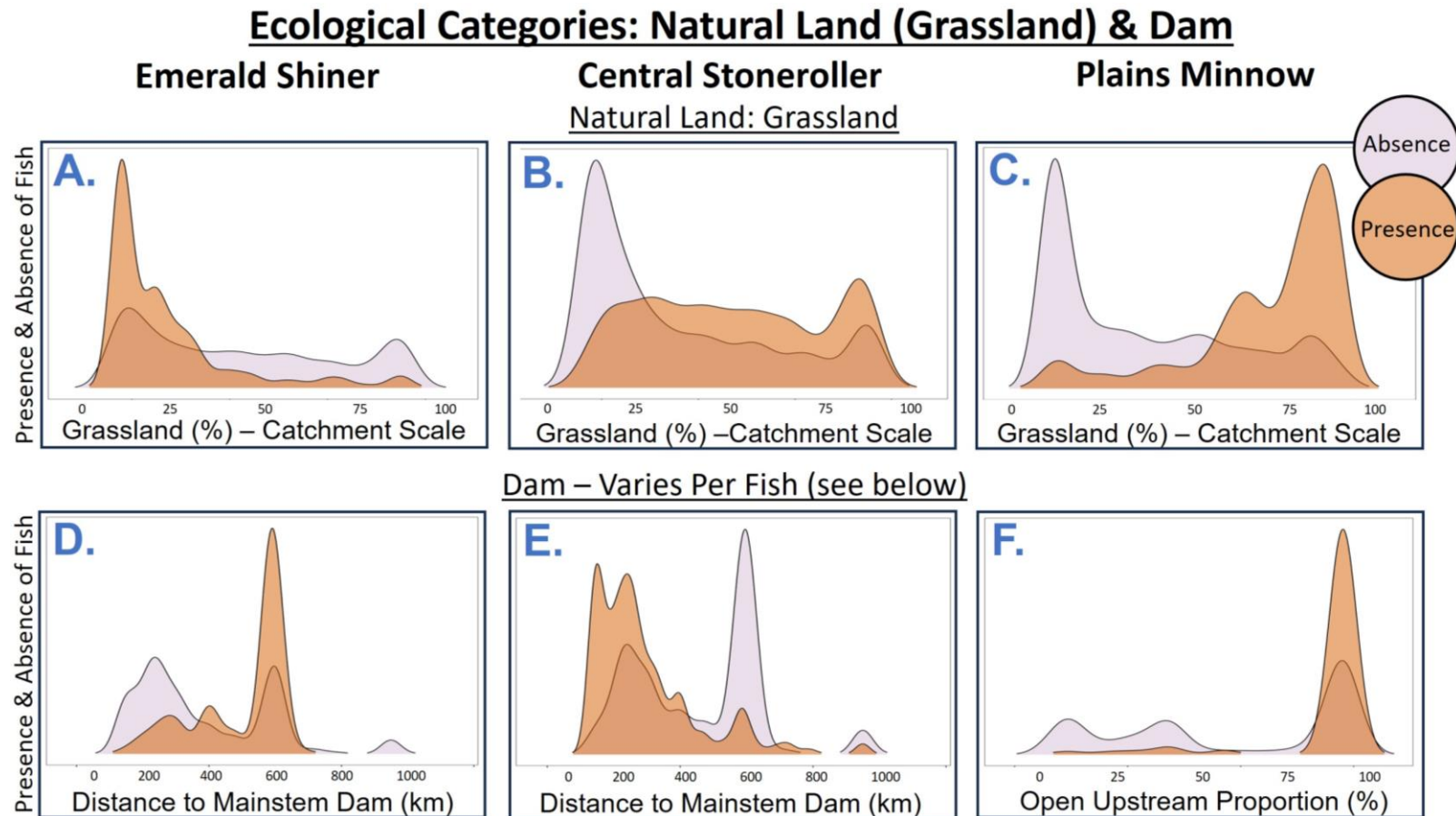


**Figure 2.16.** Statewide proportional maps for prioritized metrics in ecological categories: dams and gradient. (A) depicts the percentage of open upstream mainstem (% - UMO), statewide. (B) total mainstem distance between upstream and/or downstream mainstem dams (km – TM2D), statewide. (C) depicts the gradient, or slope, statewide. Dot size and color both indicate the metric's proportion, or value, at that site (Ex: A large, light blue dot indicates higher proportions, while a small, dark blue dot indicates lower proportions). Dots represent all unique locations sampled within our study area. Major river basins are indicated. These proportional maps represent real data, not model results, and aid in the interpretation of the multiple logistic regression.

### Ecological Categories: Dam & Gradient

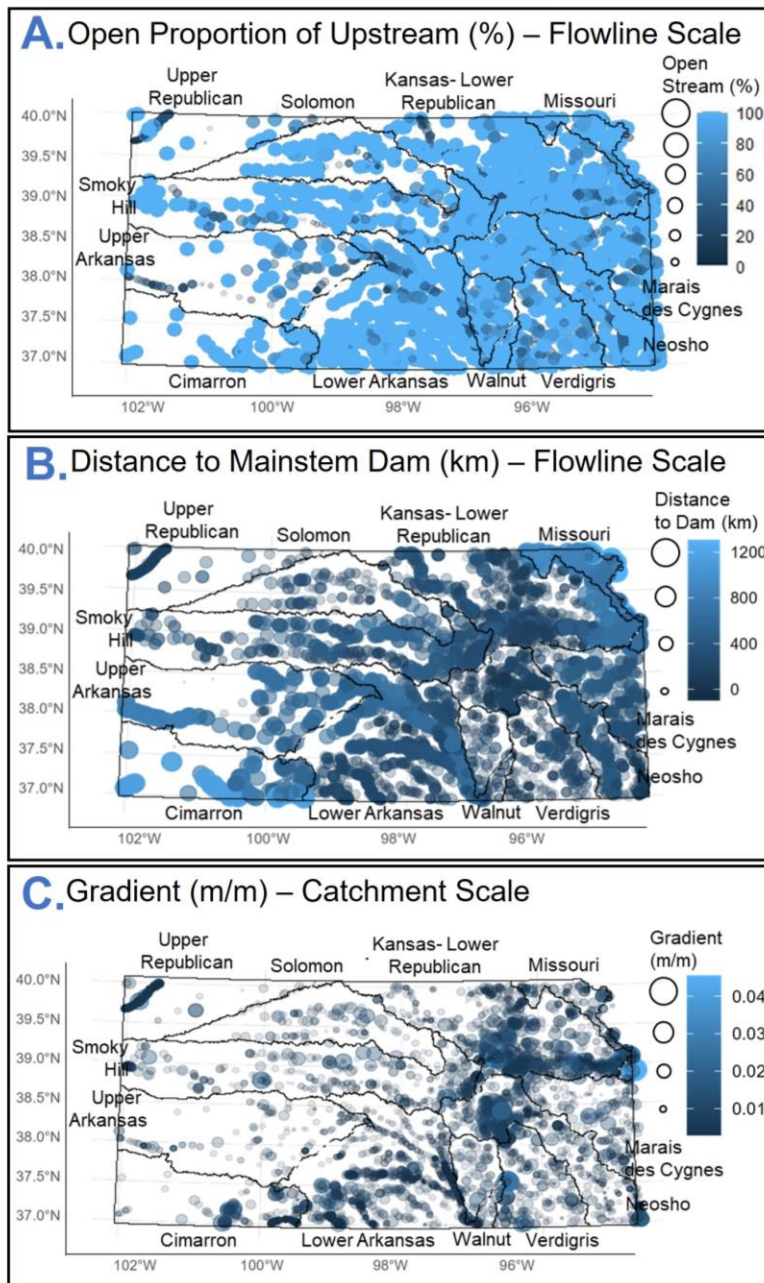




**Figure 2.17.** Five groupings were formed as a result of comparing regression responses for empirical groups. Grouping 1: Emerald Shiner contrasts with Central Stoneroller and Plains Minnow. Grouping 2: Central Stoneroller contrasts with Emerald Shiner and Plains Minnow. Grouping 3: Plains Minnow contrasts with Emerald Shiner and Central Stoneroller. Grouping 4: All three fish were comparable. Grouping 5: All three fish differ. All empirical categories are shown on the left (i.e., 2 map metrics, 11 ecological categories). X's summarize empirical responses.

| <b>Objective 3: How do Fish Group by Empirical Metrics?</b>       |                                                              |                                                              |                                                              |                                                        |                                                                    |
|-------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------------|
| <b><u>Objective</u><br/><u>1 Fish</u><br/><u>Groups:</u></b><br>➔ | 1                                                            | 2                                                            | 3                                                            | 4                                                      | 5                                                                  |
| <b><u>Empirical</u><br/><u>Groups:</u></b>                        | Central Stoneroller<br>Plains Minnow<br>vs<br>Emerald Shiner | Emerald Shiner<br>Plains Minnow<br>vs<br>Central Stoneroller | Emerald Shiner<br>Central Stoneroller<br>vs<br>Plains Minnow | Emerald Shiner<br>Central Stoneroller<br>Plains Minnow | Emerald Shiner<br>vs<br>Central Stoneroller<br>vs<br>Plains Minnow |
| <b><u>Metric Responses:</u></b>                                   |                                                              |                                                              |                                                              |                                                        |                                                                    |
| Abundance (sites)                                                 |                                                              |                                                              | X                                                            |                                                        |                                                                    |
| Distribution                                                      |                                                              | X                                                            |                                                              |                                                        |                                                                    |
| NHDPlus Flow                                                      |                                                              | X                                                            |                                                              |                                                        |                                                                    |
| Substrate<br>Specialization                                       | X                                                            |                                                              |                                                              |                                                        |                                                                    |
| Substrate Size                                                    |                                                              | X                                                            |                                                              |                                                        |                                                                    |
| Ecosystem Size                                                    |                                                              | X                                                            |                                                              |                                                        |                                                                    |
| Sinuosity                                                         |                                                              | X                                                            |                                                              |                                                        |                                                                    |
| Pasture<br>(Agricultural Land)                                    |                                                              |                                                              |                                                              |                                                        | X                                                                  |
| Crop (Agricultural<br>Land)                                       |                                                              |                                                              | X                                                            |                                                        |                                                                    |
| Developed Land                                                    | X                                                            |                                                              |                                                              |                                                        |                                                                    |
| Natural Land                                                      |                                                              |                                                              |                                                              |                                                        | X                                                                  |
| Dams                                                              |                                                              |                                                              | X                                                            |                                                        |                                                                    |
| Gradient                                                          |                                                              |                                                              | X                                                            |                                                        |                                                                    |



**Figure 2.18.** The mapped probability of Plains Minnow occurrence using top model variable parameters. (A) Dark blue sites indicate a low probability of occurrence (~0%) and red sites indicate a high probability of occurrence (~100%). (B) Three probability-region categories arose where Plains Minnow: had been sampled [orange regions with high probability of occurrence (I-II)], might occur and are worth sampling [light blue regions with high probability of occurrence (III-VIII)], and historically were captured [gray regions with low probability of occurrence (IX-XI)]. Also, depicted are the top 10 highest (>99%; green circles) and top 10 lowest (<1%; yellow circles) sites for probability of Plains Minnow occurrence. Major river basins are indicated.

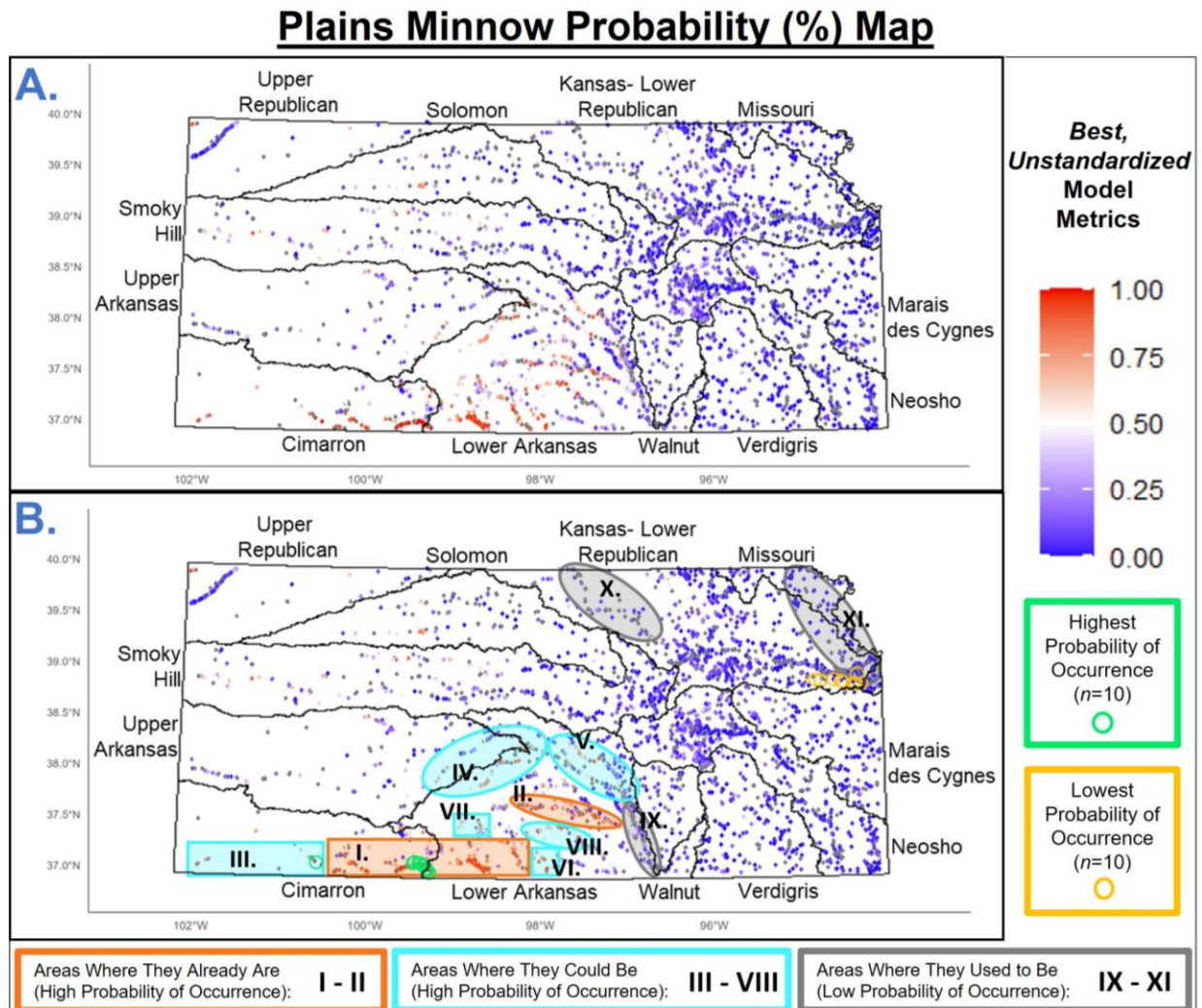
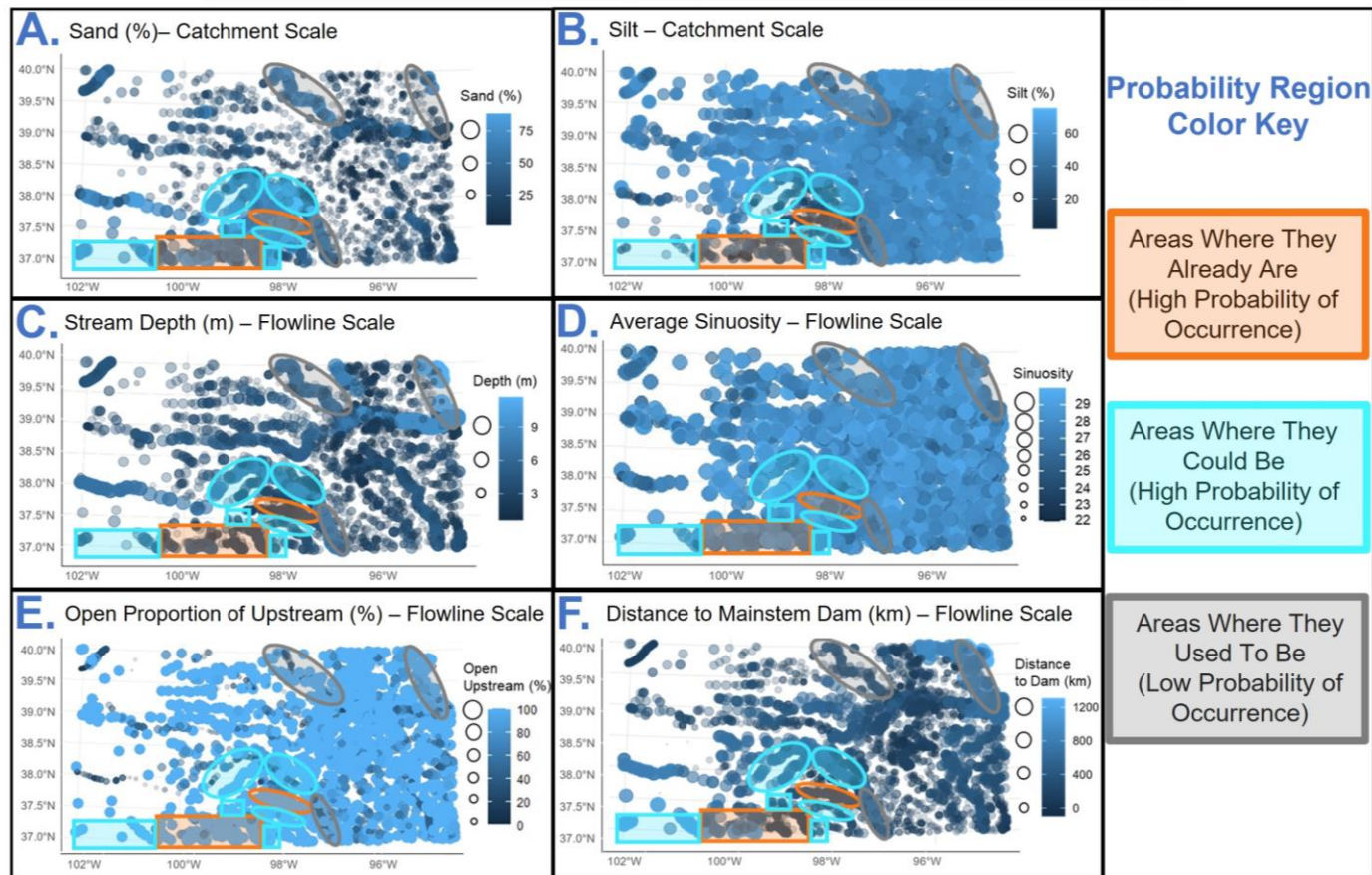


**Figure 2.19.** Probability regions from Figure 2.18B are overlaid on statewide habitat and impact proportional maps. (A-B) show substrate (sand and silt) percentages within probability-region categories. (C-D) show conditions related to system size (depth and sinuosity) within probability-region categories. (E-F) show conditions related to dam presence within probability-region categories. Orange regions indicate areas where Plains Minnow had been sampled and have high probabilities for occurrence. Light blue regions indicate areas where Plains Minnow had not been sampled but have high probabilities for occurrence. Gray regions indicate areas where Plains Minnow had been sampled historically, but now have low probabilities of occurrence. Comparing probability-regions with habitat and impact metric conditions statewide may aid fisheries managers in deciding where to concentrate restoration efforts.

### Plains Minnow Probability Regions & Habitat-Impact Maps



## Appendix A - Supplementary Materials for Chapter 1

**Appendix A Table A.1.** Table of priority questions we address here, and those that are presently, largely unanswerable and therefore not addressed.

### Questions Addressed:

- Where are specific taxa present?  
Where are specific taxa absent?
- Can we use GIS habitat and impact data? Can we use local habitat data?
- Can we build a model with presence and absence data?
  - Can we evaluate relative model performances?
  - Can we identify which habitat and impact variables are influential?
- Can we use models to predict where to sample next?
- Can we provide a series of steps that provide a systematic framework for interpretation of multiple data analyses obtained through an ensemble analysis?
- Can we learn something from the data?

### Questions NOT Addressed:

- Have specific taxa declined through time?
- Can we assess trends in fish abundance?
- Which taxa are most vulnerable?
- How has presence and absence changed through time?
- Is there sampling representative of field conditions? Are there gaps?
- Can we accurately predict probabilities?
- Can we answer all questions with confidence?

**Appendix A Table A.2.**

| Variable                                      | (1) Ecological Category       | (2) Metric Name | (3) General Definition of Metric - Fish                                                                                                                                                                                                                                                                                                                     | (4) General Definition of Metric - GIS                                                                                       | (5) Scale      | (6) Strengths                                                                           | (7) Weaknesses                                                                                                        |
|-----------------------------------------------|-------------------------------|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|----------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Average annual flow of river segment          | Flow (Discharge and Velocity) | Q0001 E         | Instream flow is the quantity of water flowing in a stream channel. It supports a larger stream ecosystem, including riparian (stream bank) and floodplain areas. Different quantities of flow are critical to supporting instream fish populations. Humans often alter the natural flow regimes of rivers, altering the flow patterns fish are adapted to. | Gage adjusted mean annual flow (cubic feet per second - CFS) at the downstream end of the flowline (1971-2000)               | Local Flowline | The best estimates of flow using the Enhanced Unit Runoff Method (EROM)                 | Annual average flow estimates do not provide context for how flows may differ among seasons                           |
| Average annual velocity of river segment      | “                             | V0001 E         | Water velocity is the rate at which water moves through a system. Water velocity is also critical to many aspects of fish life history. In changing natural flow patterns, humans also alter the natural velocities found in that system.                                                                                                                   | Gage adjusted mean annual velocity (feet per second - FPS) at the downstream end of the flowline (1971-2000) (Jobson method) | “              | The best estimates of velocity using the Enhanced Unit Runoff Method (EROM)             | Annual average velocity estimates do not provide context for how velocities may differ among seasons                  |
| Average flow for river segment in January     | “                             | Q0001 E_01      | Flow quantities change with the seasons, and fish are reliant upon these changes throughout the year for several aspects of survival (i.e. spawning triggers, habitat, food sources, etc.)                                                                                                                                                                  | Gage adjusted January mean flow (CFS) at the downstream end of the flowline (1971-2000)                                      | “              | Monthly estimates paint a more accurate picture of how flows differ among seasons.      | Monthly flow estimates are not reflective of the full range of flows that occur within that segment annually          |
| Average velocity for river segment in January | “                             | V0001 E_01      | Water velocities are higher in wet seasons, and lower in dry seasons (in correlation to flow patterns). Like with the flow regime, fish are adapted to these seasonal changes.                                                                                                                                                                              | Gage adjusted January mean velocity (FPS) at the downstream end of the flowline (1971-2000) (Jobson method)                  | “              | Monthly estimates paint a more accurate picture of how velocities differ among seasons. | Monthly velocity estimates are not reflective of the full range of velocities that occur within that segment annually |

| Variable                                                | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale | (6) Strengths          | (7) Weaknesses         |
|---------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------|----------------------------------------------|-----------|------------------------|------------------------|
| Average flow<br>for river<br>segment in<br>February     | “                             | Q0001<br>E_02         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Feb)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment<br>in February | “                             | V0001<br>E_02         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Feb)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |
| Average flow<br>for river<br>segment in<br>March        | “                             | Q0001<br>E_03         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Mar)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment<br>in March    | “                             | V0001<br>E_03         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Mar)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |
| Average flow<br>for river<br>segment in<br>April        | “                             | Q0001<br>E_04         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Apr)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment<br>in April    | “                             | V0001<br>E_04         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Apr)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |
| Average flow<br>for river<br>segment in<br>May          | “                             | Q0001<br>E_05         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for May)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment<br>in May      | “                             | V0001<br>E_05         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for May)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |

| Variable                                                 | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale | (6) Strengths          | (7) Weaknesses         |
|----------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------|----------------------------------------------|-----------|------------------------|------------------------|
| Average flow<br>for river<br>segment in<br>June          | “                             | Q0001<br>E_06         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Jun)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment<br>in June      | “                             | V0001<br>E_06         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Jun)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |
| Average flow<br>for river<br>segment in<br>July          | “                             | Q0001<br>E_07         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Jul)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment<br>in July      | “                             | V0001<br>E_07         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Jul)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |
| Average flow<br>for river<br>segment in<br>August        | “                             | Q0001<br>E_08         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Aug)         | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment in<br>August    | “                             | V0001<br>E_08         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Aug)         | “         | See V0001E_01<br>above | See V0001E_01<br>above |
| Average flow<br>for river<br>segment in<br>September     | “                             | Q0001<br>E_09         | See Q0001E and Q0001E_01                   | See Q0001E_01<br>above (but for Sept)        | “         | See Q0001E_01<br>above | See Q0001E_01<br>above |
| Average<br>velocity for<br>river segment in<br>September | “                             | V0001<br>E_09         | See V0001E and V0001E_01                   | See V0001E_01<br>above (but for Sept)        | “         | See V0001E_01<br>above | See V0001E_01<br>above |



| Variable                                                | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                                                                            | (4) General<br>Definition of Metric<br>- GIS                                                                       | (5) Scale                                 | (6) Strengths                                                                                                          | (7) Weaknesses                                             |
|---------------------------------------------------------|-------------------------------|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| Average flow<br>for river<br>segment in<br>October      | “                             | Q0001<br>E_10         | See Q0001E and Q0001E_01                                                                                                                                                                                                                                                                              | See Q0001E_01<br>above (but for Oct)                                                                               | “                                         | See Q0001E_01<br>above                                                                                                 | See Q0001E_01<br>above                                     |
| Average<br>velocity for<br>river segment in<br>October  | “                             | V0001<br>E_10         | See V0001E and V0001E_01                                                                                                                                                                                                                                                                              | See V0001E_01<br>above (but for Oct)                                                                               | “                                         | See V0001E_01<br>above                                                                                                 | See V0001E_01<br>above                                     |
| Average flow<br>for river<br>segment in<br>November     | “                             | Q0001<br>E_11         | See Q0001E and Q0001E_01                                                                                                                                                                                                                                                                              | See Q0001E_01<br>above (but for Nov)                                                                               | “                                         | See Q0001E_01<br>above                                                                                                 | See Q0001E_01<br>above                                     |
| Average<br>velocity for<br>river segment in<br>November | “                             | V0001<br>E_11         | See V0001E and V0001E_01                                                                                                                                                                                                                                                                              | See V0001E_01<br>above (but for Nov)                                                                               | “                                         | See V0001E_01<br>above                                                                                                 | See V0001E_01<br>above                                     |
| Average flow<br>for river<br>segment in<br>December     | “                             | Q0001<br>E_12         | See Q0001E and Q0001E_01                                                                                                                                                                                                                                                                              | See Q0001E_01<br>above (but for Dec)                                                                               | “                                         | See Q0001E_01<br>above                                                                                                 | See Q0001E_01<br>above                                     |
| Average<br>velocity for<br>river segment in<br>December | “                             | V0001<br>E_12         | See V0001E and V0001E_01                                                                                                                                                                                                                                                                              | See V0001E_01<br>above (but for Dec)                                                                               | “                                         | See V0001E_01<br>above                                                                                                 | See V0001E_01<br>above                                     |
| Sand (%)<br>around the local<br>flowline                | Substrates                    | f_sand                | Substrate creates important habitat<br>and plays a role in many fish life<br>history processes. It consists of<br>surface + subsurface materials in the<br>streambed, with preferences varying<br>per fish. It is usually classified by<br>particle size. Sand is a common<br>substrate in KS rivers. | Mean sand<br>percentage (0.05mm<br>to 2.0mm) from the<br>ratio of the mass of<br>sand to the mass of<br>soil fines | 60m buffer<br>around<br>local<br>flowline | Flowline scale is<br>2nd in data<br>quantity (for<br>substrates), & 2 <sup>nd</sup><br>smallest in<br>geographic scale | Not the most data,<br>not the smallest<br>geographic scale |

| Variable                                       | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                            | (4) General<br>Definition of Metric<br>- GIS                                                                 | (5) Scale       | (6) Strengths                                            | (7) Weaknesses                                     |
|------------------------------------------------|-------------------------------|-----------------------|-----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------|----------------------------------------------------|
| Clay (%) around the local flowline             | “                             | f_clay                | Clay is a common substrate in KS rivers.                                                                              | Mean clay percentage (<0.002mm) from the ratio of the mass of clay to the mass of soil fines.                | “               | “                                                        | “                                                  |
| Silt (%) around the local flowline             | “                             | f_silt                | Silt has increased in KS rivers as a result of excessive erosion stemming from agricultural activity and development. | Mean silt percentage (0.002 to 0.05mm) from the ratio of the mass of silt to the mass of soil fines.         | “               | “                                                        | “                                                  |
| Rock fragment (%) around the local flowline    | “                             | f_fragt<br>3to10      | Rocky substrates are a bit more uncommon in KS. This is a step above cobble or gravel.                                | The mean (% by weight) of the horizon occupied by rock fragments 3 to 10 inches in size                      | “               | “                                                        | “                                                  |
| Erodibility of soils around the local flowline | “                             | f_kwfa<br>ct          | The erodibility factor can tell us how susceptible a site may be to erosion and sedimentation.                        | Mean erodibility factor of soil particles (values between 0 and 1 where 1 means most susceptible to erosion) | “               | “                                                        | “                                                  |
| Sand (%) for the local catchment area          | “                             | c_sand                | See f_sand above                                                                                                      | See f_sand above                                                                                             | Local catchment | Catchment scale is 1st in data quantity (for substrates) | Catchment scale is the largest in geographic scale |
| Clay (%) for the local catchment area          | “                             | c_clay                | See f_clay above                                                                                                      | See f_clay above                                                                                             | “               | “                                                        | “                                                  |



| Variable                                                 | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale                      | (6) Strengths                               | (7) Weaknesses                                       |
|----------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------|----------------------------------------------|--------------------------------|---------------------------------------------|------------------------------------------------------|
| Silt (%) for the local catchment area                    | “                             | c_silt                | See f_silt above                           | See f_silt above                             | “                              | “                                           | “                                                    |
| Rock fragment (%) for the local catchment area           | “                             | c_fragt3to10          | See f_fragt3to10 above                     | See f_fragt3to10 above                       | “                              | “                                           | “                                                    |
| Erodibility of soils for the local catchment area        | “                             | c_kwfact              | See f_kwfact above                         | See f_kwfact above                           | “                              | “                                           | “                                                    |
| Sand (%) for the area around the fish sample             | “                             | l_sand                | See f_sand above                           | See f_sand above                             | 60m buffer around sample point | Point scale is smallest in geographic scale | Point scale is 3rd in data quantity (for substrates) |
| Clay (%) for the area around the fish sample             | “                             | l_clay                | See f_clay above                           | See f_clay above                             | “                              | “                                           | “                                                    |
| Silt (%) for the area around the fish sample             | “                             | l_silt                | See f_silt above                           | See f_silt above                             | “                              | “                                           | “                                                    |
| Rock Fragment (%) for the area around the fish sample    | “                             | l_fragt3to10          | See f_fragt3to10 above                     | See f_fragt3to10 above                       | “                              | “                                           | “                                                    |
| Erodibility of soils for the area around the fish sample | “                             | l_kwfact              | See f_kwfact above                         | See f_kwfact above                           | “                              | “                                           | “                                                    |

| Variable                                                  | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                               | (4) General<br>Definition of Metric<br>- GIS                                     | (5) Scale                        | (6) Strengths                                                                                                   | (7) Weaknesses                                                                                                |
|-----------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| Cropping land use (%) for the area around the fish sample | Land Use Agriculture          | l_crop_2021           | Agricultural activities are known to degrade nearby streams (habitat, flow regimes, etc.) leading to declines in fish populations. We include land used for crop production, or grazing - such as cattle pastures or hay | Calculated agricultural cropping land use (%) in 2021 (does not include pasture) | 60m buffer around sample point   | Point scale is smallest in geographic scale, CDL land estimates are updated yearly (most recent)                | Point scale is last in data quantity (for land use)                                                           |
| Cropping land use (%) around the local flowline           | “                             | Fcrop_CD11b_20        | “                                                                                                                                                                                                                        | “                                                                                | 60m buffer around local flowline | Flowline scale is 2 <sup>nd</sup> smallest in geographic scale, most recent data                                | Flowline scale is 2 <sup>nd</sup> to last in data quantity                                                    |
| Pasture and Hay land use (%) around the local flowline    | “                             | LB_nlcd11b_81         | “                                                                                                                                                                                                                        | Pasture/hay land use (%)                                                         | “                                | Flowline scale is 2 <sup>nd</sup> smallest in geographic scale                                                  | 2 <sup>nd</sup> to last in data quantity, and NLCD land estimates are updated every 5 years (not most recent) |
| Cropping land use (%) around the local flowline           | “                             | LB_nlcd11b_82         | “                                                                                                                                                                                                                        | Cultivated crop land use (%)                                                     | “                                | “                                                                                                               | “                                                                                                             |
| Cropping land use (%) for the local catchment             | “                             | Ccrop_CD11b_20        | “                                                                                                                                                                                                                        | See l_crop_2021 above                                                            | Local catchment                  | Catchment scale is the 3 <sup>rd</sup> smallest in geographic scale, average in data quantity, most recent data | Not the smallest in scale, and not the most numerable                                                         |
| Pasture and Hay land use (%) for the local catchment      | “                             | L_nlcd11_81           | “                                                                                                                                                                                                                        | See LB_nlcd11b_81 above                                                          | “                                | Catchment scale is 3 <sup>rd</sup> smallest in geographic scale, average in data quantity                       | Not the smallest in scale, not the most numerable, and not the most recent data                               |

| Variable                                                        | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                                                                      | (4) General<br>Definition of Metric<br>- GIS                                  | (5) Scale                                 | (6) Strengths                                                                                                                                                                     | (7) Weaknesses                                                                                                       |
|-----------------------------------------------------------------|-------------------------------|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Cropping land use (%) for the local catchment                   | “                             | L_nlcd11_82           | “                                                                                                                                                                                                                                                                                               | See LB_nlcd11b_82 above                                                       | “                                         | “                                                                                                                                                                                 | “                                                                                                                    |
| Pasture and Hay land use (%) around the entire network flowline | “                             | NB_nlcd11b_81         | “                                                                                                                                                                                                                                                                                               | See LB_nlcd11b_81 above                                                       | 60m buffer around entire network flowline | Buffer around the network flowline is high in data quantity                                                                                                                       | Buffer around the network flowline is 2 <sup>nd</sup> largest in geographic scale, and it's not the most recent data |
| Cropping land use (%) around the entire network flowline        | “                             | NB_nlcd11b_82         | “                                                                                                                                                                                                                                                                                               | See LB_nlcd11b_82 above                                                       | “                                         | “                                                                                                                                                                                 | “                                                                                                                    |
| Pasture and Hay land use (%) for the entire network catchment   | “                             | N_nlcd11_81           | “                                                                                                                                                                                                                                                                                               | See LB_nlcd11b_81 above                                                       | Entire network catchment                  | The entire network catchment scale has the most data                                                                                                                              | The entire network catchment is largest in geographic scale, and it's not the most recent data                       |
| Cropping land use (%) for the entire network catchment          | “                             | N_nlcd11_82           | “                                                                                                                                                                                                                                                                                               | See LB_nlcd11b_82 above                                                       | Entire network catchment                  | “                                                                                                                                                                                 | “                                                                                                                    |
| Developed land use (%) for the area around the fish sample      | Land Use Development          | l_dev_2021            | Human activity such as development or urbanization leads to stream pollution, channelization, and removal of resources within the stream. Developed land can vary in intensity and include uniformly vegetated areas. Therefore, developed land use could be a predictor for fish distribution. | Calculated developed land use (Open space, low-high intensities) (%) for 2021 | 60m buffer around sample point            | Point scale is smallest in geographic scale, CDL land estimates are updated yearly (most recent), & combining types of dev. (open space, all intensities) maximizes data quantity | Point scale is low in data quantity (for land use), combining dev. types may reduce interpretation accuracy          |

| Variable                                                          | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name        | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale                        | (6) Strengths                                                                                                                                          | (7) Weaknesses                                                                                        |
|-------------------------------------------------------------------|-------------------------------|------------------------------|--------------------------------------------|----------------------------------------------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Developed land use (%) around the local flowline                  | “                             | Fdev_<br>CDL_<br>2021_<br>20 | “                                          | “                                            | 60m buffer around local flowline | Flowline scale is 2 <sup>nd</sup> smallest in geographic scale, and combination (CDL) of land types maximizes data quantity, also the most recent data | Flowline scale is not the most numerable, and combining dev. types may reduce interpretation accuracy |
| Developed open space (%) around the local flowline                | “                             | LB_nl<br>cd11b_<br>21        | “                                          | Developed open space land use (%)            | “                                | 2 <sup>nd</sup> smallest in geographic scale, and specific dev. types allow for more accurate interpretations                                          | Not the most numerable, and NLCD land use estimates are updated every 5 years (not most recent)       |
| Low intensity developed land use (%) around the local flowline    | “                             | LB_nl<br>cd11b_<br>22        | “                                          | Low intensity developed land use (%)         | “                                | “                                                                                                                                                      | “                                                                                                     |
| Middle intensity developed land use (%) around the local flowline | “                             | LB_nl<br>cd11b_<br>23        | “                                          | Medium intensity developed land use (%)      | “                                | “                                                                                                                                                      | “                                                                                                     |
| High intensity developed land use (%) around the local flowline   | “                             | LB_nl<br>cd11b_<br>24        | “                                          | High intensity developed land use (%)        | “                                | “                                                                                                                                                      | “                                                                                                     |

| Variable                                                        | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name        | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale                                             | (6) Strengths                                                                                                                                     | (7) Weaknesses                                                                                     |
|-----------------------------------------------------------------|-------------------------------|------------------------------|--------------------------------------------|----------------------------------------------|-------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Developed land use (%) for the local catchment                  | “                             | Cdev_<br>CDL_<br>2021_<br>20 | “                                          | See 1_dev_2021<br>above                      | Local<br>catchment                                    | Catchment scale is 3rd smallest in geographic scale, and combination (CDL) of land types makes it 2nd in data quantity, also the most recent data | Not smallest in geographic scale, & combining dev. types may reduce interpretation accuracy        |
| Developed open space (%) for the local catchment                | “                             | L_nlcd<br>11_21              | “                                          | See LB_nlcd11b_21<br>above                   | “                                                     | 3 <sup>rd</sup> smallest in geographic scale, and specific dev. types allow for more accurate interpretations                                     | Not the smallest in geographic scale, not the most numerable, and not the most recent data         |
| Low intensity developed land use (%) for the local catchment    | “                             | L_nlcd<br>11_22              | “                                          | See LB_nlcd11b_22<br>above                   | “                                                     | “                                                                                                                                                 | “                                                                                                  |
| Middle intensity developed land use (%) for the local catchment | “                             | L_nlcd<br>11_23              | “                                          | See LB_nlcd11b_23<br>above                   | “                                                     | “                                                                                                                                                 | “                                                                                                  |
| High intensity developed land use (%) for the local catchment   | “                             | L_nlcd<br>11_24              | “                                          | See LB_nlcd11b_24<br>above                   | “                                                     | “                                                                                                                                                 | “                                                                                                  |
| Developed open space (%) around the entire network flowline     | “                             | NB_nl<br>cd11b_<br>21        | “                                          | See LB_nlcd11b_21<br>above                   | 60m buffer<br>around<br>entire<br>network<br>flowline | Buffer around the network flowline is 3rd data quantity, specific dev. types allow for more accurate interpretations                              | Buffer around the network flowline is 2nd to largest in geographic scale, not the most recent data |

| Variable                                                                                     | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale                      | (6) Strengths                                                                                                                                          | (7) Weaknesses                                                                                                           |
|----------------------------------------------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------|----------------------------------------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| Low intensity<br>developed land<br>use (%) around<br>the entire<br>network<br>flowline       | “                             | NB_nlcd11b_22         | “                                          | See LB_nlcd11b_22<br>above                   | “                              | “                                                                                                                                                      | “                                                                                                                        |
| Middle<br>intensity<br>developed land<br>use (%) around<br>the entire<br>network<br>flowline | “                             | NB_nlcd11b_23         | “                                          | See LB_nlcd11b_23<br>above                   | “                              | “                                                                                                                                                      | “                                                                                                                        |
| High intensity<br>developed land<br>use (%) around<br>the entire<br>network<br>flowline      | “                             | NB_nlcd11b_24         | “                                          | See LB_nlcd11b_24<br>above                   | “                              | “                                                                                                                                                      | “                                                                                                                        |
| Developed open<br>space (%) for<br>the entire<br>network<br>catchment                        | “                             | N_nlcd11_21           | “                                          | See LB_nlcd11b_21<br>above                   | Entire<br>network<br>catchment | Entire network<br>catchment scale is<br>1st in data quantity,<br>and specific types<br>of development<br>allow for more<br>accurate<br>interpretations | Entire network<br>catchment scale is<br>largest in<br>geographic scale,<br>and it doesn't use<br>the most recent<br>data |
| Low intensity<br>developed land<br>use (%) for the<br>entire network<br>catchment            | “                             | N_nlcd11_22           | “                                          | See LB_nlcd11b_22<br>above                   | “                              | “                                                                                                                                                      | “                                                                                                                        |

| Variable                                                                 | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                       | (4) General<br>Definition of Metric<br>- GIS                                    | (5) Scale                      | (6) Strengths                                                                                                                                                                                  | (7) Weaknesses                                                                                                                |
|--------------------------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Middle intensity developed land use (%) for the entire network catchment | “                             | N_nlcd11_23           | “                                                                                                                                                                                                                                                | See LB_nlcd11b_23 above                                                         | “                              | “                                                                                                                                                                                              | “                                                                                                                             |
| High intensity developed land use (%) for the entire network catchment   | “                             | N_nlcd11_24           | “                                                                                                                                                                                                                                                | See LB_nlcd11b_24 above                                                         | “                              | “                                                                                                                                                                                              | “                                                                                                                             |
| Natural land use (%) for the area around the fish sample                 | Land Use<br>Natural           | l_nat_2021            | Natural land is undeveloped, or uncultivated. Rivers surrounded by natural land use types, such as grasslands, forests, wetlands, etc. often have higher quality water and habitat, as well as more diverse fish assemblages.                    | Calculated natural land use (forest, grassland, wetland, and shrub) (%) in 2021 | 60m buffer around sample point | Point scale is smallest in geographic scale (for land use). CDL land estimates are updated annually (most recent), & "natural land use" combines natural cover types, maximizing data quantity | Point scale is low in data quantity (for land use, & combining natural cover types may reduce the accuracy of interpretations |
| Grassland land use (%) for the area around the fish sample               | “                             | l_grass_2021          | Grassland is a specific type of natural cover found in KS. Grasslands are associated with prairie ecosystems, large quantities of which are "protected" within KS. It's very likely that grassland land use is a predictor of fish distribution. | Calculated grassland land use (%) in 2021                                       | “                              | Smallest in geographic scale, most recent data, and specific development types allow for more accurate interpretations                                                                         | Last in data quantity                                                                                                         |

| Variable                                                  | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name          | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale                                 | (6) Strengths                                                                                                                                                                                                                                                                                                                                 | (7) Weaknesses                                                                                                                                                                                                                                                                |
|-----------------------------------------------------------|-------------------------------|--------------------------------|--------------------------------------------|----------------------------------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Natural land use<br>(%) around the<br>local flowline      | “                             | Fnat_C<br>DL_20<br>21_20       | See l_nat_2021 above                       | See l_nat_2021<br>above                      | 60m buffer<br>around<br>local<br>flowline | Flowline scale is<br>2 <sup>nd</sup> smallest in<br>geographic scale,<br>and due to<br>combination (CDL)<br>falls in the middle<br>for data quantity,<br>also uses the most<br>recent data<br>2nd smallest in<br>geographic scale,<br>most recent data,<br>and specific<br>development types<br>allow for more<br>accurate<br>interpretations | Flowline scale is<br>not the most<br>numerable, and<br>combining natural<br>cover types may<br>reduce the<br>accuracy of<br>interpretations                                                                                                                                   |
| Grassland land<br>use (%) around<br>the local<br>flowline | “                             | Fgrass<br>_CDL<br>_2021<br>_20 | See l_grass_2021 above                     | See l_grass_2021<br>above                    | “                                         | 2nd smallest in<br>geographic scale,<br>and specific<br>development types<br>allow for more<br>accurate<br>interpretations                                                                                                                                                                                                                    | Not the most<br>numerable                                                                                                                                                                                                                                                     |
| Grassland land<br>use (%) around<br>the local<br>flowline | “                             | LB_nl<br>cd11b_<br>71          | “                                          | Grassland/herbaceo<br>us land use (%)        | “                                         | 2nd smallest in<br>geographic scale,<br>and specific<br>development types<br>allow for more<br>accurate<br>interpretations<br>Catchment scale<br>(CDL) 2nd in data<br>quantity due to<br>combination of<br>types, 3 <sup>rd</sup> smallest<br>in geographic<br>scale, and the most<br>recent data                                             | Low in data<br>quantity, and<br>NLCD land use<br>estimates are<br>updated every 5<br>years (not most<br>recent)<br>Catchment scale is<br>not the smallest in<br>geographic scale,<br>and combining<br>natural cover types<br>may reduce the<br>accuracy of<br>interpretations |
| Natural land use<br>(%) for the<br>local catchment        | “                             | Cnat_<br>CDL_<br>2021_<br>20   | See l_nat_2021 above                       | See l_nat_2021<br>above                      | Local<br>catchment                        |                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                               |



| Variable                                                  | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS | (5) Scale                                 | (6) Strengths                                                                                                                                                                                                                                                                   | (7) Weaknesses                                                                                              |
|-----------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------|----------------------------------------------|-------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|
| Grassland land use (%) for the local catchment            | “                             | Cgrass_CDLCDL_2021_20 | See l_grass_2021 above                     | See l_grass_2021 above                       | “                                         | 3rd in data quantity and 3 <sup>rd</sup> smallest in geographic scale, and specific types of natural cover allow for more accurate interpretations                                                                                                                              | Not the most numerable, or the smallest in geographic scale                                                 |
| Grassland land use (%) for the local catchment            | “                             | L_nlcd11_71           | “                                          | See LB_nlcd11b_71 above                      | “                                         | Specific types of natural cover allow for more accurate interpretations                                                                                                                                                                                                         | Towards the bottom in data quantity and not the smallest in geographic scale, not the most recent data      |
| Grassland land use (%) around the entire network flowline | “                             | NB_nlcd11b_71         | “                                          | “                                            | 60m buffer around entire network flowline | Buffer around the entire network flowline is high in data quantity, and specific development types allow for more accurate interpretations<br>Entire network catchment scale is 1st in data quantity, and specific types of development allow for more accurate interpretations | Buffer around the network flowline is 4th largest in geographic scale, and doesn't use the most recent data |
| Grassland land use (%) for the entire network catchment   | “                             | N_nlcd11_71           | “                                          | “                                            | Entire network catchment                  | Entire network catchment scale is 1st in data quantity, and specific types of development allow for more accurate interpretations                                                                                                                                               | Entire network catchment is largest in geographic scale, and doesn't use the most recent data               |

| Variable                                                         | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                                                                                                                               | (4) General<br>Definition of Metric<br>- GIS                                                 | (5) Scale         | (6) Strengths                                                                                               | (7) Weaknesses                                                                                                                                                                                          |
|------------------------------------------------------------------|-------------------------------|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|-------------------|-------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dam density<br>per stream<br>length<br>(upstream,<br>mainstem)   | Dams                          | UMD                   | Dams alter the habitat, water quality,<br>and fish assemblage of a system.<br>Dams can create optimal habitat for<br>some fish and destroy essential<br>habitat for others. Therefore, we<br>utilize several aspects of dams (i.e.<br>number, location to site, proportion<br>of open river, density, etc.) to see<br>how they affect fish distribution. | Upstream mainstem<br>dam density per unit<br>upstream mainstem<br>length (#/100km)           | Local<br>flowline | Each dam variable<br>is measured using<br>the 2 <sup>nd</sup> smallest in<br>geographic scale<br>(flowline) | The importance of<br>each dam variable<br>won't be clear until<br>analyses are<br>complete due to the<br>unique<br>measurements<br>estimated in each.<br>Some may be<br>useful, while others<br>may not |
| Proportion of<br>open water<br>(upstream,<br>mainstem)           | “                             | UMO                   | “                                                                                                                                                                                                                                                                                                                                                        | Percentage of open<br>upstream mainstem<br>(%)                                               | “                 | “                                                                                                           | “                                                                                                                                                                                                       |
| Dam count<br>(downstream,<br>mainstem)                           | “                             | DMCT                  | “                                                                                                                                                                                                                                                                                                                                                        | Downstream<br>mainstem dam<br>count (#)                                                      | “                 | “                                                                                                           | “                                                                                                                                                                                                       |
| Dam density<br>per stream<br>length<br>(downstream,<br>mainstem) | “                             | DMD                   | “                                                                                                                                                                                                                                                                                                                                                        | Downstream<br>mainstem dam<br>density per unit<br>downstream<br>mainstem length<br>(#/100km) | “                 | “                                                                                                           | “                                                                                                                                                                                                       |
| Distance to dam<br>(downstream,<br>mainstem)                     | “                             | DM2D                  | “                                                                                                                                                                                                                                                                                                                                                        | Distance to<br>downstream<br>mainstem dam (km)                                               | “                 | “                                                                                                           | “                                                                                                                                                                                                       |
| Proportion of<br>open water<br>(downstream,<br>mainstem)         | “                             | DMO                   | “                                                                                                                                                                                                                                                                                                                                                        | Percentage of open<br>downstream<br>mainstem (%)                                             | “                 | “                                                                                                           | “                                                                                                                                                                                                       |
| Dam count<br>(total,<br>mainstem)                                | “                             | TMCT                  | “                                                                                                                                                                                                                                                                                                                                                        | Total mainstem dam<br>count (#)                                                              | “                 | “                                                                                                           | “                                                                                                                                                                                                       |

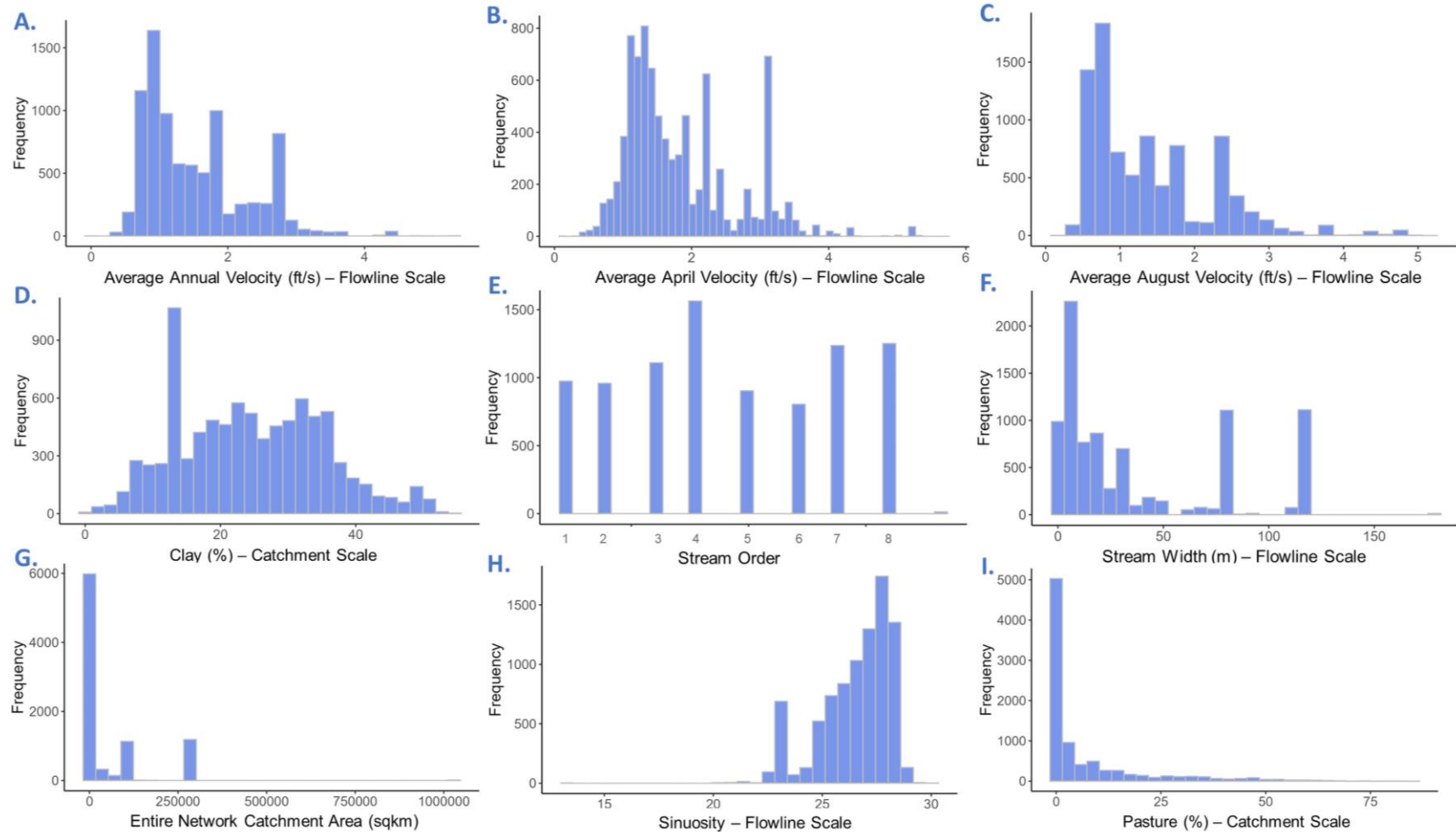
| Variable                                                                             | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish | (4) General<br>Definition of Metric<br>- GIS                                                 | (5) Scale | (6) Strengths                                                                                           | (7) Weaknesses |
|--------------------------------------------------------------------------------------|-------------------------------|-----------------------|--------------------------------------------|----------------------------------------------------------------------------------------------|-----------|---------------------------------------------------------------------------------------------------------|----------------|
| Dam density<br>per stream<br>length (total,<br>mainstem)                             | “                             | TMD                   | “                                          | Total mainstem dam<br>density per unit<br>total mainstem<br>length (#/100km)                 | “         | “                                                                                                       | “              |
| Distance<br>between dams<br>(total,<br>mainstem)                                     | “                             | TM2D                  | “                                          | Total mainstem<br>distance between<br>upstream and/or<br>downstream<br>mainstem dams<br>(km) | “         | This metric may be<br>the most useful as<br>it encapsulates<br>"proximity to dam"<br>(See Table 2.3). “ | “              |
| Proportion of<br>open water<br>(total,<br>mainstem)                                  | “                             | TMO                   | “                                          | Total percentage of<br>open mainstem (%)                                                     | “         | “                                                                                                       | “              |
| Dam count<br>(upstream, all)                                                         | “                             | UNCT                  | “                                          | Total upstream dam<br>count (#)                                                              | “         | “                                                                                                       | “              |
| Dam density<br>per stream<br>length<br>(upstream,<br>entire network)                 | “                             | UNDR                  | “                                          | Upstream network<br>dam density per unit<br>stream network<br>length (#/100km)               | “         | “                                                                                                       | “              |
| Dam density<br>per catchment<br>area (upstream,<br>entire network)                   | “                             | UNDC                  | “                                          | Upstream network<br>dam density per unit<br>network catchment<br>area (#/km <sup>2</sup> )   | “         | “                                                                                                       | “              |
| Reservoir<br>storage volume<br>per stream<br>length<br>(upstream,<br>entire network) | “                             | USR                   | “                                          | Upstream reservoir<br>storage volume per<br>unit stream network<br>length (ha-<br>m/100km)   | “         | “                                                                                                       | “              |

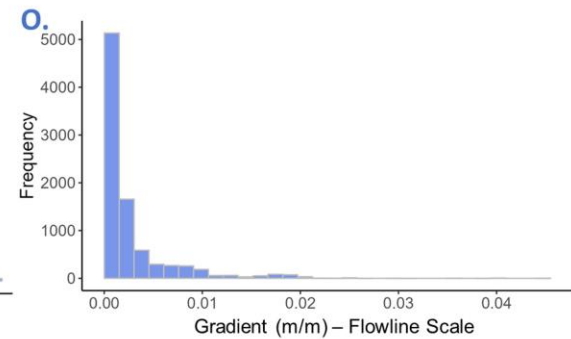
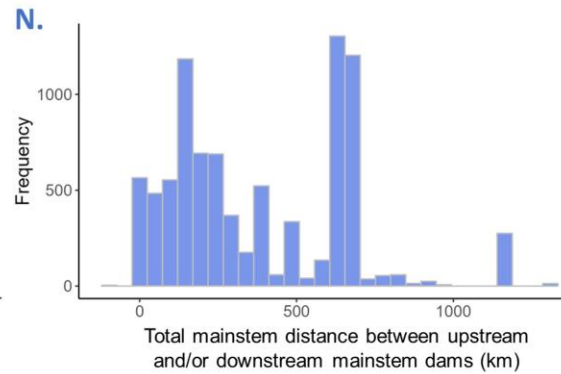
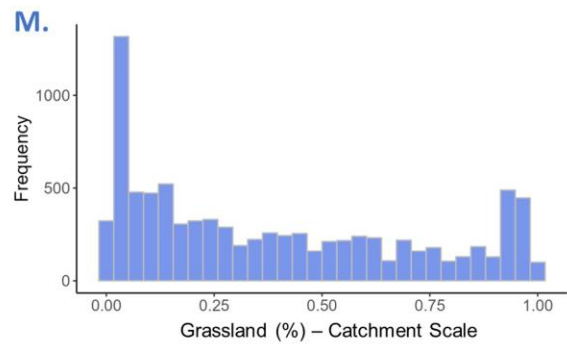
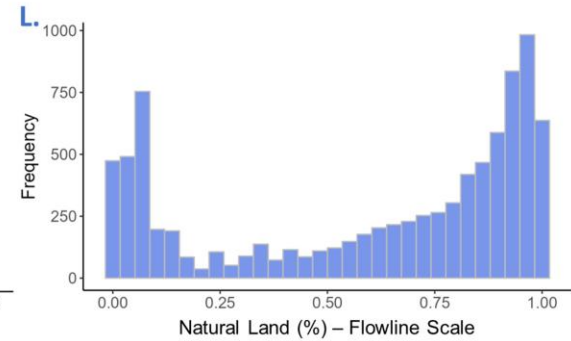
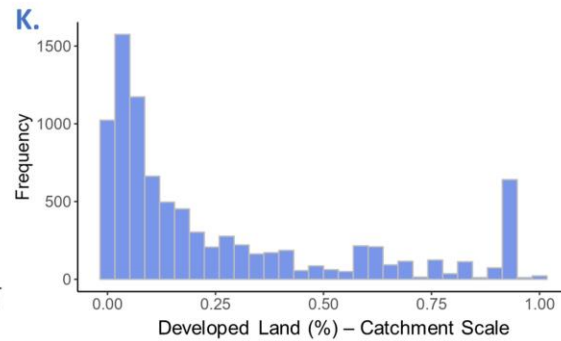
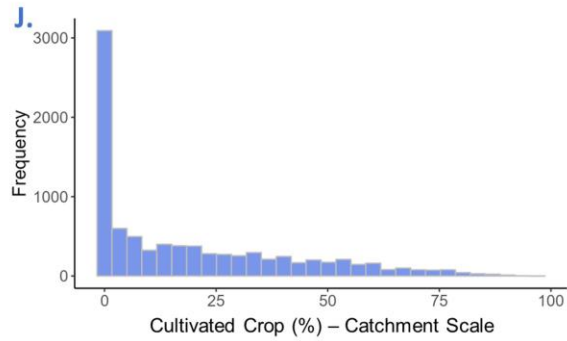
| Variable                                                                           | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                                                                                                                                    | (4) General<br>Definition of Metric<br>- GIS                                                                                                      | (5) Scale                                 | (6) Strengths                                                                                                                                                | (7) Weaknesses                                                                                                                                         |
|------------------------------------------------------------------------------------|-------------------------------|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| Reservoir<br>storage volume<br>per catchment<br>area (upstream,<br>entire network) | “                             | USC                   | “                                                                                                                                                                                                                                                                                                                                                             | Upstream reservoir<br>storage volume per<br>unit stream network<br>catchment area (ha-<br>m/km <sup>2</sup> )                                     | “                                         | “                                                                                                                                                            | “                                                                                                                                                      |
| Proportion of<br>annual<br>discharge stored<br>in reservoirs<br>(upstream)         | “                             | UDOR                  | “                                                                                                                                                                                                                                                                                                                                                             | Percentage of<br>estimated annual<br>discharge stored in<br>upstream reservoirs<br>(%)                                                            | “                                         | “                                                                                                                                                            | “                                                                                                                                                      |
| Stream order                                                                       | Stream<br>Position<br>(Other) | Stream<br>Orde        | Stream order is the position of the<br>stream in the network, with values<br>decreasing as distance to the<br>mainstem of the river grows. Some<br>fish occupy a large range of orders,<br>and others are restricted to only 1-2<br>types. Stream order is a commonly<br>used to describe and predict fish<br>distribution.                                   | Modified Strahler<br>Stream Order                                                                                                                 | N/A,<br>calculated<br>for the<br>flowline | Stream order has<br>an ideal range of<br>estimates. All<br>orders were<br>sampled, and it will<br>likely be important<br>for predicting fish<br>distribution | Stream order is<br>highly correlated<br>with many<br>variables used here,<br>which means they<br>cannot be included<br>in the same<br>regression group |
| Average<br>sinuosity of the<br>local flowline                                      | Sinuosity<br>(Other)          | CURV<br>ATUR<br>E     | Sinuosity is the curviness of a river<br>channel. It is often calculated as the<br>ratio of stream length to valley<br>length and can be used as a predictor<br>of microhabitat diversity. Humans<br>decrease a rivers sinuosity through<br>channelization, flow alteration, and<br>bank stabilization, which in turn<br>affects the structure of the stream. | Calculated average<br>curvature/ sinuosity<br>for the flowline (see<br>Curvature.R for<br>calculations)                                           | Local<br>flowline                         | Sinuosity measured<br>for the flowline has<br>a higher quantity of<br>data                                                                                   | This is the least<br>localized of the two<br>sinuosity variables                                                                                       |
| Average<br>sinuosity of the<br>area around the<br>fish sample                      | “                             | local_c<br>urv        | “                                                                                                                                                                                                                                                                                                                                                             | Calculated average<br>curvature/ sinuosity<br>for the area within<br>~60 meters of the<br>sampling point (See<br>Curvature.R for<br>calculations) | 60m buffer<br>around<br>sample<br>point   | Sinuosity measured<br>at point scale is the<br>most localized                                                                                                | There is a<br>significantly<br>smaller amount of<br>data available for<br>this scale                                                                   |

| Variable                                                        | (1)<br>Ecological<br>Category    | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                                                          | (4) General<br>Definition of Metric<br>- GIS                                                                                              | (5) Scale          | (6) Strengths                                                                                                             | (7) Weaknesses                                                                                                                              |
|-----------------------------------------------------------------|----------------------------------|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Slope<br>(Gradient)<br>calculated for<br>the local<br>flowline  | Gradient<br>(Other)              | SLOP<br>E             | Channel slope, or gradient, is a commonly measured fish habitat variable. It is defined as the change in elevation from one end of a sample reach to the other. A reaches gradient can dictate how quickly the river flows, and therefore what habitat types and fauna are present. | Slope of flowline (m/m), calculated by dividing the change in elevation by the length of the flowline (km), then multiplying by 1km/1000m | Local<br>flowline  | Both slope metrics calculate the same values, but the flowline scale is the most localized of the two                     | Error values within this column lead to difficulty when plotting and running regression                                                     |
| Slope<br>(Gradient)<br>calculated for<br>the local<br>catchment | “                                | L_fl_sl<br>ope        | “                                                                                                                                                                                                                                                                                   | Slope of catchment (degrees), see SLOPE above for calculations                                                                            | Local<br>catchment | This variable has no error values, making analysis straightforward                                                        | This is the least localized of the 2 slope metrics, but estimates are the same                                                              |
| Maximum<br>elevation for the<br>local catchment                 | “                                | L_max<br>elev         | The maximum elevation, or height above sea-level, is the highest point in the catchment. Gradient can be calculated from identifying the maximum and minimum elevations in a reach.                                                                                                 | Maximum elevation of local catchment (cm)                                                                                                 | “                  | Kansas has a gradual increase in elevation from East to West.                                                             | Maximum elevation is not a commonly measured variable when trying to predict fish distribution                                              |
| Stream width                                                    | Reach<br>Measuremen<br>t (Other) | Width_<br>m           | Flow regimes can alter a reaches width, and vice versa the width of a stream controls the speed at which water flows through it. A reaches width (m) can tell one a lot about the instream habitat there.                                                                           | Calculated stream width (m) estimated for the flowline exit point                                                                         | Local<br>flowline  | Estimates for this variable can be found at almost every site, and flowline scale is the 2nd smallest in geographic scale | Estimating stream width with remote sensing technology is not always accurate. Empirically measured widths are preferred by many biologists |

| Variable                                   | (1)<br>Ecological<br>Category | (2)<br>Metric<br>Name | (3) General Definition of Metric -<br>Fish                                                                                                                                                                                                                                                                                                                              | (4) General<br>Definition of Metric<br>- GIS                                       | (5) Scale                | (6) Strengths                                                                                                                                                                                                             | (7) Weaknesses                                                                                                                              |
|--------------------------------------------|-------------------------------|-----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Stream depth                               | “                             | Depth_<br>m           | Flow regimes can alter a reaches depth, and vice versa the depth of a stream alters how water flows through it. Shallow areas are found in portions with slower, less intense flow, and deeper areas are carved out by larger, fast-moving quantities of flow.                                                                                                          | Calculated stream depth (m) estimated for the flowline exit point                  | “                        | “                                                                                                                                                                                                                         | Estimating stream depth with remote sensing technology is not always accurate. Empirically measured depths are preferred by many biologists |
| Total area of the local catchment          | Catchment Area (Other)        | L_area<br>sqkm        | A catchment area is the area of land that drains into a waterbody. Any surface materials or nutrients on the land will eventually make their way into a waterbody, and therefore the adjacent landuse of a catchment area likely reflects the health of the system, including fish presence. Larger catchment areas mean larger areas of land that drain into a system. | Area of the local catchment in which the fish sampling point falls (sqkm)          | Local catchment          | Catchment scale is the most localized of the area (sqkm) estimates, which might have more of a direct influence on local waterways than areas far upstream. Estimates for this variable can be found at almost every site | Large jumps in estimate values make for tricky plotting and analysis                                                                        |
| Total area of the entire network catchment | “                             | N_area<br>sqkm        | “                                                                                                                                                                                                                                                                                                                                                                       | Area of the entire network catchment in which the fish sampling point falls (sqkm) | Entire network catchment | Estimates for this variable can be found at almost every site                                                                                                                                                             | Large jumps in estimate values make for tricky plotting and analysis, and not the most localized scale for area (sqkm) variables            |

**Appendix A Figure A.1.** Frequency histogram distributions for the remaining top metrics (A-O) prioritized for Emerald Shiner for all samples taken within our study area ( $n = 8,844$ ). See Figure 1.4 (A-B) for sand and silt substrate metric distributions.

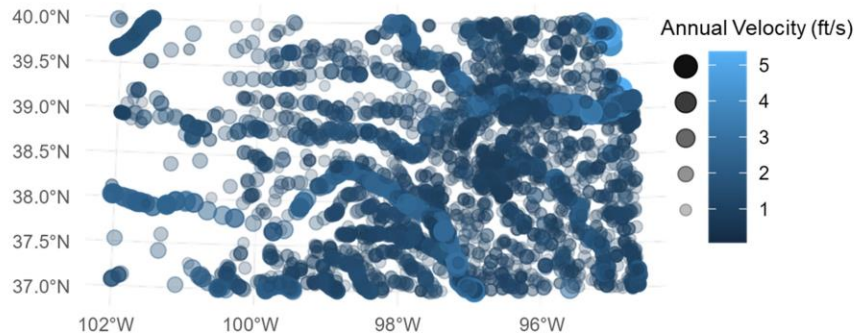




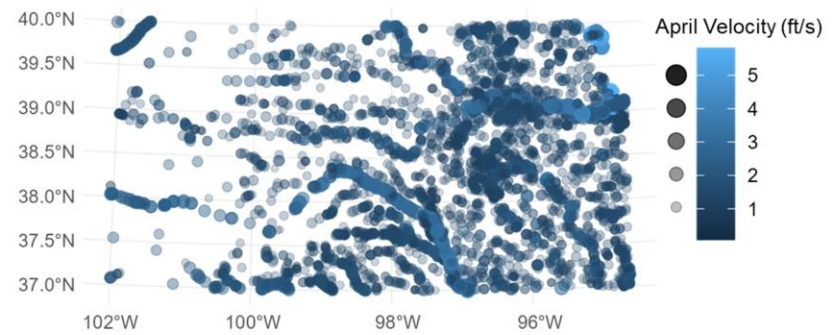


**Appendix A Figure A.2.** Statewide proportional symbol maps for the remaining top metrics (A-O) prioritized for Emerald Shiner. Dots represent all unique locations sampled within our study area ( $n=7872$ ). Dot size and color align with specific metric values, with the higher values exhibiting larger size and lighter blue colors. See Figure 1.5 (A-B) for sand and silt substrates statewide proportional maps.

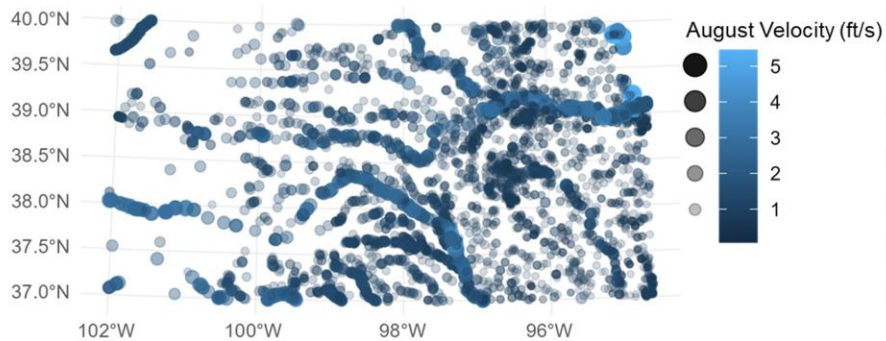
**A.** Average Annual Velocity (ft/s) – Flowline Scale



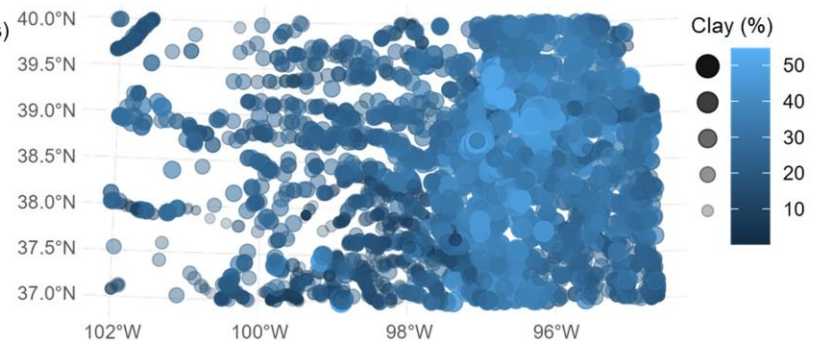
**B.** Average April Velocity (ft/s) – Flowline Scale



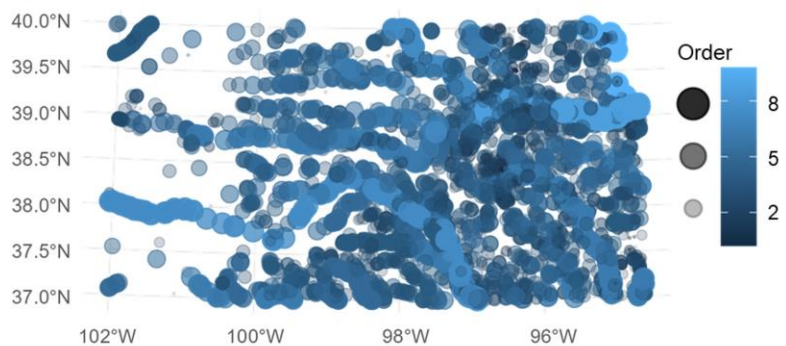
**C.** Average August Velocity (%) – Flowline Scale



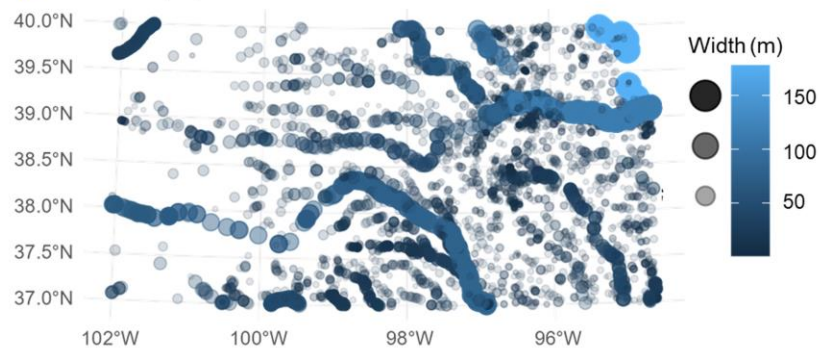
**D.** Clay (%) – Catchment Scale



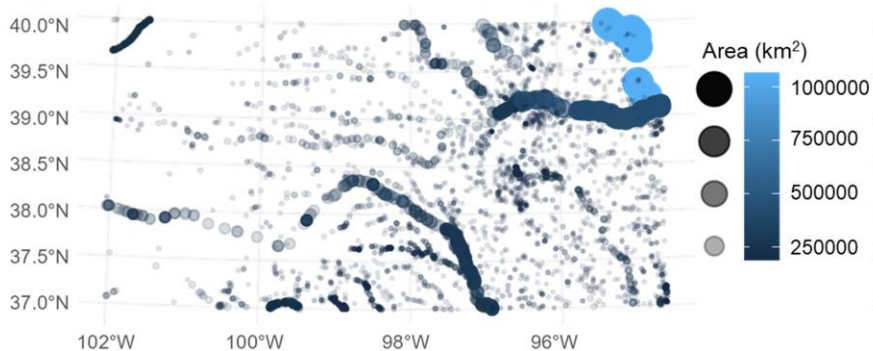
**E.** Stream Order



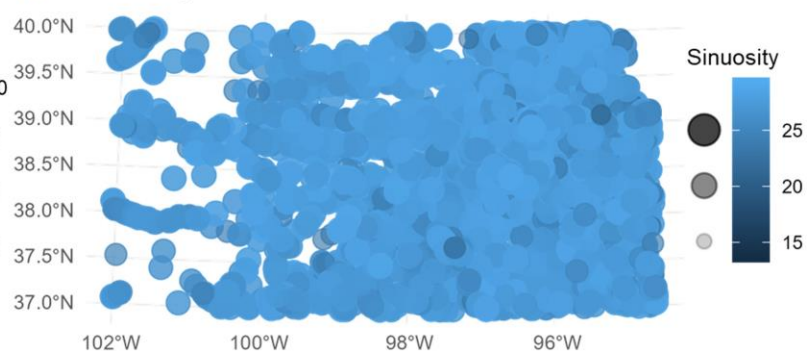
**F.** Width (m) – Flowline Scale



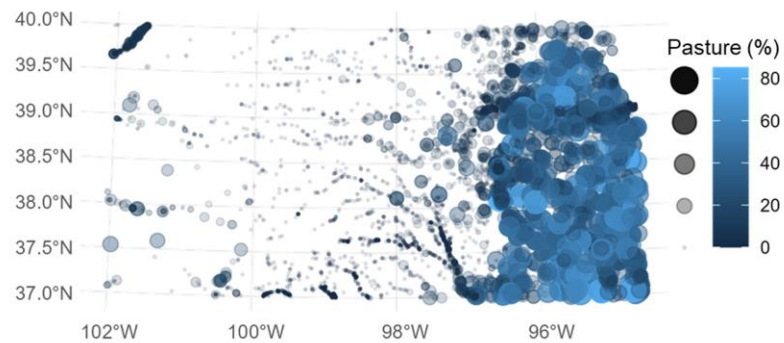
**G.** Entire Network Catchment Area (km<sup>2</sup>)



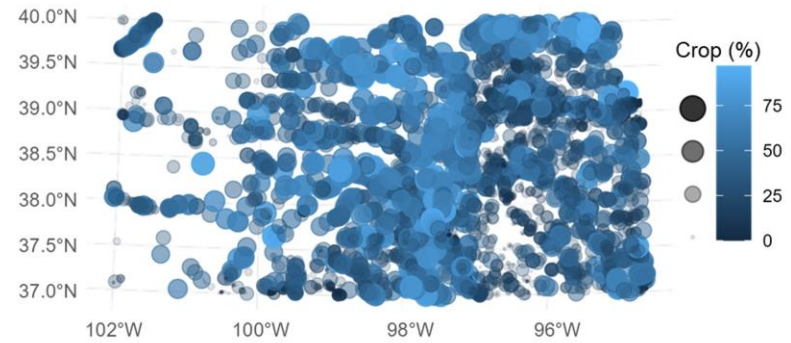
**H.** Sinuosity – Flowline Scale



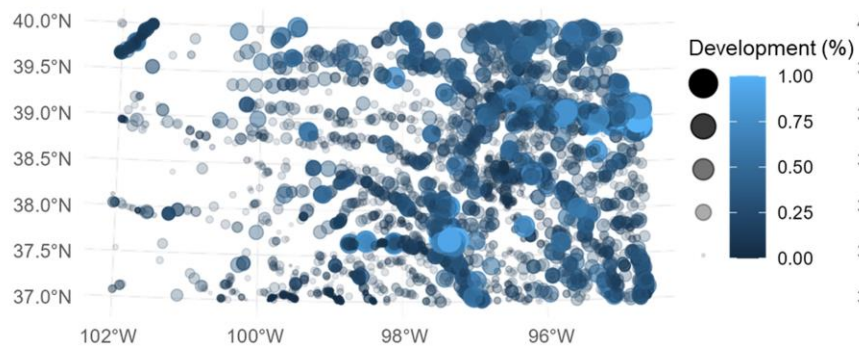
**I.** Pasture (%) – Catchment Scale



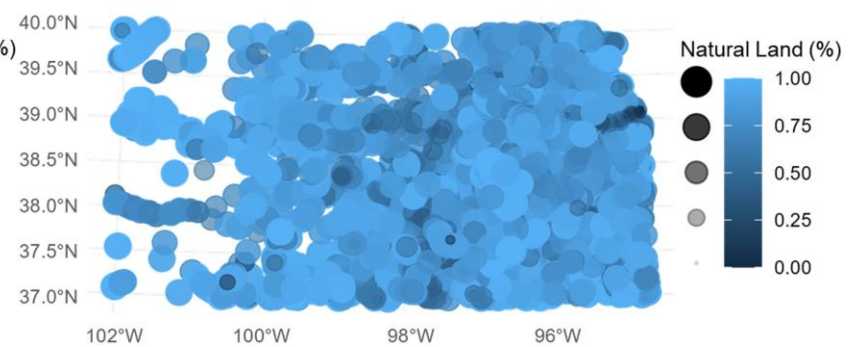
**J.** Cultivated Crop (%) – Catchment Scale



**K.** Developed Land (%) – Catchment Scale

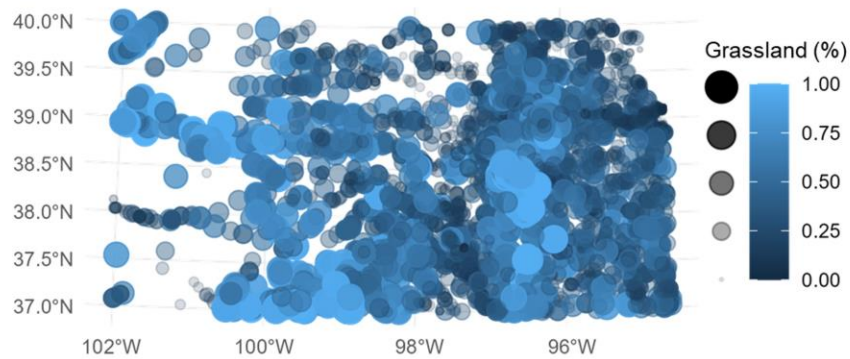


**L.** Natural Land (%) – Flowline Scale

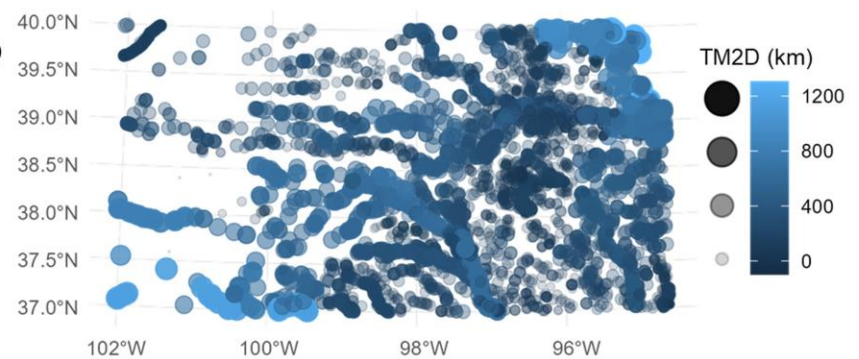




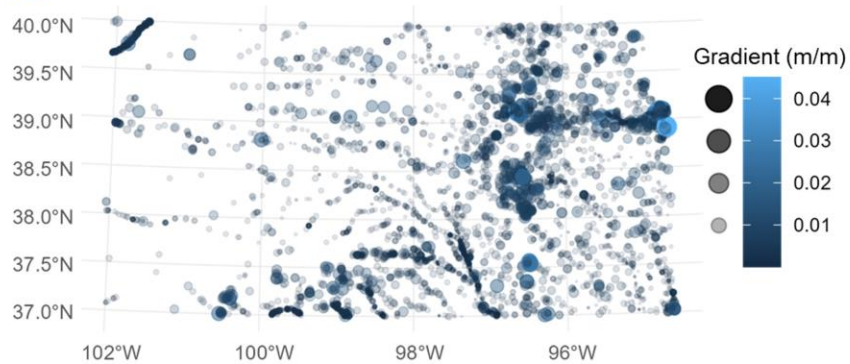
**M.** Grassland (%) – Catchment Scale



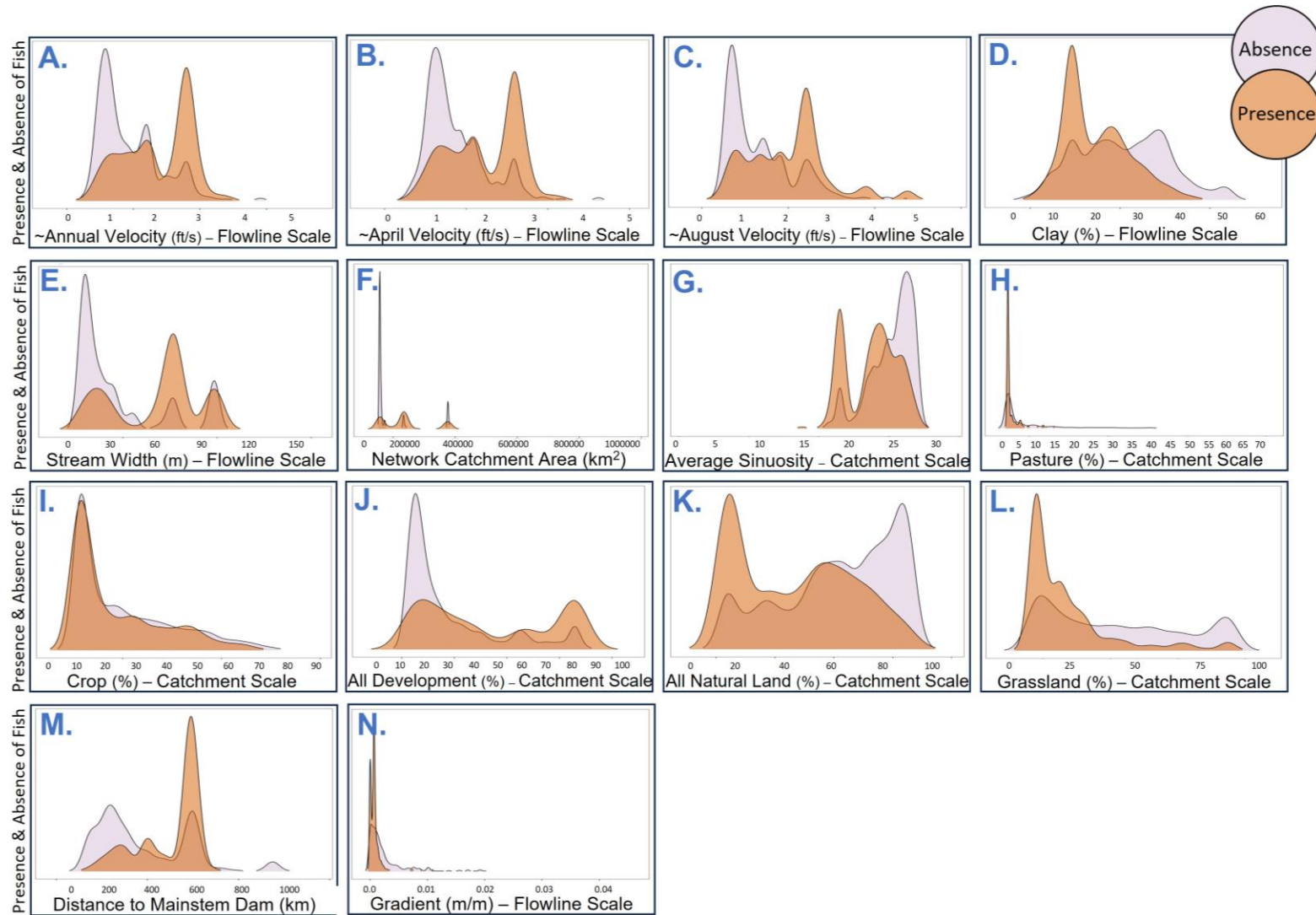
**N.** Total Distance Between Mainstem Dams (TM2D - km)



**O.** Gradient (m/m) – Flowline Scale



**Appendix A. Figure A.4.** Remaining presence and absence ridgeline plots for top metrics (A-N) prioritized for Emerald Shiner. Red ridges = Presence of Emerald Shiner, purple ridges = Absence of Emerald Shiner. Darker Red/Brown = overlap of presence/absence. See Figure 1.8 for stream order, sand, and silt presence and absence values.



## Appendix B - Supplementary Materials for Chapter 2

**Appendix B. Table B.1.** Species of Greatest Conservation Need (SGCN), as identified in the Kansas State Wildlife Action Plan (Rohweder 2022). Here we detail the current status and listings of all fish that qualified as SGCN using SWAP criteria. The first column lists federal listing status as of 2022 (i.e. Threatened [T] or Endangered [E]). The second column details the listing status for the state of Kansas as of 2022 (i.e. Threatened [T], Endangered [E], or Species in Need of Conservation [SINC]). The third column states the rank, or tier, of the SGCN species (Tier I [Federal or state threatened or endangered listings] or Tier II [Any other SGCN qualifying criteria such as SINC listing, endemism, major declines, or environmental importance]). The fourth column indicates whether the species was recommended for conservation listing per rationale outlined in Haslour et al. 2005. Species we include in our analyses are bolded.

| Common Name (SGCN Species - Kansas SWAP) | Conservation Status, Rank, or Recommendation (2022) |                          |           |                                                     |
|------------------------------------------|-----------------------------------------------------|--------------------------|-----------|-----------------------------------------------------|
|                                          | Federal Listing (T/E)                               | State Listing (T/E/SINC) | SGCN Tier | Recommended for Conservation Listing (Haslour 2005) |
| American Eel                             |                                                     |                          | II        | X                                                   |
| Arkansas Darter                          |                                                     | SINC                     | II        | X                                                   |
| Arkansas River Shiner                    | T                                                   | T                        | I         |                                                     |
| <b>Banded Darter</b>                     |                                                     | <b>SINC</b>              | <b>II</b> | <b>X</b>                                            |
| Banded Sculpin                           |                                                     | SINC                     | II        | X                                                   |
| Bigeye Shiner                            |                                                     | SINC                     | II        | X                                                   |
| Black Buffalo                            |                                                     |                          | II        |                                                     |
| Black Redhorse                           |                                                     | SINC                     | II        | X                                                   |
| Blackside Darter                         |                                                     | T                        | I         | X                                                   |
| <b>Blue Sucker</b>                       |                                                     | <b>SINC</b>              | <b>II</b> | <b>X</b>                                            |
| Bluntnose Darter                         |                                                     | SINC                     | II        | X                                                   |
| <b>Brassy Minnow</b>                     |                                                     | <b>SINC</b>              | <b>II</b> | <b>X</b>                                            |
| Brindled Madtom                          |                                                     | SINC                     | II        | X                                                   |
| Cardinal Shiner                          |                                                     | SINC                     | II        | X                                                   |
| Channel Darter                           |                                                     |                          | II        |                                                     |
| Chestnut Lamprey                         |                                                     | SINC                     | II        | X                                                   |
| Common Shiner                            |                                                     | SINC                     | II        | X                                                   |
| Fantail Darter                           |                                                     |                          | II        | X                                                   |
| Flathead Chub                            |                                                     | T                        | I         | X                                                   |
| Freckled Madtom                          |                                                     |                          | II        |                                                     |
| Golden Redhorse                          |                                                     |                          | II        |                                                     |
| Gravel Chub                              |                                                     | SINC                     | II        | X                                                   |
| Greenside Darter                         |                                                     | SINC                     | II        | X                                                   |
| Highfin Carpsucker                       |                                                     | SINC                     | II        | X                                                   |
| Highland Darter                          |                                                     |                          | II        |                                                     |
| Hornyhead Chub                           |                                                     | T                        | I         | X                                                   |
| Johnny Darter                            |                                                     | SINC                     | II        | X                                                   |
| Lake Sturgeon                            |                                                     | SINC                     | II        | X                                                   |

|                                  |          |          |           |          |
|----------------------------------|----------|----------|-----------|----------|
| Least Darter                     |          |          | II        |          |
| <b>Neosho Madtom</b>             | <b>T</b> | <b>T</b> | <b>I</b>  | <b>X</b> |
| Northern Hog Sucker              |          | SINC     | II        | X        |
| <b>Northern Plains Killifish</b> |          |          | <b>II</b> | <b>X</b> |
| Orangethroat Darter              |          |          | II        |          |
| Ozark Logperch                   |          |          | II        |          |
| Ozark Minnow                     |          | SINC     | II        | X        |
| Paddlefish                       |          |          | II        |          |
| Pallid Sturgeon                  | E        | E        | I         | X        |
| Pealip Redhorse                  |          |          | II        |          |
| Peppered Chub                    | E        | E        | I         | X        |
| <b>Plains Minnow</b>             |          | <b>T</b> | <b>I</b>  | <b>X</b> |
| Quillback                        |          |          | II        |          |
| Redfin Darter                    |          | SINC     | II        | X        |
| Redspot Chub                     |          | T        | I         | X        |
| River Darter                     |          | SINC     | II        | X        |
| River Redhorse                   |          | SINC     | II        | X        |
| River Shiner                     |          | SINC     | II        | X        |
| Shoal Chub                       |          | T        | I         | X        |
| Shorthead Redhorse               |          |          | II        |          |
| Shovelnose Sturgeon              |          |          | II        | X        |
| Sicklefin Chub                   |          | E        | I         | X        |
| Silver Chub                      |          | E        | I         | X        |
| Silverband Shiner                |          | SINC     | II        | X        |
| Slender Madtom                   |          |          | II        |          |
| Slenderhead Darter               |          |          | II        |          |
| Slough Darter                    |          | SINC     | II        | X        |
| Southern Redbelly Dace           |          | SINC     | II        | X        |
| Speckled Darter                  |          |          | II        | X        |
| Spotfin Shiner                   |          | SINC     | II        | X        |
| Spotted Gar                      |          |          | II        |          |
| Spotted Sucker                   |          | SINC     | II        | X        |
| Stonecat                         |          |          | II        |          |
| Striped Shiner                   |          | SINC     | II        | X        |
| Sturgeon Chub                    |          | T        | I         | X        |
| Sunburst Darter                  |          | SINC     | II        |          |
| Tadpole Madtom                   |          | SINC     | II        | X        |
| <b>Topeka Shiner</b>             | <b>E</b> | <b>T</b> | <b>I</b>  | <b>X</b> |
| Warmouth                         |          |          | II        |          |
| Western Blacknose Dace           |          | SINC     | II        | X        |
| Western Silvery Minnow           |          | T        | I         | X        |
| White Sucker                     |          |          | II        |          |

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**Appendix B. Table B.2.** To test for multicollinearity among regressors, we examined variable inflation factors (VIF) and condition indices (CN). Each fish had two models (Model A and Model B) that exhibited an  $\Delta AIC < 2$ . Some metrics were included in both models [BOTH (A) and (B)], while others were separated due to correlations [(A) or (B) ONLY] – see below. Most consider a  $VIF > 10$  as an indicator of collinearity (Vittinghoff 2005; James 2013; R Statistics for Political Science 2020), but some suggest investigating lower values ( $VIF > 5-10$ ; Menard 2001). A  $CN < 30$  is considered an upper level for acceptable multicollinearity (Freund and Littell 2000; Salmeron and Garcia 2022; Roever et al. 2023), and again some suggest investigating lower values ( $CN < 10-30$ ).

| <b>Emerald Shiner</b>                           |                                       |                             |
|-------------------------------------------------|---------------------------------------|-----------------------------|
| Top Models ( $\Delta AIC < 2$ ) Metric Names:   | Variable Inflation Factor Value (VIF) | Condition Number Value (CN) |
| Silt (%)                                        | 1.75 (A), 1.90                        | 1.0 (A), 1.0 (B)            |
| Stream Order                                    | 4.06 (A), 4.12                        | 6.10 (A), 5.99 (B)          |
| Sinuosity                                       | 1.79 (A), 1.79                        | 8.76 (A), 7.30 (B)          |
| Area of Network Catchment (km <sup>2</sup> )    | 3.32 (A), 3.23                        | 19.97 (A), 19.10            |
| Pasture (Agricultural Land Use - %)             | 1.21 (B)                              | 2.01 (B)                    |
| Crop (Agricultural Land Use - %)                | 1.72 (A)                              | 2.08 (A)                    |
| Developed Land Use (All Types - %)              | 2.78 (A), 2.20                        | 2.92 (A), 2.86 (B)          |
| Grassland (Natural Land - %)                    | 2.97 (A), 2.26                        | 3.76 (A), 3.52 (B)          |
| Total Distance to Mainstem Dam (TM2D - km)      | 1.94 (A), 1.91                        | 4.31 (A), 4.24 (B)          |
| Gradient (m/m)                                  | 1.50 (A), 1.48                        | 11.26 (A), 10.52            |
| <b>Central Stoneroller</b>                      |                                       |                             |
| Average June Discharge (ft <sup>3</sup> /s)     | 1.52 (A)                              | 1.0 (A)                     |
| Average Annual Discharge (ft <sup>3</sup> /s)   | 1.55 (B)                              | 1.0 (B)                     |
| Rock Fragments (%)                              | 1.26 (A), 1.26                        | 1.72 (A), 1.72 (B)          |
| Stream Depth (m)                                | 2.51 (A), 2.55                        | 12.59 (A), 12.52            |
| Sinuosity                                       | 1.21 (A), 1.21                        | 5.68 (A), 5.68 (B)          |
| Pasture (Agricultural Land Use - %)             | 1.19 (A), 1.20                        | 2.45 (A), 2.45 (B)          |
| Crop (Agricultural Land Use - %)                | 1.46 (A), 1.45                        | 2.82 (A), 2.82 (B)          |
| High Intensity Development (Developed Land Use) | 1.47 (A), 1.47                        | 3.53 (A), 3.52 (B)          |
| Natural Land (All Types - %)                    | 1.54 (A), 1.54                        | 3.94 (A), 3.87 (B)          |
| Total Distance to Mainstem Dam (TM2D - km)      | 1.35 (A), 1.35                        | 4.83 (A), 4.81 (B)          |
| Gradient (m/m)                                  | 1.56 (A), 1.57                        | 8.78 (A), 8.72 (B)          |
| <b>Plains Minnow</b>                            |                                       |                             |
| Average August Discharge (ft <sup>3</sup> /s)   | 1.32 (A)                              | 1.0 (A)                     |
| Average May Discharge (ft <sup>3</sup> /s)      | 1.41 (B)                              | 1.0 (B)                     |
| Sand (%)                                        | 1.34 (A), 1.36                        | 2.31 (A), 2.29 (B)          |
| Stream Depth (m)                                | 5.61 (A), 5.73                        | 17.35 (A), 17.43            |
| Sinuosity                                       | 1.17 (A), 1.17                        | 8.11 (A), 8.24 (B)          |
| Crop (Agricultural Land Use - %)                | 1.91 (A), 1.92                        | 2.82 (A), 2.84 (B)          |
| Developed Open Space (Developed Land Use - %)   | 1.28 (A), 1.29                        | 2.88 (A), 2.88 (B)          |
| Grassland (Natural Land - %)                    | 2.87 (A), 2.85                        | 3.73 (A), 3.81 (B)          |
| Open Upstream Proportion (UMO - %)              | 3.16 (A), 3.16                        | 6.08 (A), 6.35 (B)          |
| Gradient (m/m)                                  | 1.54 (A), 1.54                        | 10.48 (A), 10.49            |



**Appendix B Table B.3. (A)** Standardized, multiple logistic regression models for all three fish using our Best-Species-Specific Metric (BSSM-S) approach. Each model includes 1 non-correlated, prioritized variable from each ecological category. Exceptions include if a metric is removed entirely due to correlations [NA (corr)], or if metrics within the same category are not correlated and thus do not need to be separated. Column sections include (1) model identifier, (2) *comparable* parameter estimates ( $\beta$ ) and standard errors (SE) for metrics within each of the 11 ecological categories, and (3) model evaluation statistics including:  $\Delta$  AIC, model accuracy (%), and D2 (%). For each fish, models are listed in order of descending AIC. Models A, B have a  $\Delta$  AIC < 2 and are considered top models (above the thick, dark gray dividing line). Metrics that were significant ( $P < 0.5$ ) are **bolded** and underlined. Regressor names and scale (if relevant – P: point, F: flowline, C: catchment, N: network catchment) can be found within each ecological category section underneath the **fish's name** and *prioritized metric* headings.

| A. Best Species-Specific Metric - Standardized Regression (BSSM-S) |                             |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
|--------------------------------------------------------------------|-----------------------------|----------------|-------|--------------------|----------|------------------|--------------------|----------------------|-------------------|---------------|---------------------------|---------------|------------------------|----------|------------------|----------------|----------|----------------|---------------|-----------|---------------|--------------|-----------|-------|-------|--------------|----|--------|--|
| Models                                                             | Ecological Categories       |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       | Δ AIC | Accuracy (%) |    | D² (%) |  |
|                                                                    | NHDPlus Flow (CFS or FPS)   | Substrates (%) |       |                    |          | Stream Order (#) | Reach Measures (m) | Catchment Area (km²) | Average Sinuosity |               | Agricultural Land Use (%) |               | Developed Land Use (%) |          | Natural Land (%) |                | Dams     | Gradient (m/m) |               |           |               |              |           |       |       |              |    |        |  |
|                                                                    | Emerald Shiner              |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
|                                                                    | Prioritized Metrics (Scale) |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
|                                                                    | Silt (C)                    |                |       |                    | Sand (C) |                  | Clay (C)           |                      | Order             |               | Area (N)                  |               | Sinuosity (F)          |          | Pasture (C)      |                | Crop (C) |                | All Types (C) |           | Grassland (C) |              | TM2D (km) |       |       |              |    |        |  |
| β                                                                  | SE                          | β              | SE    | β                  | SE       | β                | SE                 | β                    | SE                | β             | SE                        | β             | SE                     | β        | SE               | β              | SE       | β              | SE            | β         | SE            | β            | SE        | β     | SE    |              |    |        |  |
| A                                                                  | NA (corr)                   | -0.63          | 0.07  |                    |          |                  |                    | 0.42                 | 0.11              | -0.04         | 0.09                      | -0.15         | 0.07                   |          |                  | -0.19          | 0.07     | -0.11          | 0.09          | -0.92     | 0.10          | -0.10        | 0.07      | -0.04 | 0.08  | 0            | 74 | 23     |  |
| B                                                                  |                             | -0.59          | 0.07  |                    |          |                  |                    | 0.40                 | 0.11              | 0.00          | 0.09                      | -0.17         | 0.07                   | -0.17    | 0.07             |                |          | -0.02          | 0.08          | -0.80     | 0.08          | -0.07        | 0.07      | -0.02 | 0.08  | 1            | 74 | 23     |  |
| C                                                                  |                             |                |       | 0.61               | 0.07     |                  |                    | 0.41                 | 0.11              | -0.08         | 0.08                      | -0.16         | 0.07                   |          |                  | -0.19          | 0.07     | -0.13          | 0.09          | -0.89     | 0.10          | -0.09        | 0.07      | -0.03 | 0.07  | 12           | 74 | 22     |  |
| D                                                                  |                             |                |       | 0.55               | 0.07     |                  |                    | 0.40                 | 0.11              | -0.03         | 0.08                      | -0.18         | 0.07                   | -0.17    | 0.07             |                |          | -0.04          | 0.08          | -0.77     | 0.08          | -0.06        | 0.07      | -0.02 | 0.07  | 14           | 74 | 22     |  |
| E                                                                  |                             |                |       |                    |          | -0.29            | 0.07               | 0.51                 | 0.11              | -0.22         | 0.08                      | -0.28         | 0.07                   | -0.26    | 0.07             |                |          | -0.06          | 0.08          | -0.65     | 0.08          | 0.01         | 0.07      | -0.04 | 0.07  | 57           | 73 | 21     |  |
| F                                                                  |                             |                |       |                    |          | -0.35            | 0.07               | 0.55                 | 0.11              | -0.28         | 0.08                      | -0.27         | 0.07                   |          |                  | -0.21          | 0.06     | -0.15          | 0.09          | -0.76     | 0.09          | -0.02        | 0.07      | -0.04 | 0.07  | 64           | 73 | 21     |  |
| Central Stoneroller                                                |                             |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
| Prioritized Metrics (Scale)                                        |                             |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
| D-Annual                                                           |                             | D-Jun.         |       | Rock Fragments (C) |          | Order            |                    | Depth (F)            |                   | Sinuosity (F) |                           | Pasture (N)   |                        | Crop (N) |                  | High Int. (C)  |          | All Types (C)  |               | TM2D (km) |               | Gradient (F) |           |       |       |              |    |        |  |
| β                                                                  | SE                          | β              | SE    | β                  | SE       | β                | SE                 | β                    | SE                | β             | SE                        | β             | SE                     | β        | SE               | β              | SE       | β              | SE            | β         | SE            | β            | SE        |       |       |              |    |        |  |
| A                                                                  |                             | -0.25          | 0.13  | 0.12               | 0.05     |                  |                    | -1.30                | 0.08              | NA (Corr)     | 0.20                      | 0.04          | 0.14                   | 0.03     | -0.22            | 0.03           | -0.53    | 0.11           | 0.05          | 0.05      | -0.01         | 0.04         | -0.02     | 0.04  | 0     | 76           | 31 |        |  |
| B                                                                  | -0.20                       | 0.13           | 0.12  | 0.05               |          |                  | -1.32              | 0.08                 | 0.19              |               | 0.04                      | 0.14          | 0.03                   | -0.22    | 0.03             | -0.53          | 0.11     | 0.05           | 0.05          | -0.01     | 0.04          | -0.02        | 0.04      | 2     | 76    | 31           |    |        |  |
| C                                                                  |                             | -0.72          | 0.12  | 0.10               | 0.04     | -0.80            | 0.06               |                      |                   |               | 0.29                      | 0.04          | 0.21                   | 0.03     | -0.28            | 0.03           | -0.73    | 0.11           | -0.01         | 0.05      | -0.10         | 0.04         | -0.06     | 0.05  | ##    | 75           | 30 |        |  |
| D                                                                  | -0.71                       | 0.12           | 0.10  | 0.04               | -0.81    | 0.06             |                    |                      | 0.29              |               | 0.04                      | 0.21          | 0.03                   | -0.28    | 0.03             | -0.73          | 0.11     | -0.01          | 0.05          | -0.10     | 0.04          | -0.06        | 0.05      | ##    | 75    | 30           |    |        |  |
| Plains Minnow                                                      |                             |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
| Prioritized Metrics (Scale)                                        |                             |                |       |                    |          |                  |                    |                      |                   |               |                           |               |                        |          |                  |                |          |                |               |           |               |              |           |       |       |              |    |        |  |
| D-May                                                              |                             | D-Aug.         |       | Silt (P)           |          | Sand (C)         |                    | Order                |                   | Depth (F)     |                           | Sinuosity (P) |                        | Crop (C) |                  | Open Space (C) |          | Grassland (C)  |               | UMO (%)   |               | Gradient (C) |           |       |       |              |    |        |  |
| β                                                                  | SE                          | β              | SE    | β                  | SE       | β                | SE                 | β                    | SE                | β             | SE                        | β             | SE                     | β        | SE               | β              | SE       | β              | SE            | β         | SE            | β            | SE        |       |       |              |    |        |  |
| A                                                                  |                             |                |       |                    |          | 1.04             | 0.14               |                      |                   | 1.20          | 0.23                      | -0.29         | 0.11                   | -0.03    | 0.13             | -0.47          | 0.16     | 1.10           | 0.18          | 1.42      | 0.19          | -0.39        | 0.15      | 0     | 89    | 55           |    |        |  |
| B                                                                  | -0.08                       | 0.12           |       |                    |          | 1.04             | 0.14               |                      |                   | 1.19          | 0.24                      | -0.30         | 0.11                   | -0.03    | 0.13             | -0.47          | 0.16     | 1.10           | 0.18          | 1.42      | 0.19          | -0.39        | 0.15      | 0     | 89    | 55           |    |        |  |
| C                                                                  | 0.05                        | 0.10           |       |                    |          | 1.14             | 0.14               | 0.74                 | 0.16              | NA (Corr)     | -0.34                     | 0.11          | -0.21                  | 0.12     | -0.55            | 0.16           | 0.92     | 0.16           | 1.03          | 0.15      | -0.42         | 0.16         | 7         | 89    | 54    |              |    |        |  |
| D                                                                  |                             |                | 0.03  | 0.10               |          | 1.14             | 0.14               | 0.74                 | 0.16              |               | -0.34                     | 0.11          | -0.21                  | 0.12     | -0.55            | 0.16           | 0.92     | 0.16           | 1.03          | 0.14      | -0.42         | 0.16         | 7         | 89    | 54    |              |    |        |  |
| E                                                                  |                             |                | -0.10 | 0.17               | -0.81    | 0.13             |                    |                      | 1.42              |               | 0.23                      | -0.38         | 0.11                   | -0.04    | 0.13             | -0.45          | 0.15     | 1.22           | 0.18          | 1.50      | 0.19          | -0.43        | 0.16      | 16    | 88    | 54           |    |        |  |
| F                                                                  | -0.09                       | 0.15           |       |                    | -0.81    | 0.13             |                    |                      | 1.42              |               | 0.23                      | -0.38         | 0.11                   | -0.04    | 0.13             | -0.45          | 0.15     | 1.22           | 0.18          | 1.50      | 0.19          | -0.43        | 0.16      | 16    | 88    | 54           |    |        |  |
| G                                                                  | 0.09                        | 0.12           |       |                    | -0.92    | 0.12             |                    |                      | 0.91              |               | 0.15                      | -0.43         | 0.10                   | -0.26    | 0.12             | -0.54          | 0.15     | 1.03           | 0.16          | 1.03      | 0.15          | -0.44        | 0.16      | 24    | 88    | 53           |    |        |  |
| H                                                                  |                             |                | 0.07  | 0.12               | -0.92    | 0.12             |                    |                      | 0.92              |               | 0.15                      | -0.44         | 0.10                   | -0.26    | 0.12             | -0.54          | 0.15     | 1.03           | 0.16          | 1.03      | 0.15          | -0.44        | 0.16      | 24    | 88    | 53           |    |        |  |

**Appendix B Table B.3. (B)** Having standardized our results, the significant coefficients are now comparable within each fish’s model. Columns include: (1) the rank of the coefficient value, (2) the significant metric name and ecological category, and (3) the coefficient value. The larger the value (negative or positive) the better the predictive capability of the metric within the model.

| <u>B. Best Species-Specific Metric – Standardized Regression (BSSM-S)</u> |                                                 |                          |
|---------------------------------------------------------------------------|-------------------------------------------------|--------------------------|
| <b>Emerald Shiner</b>                                                     |                                                 |                          |
| <i>Rank</i>                                                               | <i>Metric Name &amp; Category</i>               | <i>Coefficient Value</i> |
| 1                                                                         | Grassland (Natural Land)                        | -0.92                    |
| 2                                                                         | Silt (Substrate)                                | -0.63                    |
| 3                                                                         | Stream Order (Ecosystem Size)                   | 0.42                     |
| 4                                                                         | Crop (Agricultural Land Use)                    | -0.19                    |
| 5                                                                         | Pasture (Agricultural Land Use)                 | -0.17                    |
| 6                                                                         | Sinuosity (Ecosystem Size <i>related</i> )      | -0.15                    |
| <b>Central Stoneroller</b>                                                |                                                 |                          |
| <i>Rank</i>                                                               | <i>Metric Name &amp; Category</i>               | <i>Coefficient Value</i> |
| 1                                                                         | Stream Depth (Ecosystem Size)                   | -1.3                     |
| 2                                                                         | High Intensity Development (Developed Land Use) | -0.53                    |
| 3                                                                         | Average June Discharge (NHDPlus Flow)           | -0.25                    |
| 4                                                                         | Crop (Agricultural Land Use)                    | -0.22                    |
| 5                                                                         | Sinuosity (Ecosystem Size <i>related</i> )      | -0.2                     |
| 6                                                                         | Pasture (Agricultural Land Use)                 | 0.14                     |
| 7                                                                         | Rock Fragments (Substrate)                      | 0.12                     |
| <b>Plains Minnow</b>                                                      |                                                 |                          |
| <i>Rank</i>                                                               | <i>Metric Name &amp; Category</i>               | <i>Coefficient Value</i> |
| 1                                                                         | Open Upstream Proportion [UMO] (Dams)           | 1.42                     |
| 2                                                                         | Stream Depth (Ecosystem Size)                   | 1.2                      |
| 3                                                                         | Grassland (Natural Land)                        | 1.1                      |
| 4                                                                         | Sand (Substrates)                               | 1.04                     |
| 5                                                                         | Developed Open Space (Developed Land Use)       | -0.47                    |
| 6                                                                         | Gradient                                        | -0.39                    |
| 7                                                                         | Sinuosity (Ecosystem Size <i>related</i> )      | -0.29                    |

**Appendix B Table B.4.** Unstandardized, multiple logistic regression models for all three fish using our Same-Species-Specific Metric (SSSM-U) approach. Each model for all three fish includes 1 non-correlated, consistent variable from each ecological category. Column sections include (1) model identifier, (2) parameter estimates ( $\beta$ ) and standard errors (SE) for the metric within each of the 11 ecological categories, and (3) model evaluation statistics including:  $\Delta$  AIC, model accuracy (%), and  $D^2$  (%). For each fish, models are listed in order of descending AIC. Model A has a  $\Delta$  AIC < 2 and is considered the top model (above the thick, dark gray dividing line). Metrics that were significant ( $P < 0.5$ ) are bolded and underlined. Regressor names and scale (if relevant – P: point, F: flowline, C: catchment, N: network catchment) can be found within each ecological category section underneath the fish’s name and same metrics headings.

| Same Species-Specific Metric - Unstandardized Regression (SSSM-U) |                           |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
|-------------------------------------------------------------------|---------------------------|----------------|--------------|------------------|--------------|--------------------|--------------|-----------------------------------|--------------|-------------------|---------------|---------------------------|-------------|------------------------|---------------|------------------|---------------|-------------|-------------|----------------|----------------|--------------|-------|--------------|--------------------|
| Models                                                            | Ecological Categories     |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              | Δ AIC | Accuracy (%) | D <sup>2</sup> (%) |
|                                                                   | NHDPlus Flow (CFS or FPS) | Substrates (%) |              | Stream Order (#) |              | Reach Measures (m) |              | Catchment Area (km <sup>2</sup> ) |              | Average Sinuosity |               | Agricultural Land Use (%) |             | Developed Land Use (%) |               | Natural Land (%) |               | Dams        |             | Gradient (m/m) |                |              |       |              |                    |
|                                                                   | Emerald Shiner            |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
|                                                                   | Same Metrics (Scale)      |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
|                                                                   | D - April (F)             |                | Sand (C)     |                  | Order        |                    | Width (F)    |                                   | Area (C)     |                   | Sinuosity (F) |                           | Crop (C)    |                        | All Types (P) |                  | All Types (C) |             | TMO (%)     |                | Gradient (F)   |              |       |              |                    |
| β                                                                 | SE                        | β              | SE           | β                | SE           | β                  | SE           | β                                 | SE           | β                 | SE            | β                         | SE          | β                      | SE            | β                | SE            | β           | SE          | β              | SE             |              |       |              |                    |
| A                                                                 | <u>-0.00</u>              | <u>0.00</u>    | <u>0.02</u>  | <u>0.00</u>      | <u>0.31</u>  | <u>0.04</u>        |              |                                   | <u>-0.02</u> | <u>0.00</u>       | <u>-0.16</u>  | <u>0.05</u>               | 0.12        | 0.27                   | -0.21         | 0.26             | <u>-1.90</u>  | <u>0.26</u> | -0.00       | 0.01           | -6.60          | 19.58        | 0     | 72           | 21                 |
| B                                                                 |                           |                | <u>0.02</u>  | <u>0.00</u>      |              |                    | <u>0.01</u>  | <u>0.00</u>                       | <u>-0.02</u> | <u>0.00</u>       | <u>-0.16</u>  | <u>0.04</u>               | 0.46        | 0.27                   | -0.13         | 0.26             | <u>-1.82</u>  | <u>0.26</u> | -0.00       | 0.01           | -33.38         | 20.36        | 17    | 72           | 20                 |
| Central Stoneroller                                               |                           |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
| Same Metrics (Scale)                                              |                           |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
| D - April (F)                                                     |                           | Sand (C)       |              | Order            |              | Width (F)          |              | Area (C)                          |              | Sinuosity (F)     |               | Crop (C)                  |             | All Types (P)          |               | All Types (C)    |               | TMO (%)     |             | Gradient (F)   |                |              |       |              |                    |
| β                                                                 | SE                        | β              | SE           | β                | SE           | β                  | SE           | β                                 | SE           | β                 | SE            | β                         | SE          | β                      | SE            | β                | SE            | β           | SE          | β              | SE             |              |       |              |                    |
| A                                                                 |                           |                | <u>-0.01</u> | <u>0.00</u>      |              |                    | <u>-0.04</u> | <u>0.00</u>                       | -0.00        | 0.00              | <u>0.11</u>   | <u>0.03</u>               | 0.07        | 0.17                   | 0.13          | 0.16             | <u>1.17</u>   | <u>0.17</u> | 0.00        | 0.00           | <u>21.87</u>   | <u>9.02</u>  | 0     | 76           | 30                 |
| B                                                                 | <u>-0.00</u>              | <u>0.00</u>    | <u>-0.02</u> | <u>0.00</u>      | <u>-0.29</u> | <u>0.03</u>        |              |                                   | <u>-0.01</u> | <u>0.00</u>       | <u>0.14</u>   | <u>0.03</u>               | <u>0.35</u> | <u>0.17</u>            | 0.19          | 0.16             | <u>1.36</u>   | <u>0.16</u> | 0.00        | 0.00           | -2.55          | 9.62         | 84    | 73           | 29                 |
| Plains Minnow                                                     |                           |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
| Same Metrics (Scale)                                              |                           |                |              |                  |              |                    |              |                                   |              |                   |               |                           |             |                        |               |                  |               |             |             |                |                |              |       |              |                    |
| D - April (F)                                                     |                           | Sand (C)       |              | Order            |              | Width (F)          |              | Area (C)                          |              | Sinuosity (F)     |               | Crop (C)                  |             | All Types (P)          |               | All Types (C)    |               | TMO (%)     |             | Gradient (F)   |                |              |       |              |                    |
| β                                                                 | SE                        | β              | SE           | β                | SE           | β                  | SE           | β                                 | SE           | β                 | SE            | β                         | SE          | β                      | SE            | β                | SE            | β           | SE          | β              | SE             |              |       |              |                    |
| A                                                                 |                           |                | <u>0.06</u>  | <u>0.00</u>      |              |                    | <u>-0.02</u> | <u>0.00</u>                       | -0.01        | 0.01              | -0.01         | 0.08                      | -0.83       | 0.45                   | <u>-1.94</u>  | <u>0.53</u>      | <u>1.29</u>   | <u>0.44</u> | <u>0.04</u> | <u>0.01</u>    | <u>-182.24</u> | <u>42.81</u> | 0     | 87           | 49                 |
| B                                                                 | 0.00                      | 0.00           | <u>0.06</u>  | <u>0.00</u>      | <u>-0.22</u> | <u>0.07</u>        |              |                                   | -0.01        | 0.01              | 0.04          | 0.08                      | -0.24       | 0.44                   | <u>-1.74</u>  | <u>0.53</u>      | <u>2.18</u>   | <u>0.43</u> | <u>0.03</u> | <u>0.01</u>    | <u>-186.25</u> | <u>45.34</u> | 24    | 87           | 48                 |

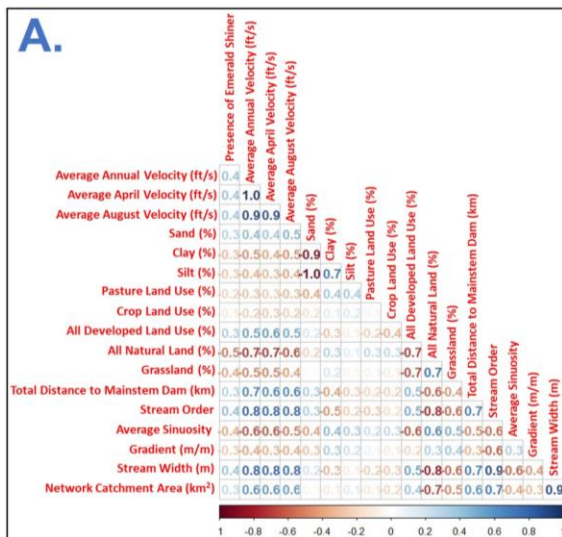
**Appendix B Table B.6.** Standardized, multiple logistic regression models for all three fish using our Same-Species-Specific Metric (SSSM-S) approach. Each model for all three fish includes 1 non-correlated, consistent variable from each ecological category. Column sections include (1) model identifier, (2) comparable parameter estimates ( $\beta$ ) and standard errors (SE) for the metric within each of the 11 ecological categories, and (3) model evaluation statistics including:  $\Delta$  AIC, model accuracy (%), and  $D^2$  (%). For each fish, models are listed in order of descending AIC. Model A has a  $\Delta$  AIC < 2 and is considered the top model (above the thick, dark gray dividing line). Metrics that were significant ( $P < 0.5$ ) are bolded and underlined. Regressor names and scale (if relevant – P: point, F: flowline, C: catchment, N: network catchment) can be found within each ecological category section underneath the fish’s name and same metrics headings.

| Models               | Same Species-Specific Metric - Standardized Regression (SSSM-S) |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             | Δ AIC | Accuracy (%) | D <sup>2</sup> (%) |
|----------------------|-----------------------------------------------------------------|-------------|----------------|-------------|------------------|-------------|--------------------|-------------|-----------------------------------|---------------|-------------------|-------------|---------------------------|---------------|------------------------|---------------|------------------|-------------|-------------|--------------|----------------|-------------|-------|--------------|--------------------|
|                      | Ecological Categories                                           |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
|                      | NHDPlus Flow (CFS or FPS)                                       |             | Substrates (%) |             | Stream Order (#) |             | Reach Measures (m) |             | Catchment Area (km <sup>2</sup> ) |               | Average Sinuosity |             | Agricultural Land Use (%) |               | Developed Land Use (%) |               | Natural Land (%) |             | Dams        |              | Gradient (m/m) |             |       |              |                    |
|                      | Emerald Shiner                                                  |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
|                      | Same Metrics (Scale)                                            |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
| D - April (F)        |                                                                 | Sand (C)    |                | Order       |                  | Width (F)   |                    | Area (C)    |                                   | Sinuosity (F) |                   | Crop (C)    |                           | All Types (P) |                        | All Types (C) |                  | TMO (%)     |             | Gradient (F) |                |             |       |              |                    |
| β                    | SE                                                              | β           | SE             | β           | SE               | β           | SE                 | β           | SE                                | β             | SE                | β           | SE                        | β             | SE                     | β             | SE               | β           | SE          | β            | SE             |             |       |              |                    |
| A                    | <u>-0.21</u>                                                    | <u>0.08</u> | <u>0.40</u>    | <u>0.07</u> | <u>0.69</u>      | <u>0.10</u> |                    |             | <u>-0.35</u>                      | <u>0.09</u>   | <u>-0.28</u>      | <u>0.07</u> | 0.03                      | 0.06          | -0.06                  | 0.07          | <u>-0.61</u>     | <u>0.08</u> | -0.04       | 0.06         | -0.03          | 0.08        | 0     | 72           | 21                 |
| B                    |                                                                 |             | <u>0.55</u>    | <u>0.06</u> |                  |             | <u>0.41</u>        | <u>0.08</u> | <u>-0.33</u>                      | <u>0.08</u>   | <u>-0.28</u>      | <u>0.07</u> | 0.10                      | 0.06          | -0.04                  | 0.07          | <u>-0.59</u>     | <u>0.08</u> | -0.01       | 0.06         | -0.13          | 0.08        | 17    | 72           | 20                 |
| Central Stoneroller  |                                                                 |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
| Same Metrics (Scale) |                                                                 |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
| D - April (F)        |                                                                 | Sand (C)    |                | Order       |                  | Width (F)   |                    | Area (C)    |                                   | Sinuosity (F) |                   | Crop (C)    |                           | All Types (P) |                        | All Types (C) |                  | TMO (%)     |             | Gradient (F) |                |             |       |              |                    |
| β                    | SE                                                              | β           | SE             | β           | SE               | β           | SE                 | β           | SE                                | β             | SE                | β           | SE                        | β             | SE                     | β             | SE               | β           | SE          | β            | SE             |             |       |              |                    |
| A                    |                                                                 |             | <u>-0.38</u>   | <u>0.04</u> |                  |             | <u>-1.40</u>       | <u>0.07</u> | -0.06                             | 0.04          | <u>0.17</u>       | <u>0.04</u> | 0.02                      | 0.04          | 0.03                   | 0.04          | <u>0.35</u>      | <u>0.05</u> | 0.04        | 0.04         | <u>0.10</u>    | <u>0.04</u> | 0     | 76           | 30                 |
| B                    | <u>-0.87</u>                                                    | <u>0.11</u> | <u>-0.45</u>   | <u>0.04</u> | <u>-0.65</u>     | <u>0.06</u> |                    |             | <u>-0.17</u>                      | <u>0.05</u>   | <u>0.22</u>       | <u>0.04</u> | <u>0.08</u>               | <u>0.04</u>   | 0.05                   | 0.04          | <u>0.41</u>      | <u>0.05</u> | 0.03        | 0.03         | -0.01          | 0.04        | 84    | 73           | 29                 |
| Plains Minnow        |                                                                 |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
| Same Metrics (Scale) |                                                                 |             |                |             |                  |             |                    |             |                                   |               |                   |             |                           |               |                        |               |                  |             |             |              |                |             |       |              |                    |
| D - April (F)        |                                                                 | Sand (C)    |                | Order       |                  | Width (F)   |                    | Area (C)    |                                   | Sinuosity (F) |                   | Crop (C)    |                           | All Types (P) |                        | All Types (C) |                  | TMO (%)     |             | Gradient (F) |                |             |       |              |                    |
| β                    | SE                                                              | β           | SE             | β           | SE               | β           | SE                 | β           | SE                                | β             | SE                | β           | SE                        | β             | SE                     | β             | SE               | β           | SE          | β            | SE             |             |       |              |                    |
| A                    |                                                                 |             | <u>1.69</u>    | <u>0.11</u> |                  |             | <u>-0.73</u>       | <u>0.13</u> | -0.10                             | 0.09          | -0.01             | 0.10        | -0.17                     | 0.09          | <u>-0.42</u>           | <u>0.11</u>   | <u>0.39</u>      | <u>0.13</u> | <u>0.51</u> | <u>0.13</u>  | <u>-0.67</u>   | <u>0.16</u> | 0     | 87           | 49                 |
| B                    | 0.19                                                            | 0.10        | <u>1.80</u>    | <u>0.12</u> | <u>-0.43</u>     | <u>0.14</u> |                    |             | -0.09                             | 0.09          | 0.05              | 0.10        | -0.05                     | 0.09          | <u>-0.37</u>           | <u>0.11</u>   | <u>0.66</u>      | <u>0.13</u> | <u>0.35</u> | <u>0.13</u>  | <u>-0.68</u>   | <u>0.17</u> | 24    | 87           | 48                 |

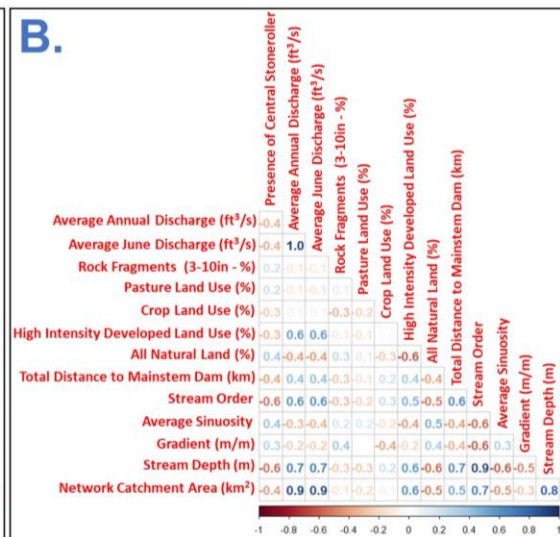
**Appendix B Figure B.1.** Correlation plots for all prioritized variables in fish BSSM-U and BSSM-S multiple logistic regressions. Variables with correlations > 0.7 were excluded from final models or were used in separate models. (A) Emerald Shiner metric correlation table – Velocity types (3 metrics), stream width (1 metric), and natural land (1 metric) were removed for correlations (> 0.7). Substrates (3 metrics) and agricultural land use types (2 metrics) were used in separate models. (B) Central Stoneroller metric correlation table - Catchment area (1 metric) was removed for correlation (> 0.7). Discharge types (2 metrics), and stream depth and order (2 metrics) were used in separate models. (C) Plains Minnow metric correlation table - Catchment area (1 metric) was removed for correlation (> 0.7). Discharge types (2 metrics), substrates (2 metrics), and stream depth and order (2 metrics) were used in separate models.

### Correlation Plots of All Prioritized Metrics in BSSM Regressions

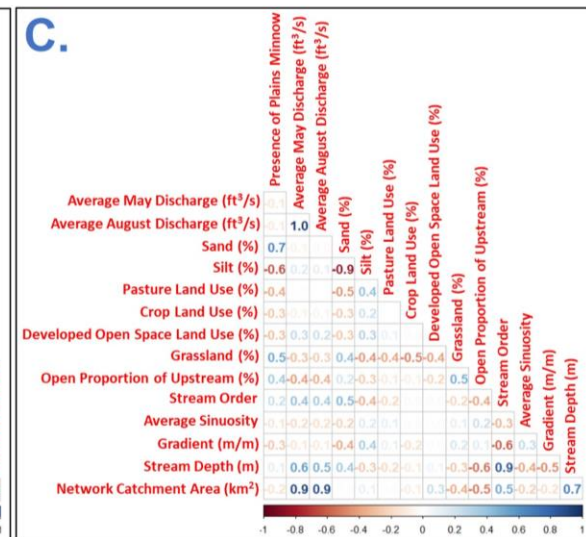
#### **Emerald Shiner**



#### **Central Stoneroller**



#### **Plains Minnow**



## **Appendix C - What Literature was Reviewed: Why, Results, and**

### **Next Steps**

#### **Introduction**

Literature is an important component of any study. Providing literature context is step 3 in our adaptive management framework. Specific aspects of the literature are incorporated into Chapters 1, 2, but here we summarize the general components of the broader literature review that we have undertaken thus far. Three objectives were addressed in this broader literature review. First, what habitat variables are commonly examined for fish overall, and specifically for prairie stream fish. Second, what habitat variables exist for our 15 common and uncommon target Kansas fish in a focused literature review, and what habitat variables do they examine? Finally, from this literature, what expectations do we have for the shape (e.g., positive, negative, no relationship) of the response (Y axis) for each individual habitat-impact regression variable (X axis) across studies for the three target fish taxa on which we focus in Chapters 1 and 2 (Emerald Shiner, Central Stoneroller, Plains Minnow). The goal of this last objective is to be able to make predictions and compare expected responses to observed responses for statistical analyses in our adaptive management framework for which probability of fish presence is the Y axis and values for the habitat or impact variable (across the range, state, or region) is the X axis. For clarity, objective 2 reviews the expanse of the habitat literature and identifies the resultant target variables, whereas objective 3 reviews the trends in select variables from the literature on the 3 fish that we targeted in Chapters 1, 2. Although it is not possible to conduct a comprehensive habitat review for this many fish for such a common topic, our purpose here is to demonstrate that a substantial, systematic, and objective effort was made to review to the

literature on our target fish, especially in Kansas, the Midwestern region and the Great Plains. This appendix is intended to provide a general overview of efforts to review the ecological-life history literature on select fish, but is not intended to be a detailed or comprehensive summary. Under other circumstances, a comprehensive literature review of select concept could be useful. For example, Busch et al. 2020 reviewed the literature to identify inconsistency in nomenclature for intermittent streams, assess if there were consistent associations between terms and disciplines, and recommend standard language. However, this type of comprehensive review was not undertaken here.

## **Objective 1 – What Habitat Variables are Commonly Examined for Stream Fish Overall and Specifically for Prairie Stream Fish?**

**Objective 1 - Background.** Fish habitat can be a link between environmental conditions and a healthy vs degraded fish community. If we don't define, categorize, standardize, and synthesize how fish habitat studies are done, we won't know what we have, what it means, and what more is needed in future studies. In this first objective, we examine consistency or lack of consistency in fish habitat studies.

**Objective 1 - Methods.** For literature review objective 1, we created two representative databases of peer-reviewed papers on fish habitat. These two different but related databases focused on (A) general fish (Figure C.1A) and (B) prairie stream fish (Fig. C.1B). To create both databases, we used a standard sequence of steps applied to the Web of Science (WoS) bibliographic database (Fig. C.1A-B). The goal of this process was to representatively identify a broad range of fish habitat papers, then systematically and objectively reduce the papers in each

dataset to a number that could be examined with a logistically tractable level of effort. In using this approach, we seek to identify general trends with a realistic amount of effort.

For this process related to objective 1, “fish” and “habitat” were inputted first as Web of science topics. Then, other filters excluded many off-topic subjects such as “sharks” or “reptiles” as many non-fish papers snuck into the results. To continue to reduce the number of references, “fish” and “habitat” were again inputted as title “keywords” in the Web of Science bibliographic database. To further narrow down general fish habitat papers (Fig. C.1A), the most relevant categories on Web of Science were selected as well. These categories included: Marine and Freshwater Biology, Ecology, and Fisheries. To further narrow down prairie fish habitat papers (Fig. C.1B), the keywords “Prairie,” “Midwest/ern,” and “Great Plains” were inputted as topics. Then, for both databases, the years were cut down to 2019-2020. In the end, our two manageable but representative test datasets limited the general fish habitat search to recent years (Fig. C.1A) or used appropriate refining terms to limit trends to prairie fish (Fig. C.1B). The literature summary below is based on 45 and 38 representative publications on general fish habitat and prairie fish habitat, respectively that were determined objectively.

**Objective 1 - Results.** The first trend that we identified examined how the authors used and defined fish habitat. For the general fish literature review, all of the papers mentioned “habitat” in the title (Figure C.2A), but only two of these papers defined what the authors meant by the term “habitat” (Fig. C.2C). For the prairie fish review, each paper mentioned “habitat” in the title once again, but only one paper had a clear definition (Fig. C.2B). Furthermore, authors associated general fish habitat with an array of different terms, such as habitat-use, habitat-loss, and pelagic-habitat (Fig. C.2E). In prairie fish papers, authors commonly associated habitat with terms like microhabitat, habitat structure, habitat quality, and habitat quantity (Fig. C.2F).



A second trend that we identified was that different researchers measured different variables (Figure C.3A-B). For example, no study examined all of the same habitat variables. Instead, these studies measured an array of different variables under the shared but undefined term “habitat” for both the general fish (Fig. C.3A) and prairie fish (Fig. C.3B) datasets. The generalized groupings of habitat that were finalized after repeating rounds of review were as follows: flow variables, physical structure, integrated variables (micro or macrohabitat), abiotic variables, vegetation (submergent or riparian vegetation), prey, and other biotic variables (predation or competition) (Fig. C.3A-B). It was the identification of these groups that allowed us to devise our dataset for our chosen Kansas fish in later objectives. These data show that no one looks at all of the same variables, but they don’t show that the measurements are different. Elsewhere, we observed this measurement mismatch in our review, however we don’t report it here (for example, related to flow, some researchers empirically measured velocity at a specific place and time and others used measurements of discharge for an entire catchment across a season or year). This lack of standardization and consistency among researchers can limit generality.

**Objective 1 – Conclusion and Next Steps.** Many researchers collect fish habitat data, yet not all researchers measure the same habitat variables in the same way. Objective 1 identified sources of inconsistency that inhibit synthesis. In addition to the themes reported above, we observed measurement mismatches in our review. For example, related to flow, some researchers empirically measured velocity at a specific place and time and others used measurements of discharge for an entire catchment across a season or year). This lack of standardization and consistency among researchers can limit generality. This inconsistency can make comparison of datasets, collected by different researchers at different times in different places, difficult. As a

result, existing fish habitat datasets (like individual jigsaw puzzle pieces) cannot be connected, thereby preventing fisheries professionals from seeing a bigger integrated picture across time, space, and studies. .

The literature reviews from objective 1 also identified some potential functional themes that can guide categorization, standardization, and integration of the fish habitat literature in general and for the topics addressed in Chapters 1, 2 of this thesis.

Of the common habitat and impact variables that are found in the literature, we sought to identify consistently important habitat and impact variables for which we could get data at all fish sample sites (Rode et al. Appendix A Table A.2).

Although we identify the lack of habitat variable standardization as a potential gap that impedes synthesis, we, like the authors of many of the studies we reviewed, were not able to report on all common variables. For us and probably for others, a complete data set for all habitat variables was not present at the locations where fish were sampled. For example, we could not get site specific velocity measurements, but we were able to get NHDPlus flow. We were able to acquire measurements for physical and abiotic habitat at each site [substrate, stream order, catchment size, reach measures such as width, depth, gradient, and sinuosity (curviness)] and impact variables that can affect habitat (agricultural land use, developed land use, natural land, dam characteristics), but we were not able to acquire consistently measured data on integrated habitat (like pool, riffle, run), vegetation, prey, or biotic responses. When we merged the objective 1 review with data available at our fish sampling sites, we identified 11 habitat and impact categories (substrate, stream order, catchment size, reach measures such as width and depth, sinuosity, agricultural land use, developed land use, natural land, dam characteristics, and gradient) for our quantitative analyses in Chapters 1, 2.

## **Objective 2 - What Papers and Habitat Variables were Important for our 15 Common and Uncommon Target Kansas Fish?**

**Objective 2 - Background.** The diverse suite of fish native to Great Plains streams and rivers requires an array of different habitats to survive and thrive. *Kansas Fishes*, published in 2014, is an excellent addition to the Kansas fish literature. Yet, different levels of detail are addressed by different authors for different Kansas fish. In some cases, additional geographic data can be added, and additional literature has been made available since this important Kansas fish resource was published. Here, we systematically review what is known about each of our 15-target fish related to habitat. Much of the literature on our target fish does not specifically relate to habitat and thus is not included here. As with objective 1, we tried to be representative, make a strong effort, but it was not logistically feasible to review every paper on every fish. Although we do not review every paper, the summary we provide here shows that we made a strong effort to address relevant literature. Objective 2 details the number and identity of relevant papers. Chapter 2 summarizes the ecological findings of these citations.

**Methods.** For this objective, three sources were utilized: Web of Science (here after WoS), NatureServe Explorer database (<https://explorer.natureserve.org/>), and *Kansas Fishes* (Distler et al. 2014). We only examined papers that addressed habitat variables that fell into our 11 ecological categories established through our review in objective 1 above. Therefore, we did not include variables such as water quality or biotic threats (e.g. nonnative piscivores).

For WoS, two systematic searches were made. The specified search terms chosen for each of these systematic searches can be found in Table C.1. The first WoS search terms included a topic search of the: "common name" OR the "scientific name," and the results were recorded to gain an understanding of the breadth of existing literature per fish (Table C.2). The

second search terms included a topic search of multiple ecological terms used to separate habitat related literature from literature on genetics, taxonomy, life history, or other areas outside of our interests for objective 2. A variety of commonly used terms in association with habitat, like “ecosystem structure”, were searched for to try and yield as many relevant results as possible (Table C.1). Additionally, results were recorded following this second search for each fish (Table C.2).

For NatureServe, the reference section was assessed for literature cited in the “habitat” webpage section, and the results were recorded. The “threat” and “reproduction” sections often included information regarding habitat impacts fish were facing, or habitat needed for spawning, so these sections were also assessed, and the results recorded (Table C.2).

For *Kansas Fishes*, general conclusions from each chapter (taxon) were recorded. In addition, the reference section for each taxon was reviewed for citations on habitat, reproduction and growth, and conservation status sections pertaining to relevant ecological categories. All results were recorded (Table C.2).

To gain an even better understanding of the general habitat preferred for each fish, each of these sources was further explored to decipher which ecological parameters were included within each study (Table C.3). Assessing the habitat-references included in NatureServe and *Kansas Fishes* was relatively straightforward, as preferences are stated and directly cited, allowing for straightforward documentation of what ecological categories were included. The results of these category searches of NatureServe and *Kansas Fishes* references are found below (Table C.3).

Organizing WoS habitat papers per fish, and searching each for evidence of empirical collection data was more complicated. To make this task easier, search terms were formed for

each ecological category. These search terms, along with those utilized to identify fish-habitat literature, can be viewed in Table C.1. All results were double checked to ensure search terms corresponded to legitimate measures of interest for each category prior to being recorded (Table C.3). If little or no results were produced by search terms, further investigation occurred into the overall pool of fish-habitat papers (Table C.2: Fish-Habitat - WoS) to ensure obvious metric inclusions were not overlooked in all-habitat papers associated with each fish.

**Objective 2 - Results.** Fish-habitat citations from the NatureServe ranged from 1 (Brassy Minnow) to 14 (Topeka Shiner) with 4, 5, and 12 fish habitat citations for the three fish on which we focus in Chapters 1 and 2 (Central Stoneroller, Emerald Shiner, Plains Minnow). Fish-habitat citations from *Kansas Fishes* ranged from 7 (Banded Darter) to 25 (Neosho Madtom) with 12, 15, and 26 for the fish on which we focus in Chapters 1 and 2 (Central Stoneroller, Emerald Shiner, Plains Minnow). The literature for each taxon from WoS was substantial and ranged from 16 to 447 (Orangespotted Sunfish, Blue Catfish). Fewer WoS papers addressed fish habitat issues (1 to 68; Northern Plains Killifish, Red Shiner) with 49, 41, and 15 on the three fish that we examined in detail in Chapters 1 and 2 (Central Stoneroller, Emerald Shiner, Plains Minnow).

In observing Table C.2 we can observe a stark difference in quantity of papers between *fish* literature and *fish habitat* literature (134 to 16; Longnose Gar). This large drop in paper number, specifically for taxon with 100+ results corresponding to their name, was notable and perhaps can be explained by (1) the lack of consistent terminology associated with fish-habitat literature, and (2) the breadth of other topics within fish literature (i.e. population demographics, anatomy, and taxonomy) (Table C.2). For example, much of the body of literature for Longnose Gar focused on morphology, genetics, and overall development, which left a smaller pool of papers available that focused on habitat. Overall, standard, yet thoughtful, labeling of

information within fish-habitat literature would advance our understanding of fish ecosystem preferences greatly, and as a result allow us to take meaningful strides towards conservation action.

A wide variety of habitat features were identified in each of our three literature sources. For WoS, NatureServe, and *Kansas Fishes*, measurements and preferences of flow, substrate, and system size were most often mentioned, as indicated by these crowded columns in Table C.3 below. Habitat degradation related to dams was the most often mentioned anthropogenic impact facing fish, according to these sources. Related to the variables that were explored for each, we used WoS to identify major trends. Most taxa had at least one WoS citation related to our 11 ecological variables grouped as flow, substrate, size, sinuosity, land use, dams, and gradient with missing data for substrate (Northern Plains Killifish), sinuosity (Banded Darter, Blue Catfish, Emerald Shiner, Northern Plains Killifish, Red Shiner), land-use (Northern Plains Killifish), dams (Banded Darter, Northern Plains Killifish), and gradient (Blue Catfish, Blue Sucker, Northern Plains Killifish, Orangespotted Sunfish, Plains Minnow, Red Shiner, Topeka Shiner). Of all variables examined in our WoS sources, the most studies examined flow ( $n=172$ ), and the least number of studies examined gradient ( $n=14$ ) and sinuosity ( $n=14$ ; Table C.3). For the fish on which we focus in Chapters 1 and 2 (Central Stoneroller, Emerald Shiner, Plains Minnow), flow, substrate, and system sizes were all measured frequently. Regarding impact variables (i.e. land-use and dams), land use was more frequently measured for Central Stoneroller, while dams were frequently measured for Emerald Shiner and Plains Minnow (Table C.3). The trends described above for WoS were generally reflected in our other two data sources, NatureServe and *Kansas Fishes* (i.e. fish often missing data for gradient and sinuosity, and many flow measurements) (Table C.3). Even when there were multiple citations on a variable for a taxa, the

studies were not always conducted the same way or did not always draw the same conclusion. We used these references to try to make predictions about expectations for probability of presence to compare to our multiple logistic regression models. For this exercise (see objective 3), many of these taxa-habitat citations were not comparable, relevant, or measured in a way that links to species distribution models.

**Objective 2 - Conclusions and Next Steps.** Difficulties were had in the search of specific parameters associated with each ecological category in WoS habitat papers (Table C.3). Because there are no standard terms for many of the variables we included in our analyses, identifying search terms that produced relevant results was challenging. Therefore, search terms had to be refined several times throughout the review period. Even after refinement, many studies continued to be overlooked, resulting in many papers being reviewed one-by-one to ensure that relevant variables were or were not measured. Often, following individual review, multiple parameters were found to be measured for a study, but bared no mention in the title, abstract, or in the keywords. Further, these measures often were significant, or seemingly a focus of the paper, and yet multiple rounds of investigation were needed to confirm their inclusion. Regardless of this difficulty, many studies with valuable information pertaining to each ecological category were reviewed for each fish.

Objective 3 summarizes the specific ecological and life history information for the fish on which we focus in Chapters 1 and 2 (Central Stoneroller, Emerald Shiner, Plains Minnow) using the literature identified in objective 2.

**Objective 3 - What expectations do we have for the shape (positive, negative, no relationship) of the response (Y axis) for each**

## **individual habitat-impact regression variable (X axis) across studies for the three target fish taxa on which we focus in Chapters 1, 2?**

**Objective 3 - Background and Methods.** Objective 3 summarizes the ecological expectations for the 11 categories of habitat variables used in Chapters 1, 2 for our three target taxa in a way that is relevant our Chapter 1, 2 statistical models. A goal of our adaptive management framework is to build on and connect what is known from existing literature to analyses of existing monitoring databases. To build on what we know from the literature, we must first establish a general consensus of knowledge (i.e., expectations or predictions) in a form to which we can compare multiple logistic regression model results (i.e. observed). The expectation/prediction of interest is a plot of probability of presence (Y axis) versus each of the 11 habitat impact variables (X axis) across the range of habitat-impact variables occurring in Kansas or regionwide (not just one location) because this will be the outcome of our multiple logistic regression models (Chapters 1 and 2). To summarize predictions or expectations for our three target taxa from the literature for our 11 ecological categories, we used the literature from objective 2 (Table C.3). Below, we review expectations for our three fish taxa from Chapter 2 (Rode et al. 2023) for each of our 11 generalized, ecological categories utilizing our three data sources (WoS, NatureServe, and *Kansas Fishes*) (Tables C.4-C.6). Additionally, we describe the WoS sources from which we drew quantitative information to help formulate presence trends for our three grouped fish (Tables C.4-6). Given the lack of standardization in the literature identified in objectives 1 and 2, for many variables, either no predictions can be made, or multiple predictions must be considered.

**Objective 3 - Results. NHDPlus Flow (Ecological Category 1).** For Emerald Shiner, few stream flow preferences (velocity and discharge) are documented in the literature. To



examine the quantitative relationship between flow and Emerald Shiner I utilized these references: Allen et al. 2017 (#1), Brown and Coon 1994 (#8), Duncan et al. 2016 (#15), Haupt and Phelps 2016 (#17), Lang et al. 2019 (#21), and Lehtinen et al. 1997 (#23). The 11 WoS citations included in Table C.3 that mentioned flow for Emerald Shiner were not all utilized because many of the references were not specifically about flow (3) or did not present quantitative data on flow (2). Emerald Shiner can be abundant in lacustrine, reservoir conditions (Cross and Collins 1995, Enders et al. 2021) but in Kansas streams these fish have been found in areas of moderate current (Cross 1967). Thus, for lotic systems, we expect that Emerald Shiner will be more likely to be present at sites with moderate flow and absent from sites with extreme values (Table C.4 – Row 1). Central Stoneroller and Plains Minnow are ecosystem specialists that occur only in lotic systems (Lee et al. 1980; Sublette et al. 1990; Page and Burr 2011). However, preferences between the two vary. To examine the quantitative relationship between flow and Central Stoneroller I utilized these references: Braaten and Berry 1997 (#5), Bruckerhoff and Magoulick 2017 (#6), Peoples et al. 2016 (#31), Quinn and Kwak 2003 (#32), Stanley et al. 2012 (#41), Taylor et al. 2012 (#43), and Wesner 2011 (#48). The 17 WoS citations included in Table C.3 that mentioned flow for Central Stoneroller were not all utilized because many of the references were not specifically about flow (4), did not present quantitative data on flow (3), or if there were flow values, they did not present data in the format needed for predicting Central Stoneroller distribution (3). For Central Stoneroller, intermittency is common in streams they inhabit, but some current is preferred (Metcalf 1959; Braaten and Berry 1997; Holm and Crossman 2001); thus, the presence trend line for this variable will decrease as flows increase near higher values (Table C.5 – Row 1). To examine the quantitative relationship between flow and Plains Minnow I utilized these WoS references: Hoagstrom et al. 2010 (#4),

Kehmeier et al. 2007 (#5), Kelsch 1994 (#6), Taylor and Mayes 2022 (#13), Widmer et al. 2010 (#14), and Winston et al. 1991 (#15). The 11 WoS citations included in Table C.3 that mentioned flow for Plains Minnow were not all utilized because many of the references did not present quantitative data on flow (2), or if there were flow values, they did not present data in the format needed for predicting Plains Minnow distribution (3). Plains Minnow require fluctuating, erratic flows to reproduce successfully (Durham and Wilde 2006; Perkin and Gido 2011, Taylor and Mayes 2022), but are associated with slight current from day to day (Cross 1967). Therefore, we predict a gradual decline in presence as flows increase (Table C.6 – Row 1). In summary, the literature says Emerald Shiner are found in lotic systems with moderate flow, so our trend depicted an increase in presence as flows increased (Table C.4 – Row 1). The literature says Central Stoneroller are often found in streams with intermittency, thus our trend illustrated a decrease in presence as flows neared higher values (Table C.5 – Row 1). Finally, the literature says Plains Minnow are adapted to systems with highly variable flow, but are primarily found in areas with slight current, so our trend depicted a gradual decline in presence as flows near higher values (Table C.6 – Row 1).

**Objective 3 – Results. Substrates (Ecological Category 2).** To examine the quantitative relationship between substrate and Emerald Shiner I utilized these references: Brown and Coon 1994 (#8), Catalano et al. 2007 (#11), Haupt and Phelps 2016 (#17), Hilling et al. 2021 (#20), and Lehtinen et al. 1997 (#23). The 13 WoS citations included in Table C.3 that mentioned substrate for Emerald Shiner were not all utilized because many of the references were not specifically about substrate (3), did not present quantitative data on substrate (1), or if there were substrate values, they did not present data in the format needed for predicting Emerald Shiner distribution (4). The literature on Emerald Shiner reports that although these fish can exhibit

broad substrate preferences, in Kansas they are most abundant over sand beds (Cross 1967; Boschung and Mayden 2004). Thus, we expect that Emerald Shiner presence will peak with sand and decline as substrate size increases (Table C.4 – Row 2). The literature states that the Central Stoneroller and Plains Minnow display substrate specialist tendencies (Cross 1967; Pflieger 1997; Platania and Altenbach 1998). To examine the quantitative relationship between substrate and Central Stoneroller I utilized these references: Dekar and Magoulick 2007 (#7), Dekar and Magoulick 2013 (#8), Etchison and Pyron 2014 (#9), Fischer et al. 2010 (#11), Gerkin and Paukert 2013 (#13), Ludlam and Magoulick 2010 (#24), Lynch and Magoulick 2016 (#25), Peoples et al. 2016 (#31), Rakes et al. 1999 (#34), Taylor et al. 2012 (#43), Trentman et al. 2020 (#45), and Wesner 2011 (#48). The 22 WoS citations included in Table C.3 that mentioned substrate for Central Stoneroller were not all utilized because many of the references were not specifically about substrate (1), did not present quantitative data on substrate (6), or if there were substrate values, they did not present data in the format needed for predicting Central Stoneroller distribution (3). Thus, for Central Stoneroller we predict their presence will peak around medium-large substrates, which they need for reproduction (Metcalf 1966; Peoples et al. 2016) (Table C.5 – Row 2). To examine the quantitative relationship between substrate and Plains Minnow I utilized this WoS reference: Quist et al. 2014 (#11). The 4 WoS citations included in Table C.3 that mentioned substrate for Plains Minnow were not all utilized because many of the references did not present quantitative data on substrate (2), or if there were substrate values, they did not present data in the format needed for predicting Plains Minnow distribution (1). For Plains Minnow, we predict their presence will decrease exponentially as substrate size increases, as they are associated with sand bed rivers, and moderately silty streams (Eberle et al. 2002, Quist et al. 2004, Kehmeier et al. 2007) (Table C.6 – Row 2). In summary, the literature says

Emerald Shiner can tolerate various substrates, but in Kansas can often be found over sand, so our trend depicted a decrease in presence as substrate sizes increased (Table C.4 – Row 2). The literature says Central Stoneroller are often found over cobble or rock substrates; thus, our trend illustrated an increase in presence as substrate sizes increased (Table C.5 – Row 2). Finally, the literature says Plains Minnow are commonly found in sand bed or fairly silty rivers, so our trend depicted an exponential decrease in presence as substrates sizes increased (Table C.6 – Row 2).

**Objective 3 – Results. System Size (Ecological Categories 3-5).** To examine the quantitative relationship between system size and Emerald Shiner I utilized these references: Brown and Coon 1994 (#8), Haupt and Phelps 2016 (#17), Laplante-Albert et al. 2010 (#22), Lehtinen et al. 1997 (#23), Lumb et al. 2012 (#25), Roseman and O’Brien 2013 (#34), and Stucker et al. 2012 (#37). The 18 WoS citations included in Table C.3 that mentioned system size for Emerald Shiner were not all utilized because many of the references were not specifically about system size (2), or if there were system size values, they did not present data in the format needed for predicting Emerald Shiner distribution (9). Emerald Shiner is reported to be a big-river fish (Distler et al. 2014; Haupt and Phelps 2016), but they can be found in a wide variety of depths (Becker 1983; Lehitinen et al. 1997; Distler et al. 2014; Haupt and Phelps 2016). Little information exists on the effects of stream width and catchment area for Emerald Shiner. Based on generalizations of the common assertion about river size, we expect that the probability of Emerald Shiner presence will increase with increasing stream order and stream depth, and likely increase for stream width and catchment area (Table C.4 – Rows 3, 4A, 4B, 5). To examine the quantitative relationship between system size and Central Stoneroller I utilized these references: Angermeier 1992 (#1), Blum et al. 2012 (#3), Braaten and Berry 1997 (#5), Dekar and Magoulick 2007 (#7), Dekar and Magoulick 2013 (#8), Fischer et al. 2010 (#11),

Gelwick 2000 (#12), Gerkin and Paukert 2013 (#13), Harvey and Stewart 1991 (#15), Ludlam and Magoulick 2009 (#22), Ludlam and Magoulick 2010 (#24), Lynch and Magoulick 2016 (#25), Maloney et al. 2013 (#26), Matthews and Marsh-Matthews 2003 (#27), Palic et al. 2007 (#29), Peoples et al. 2016 (#31), Trentman et al. 2020 (#45), Weaver et al. 2014 (#47), and Wesner 2011 (#48). The 22 WoS citations included in Table C.3 that mentioned system size for Central Stoneroller were not all utilized because many of the references were not specifically about system size (1), did not present quantitative data on system size (1), or if there were system size values, they did not present data in the format needed for predicting Central Stoneroller distribution (1). Central Stoneroller is a fish found in primarily small streams, but occasionally can be found in medium sized waterways as well (Matthews et al. 1986; Palic et al. 2007). In alignment with this preference for smaller sizes, the literature reports low values of depth and width in association with Central Stoneroller (Holm and Crossman 2001; Ludlam and Magoulick 2010). Although few estimates are reported for catchment area for Central Stoneroller, we can expect a similar declining trend based on other size-parameter preferences. Therefore, we predict Central Stoneroller presence will decline as system size metrics increase (Table C.5 – Row 3, 4A, 4B, 5). To examine the quantitative relationship between system size and Plains Minnow I utilized these 9 WoS references: Bestgen and Platania 1991 (#1), Dunn et al. 2018 (#3), Kehmeier et al. 2007 (#4), Ostrand and Wilde 2004 (#9) and Widmer et al. 2010 (#14). The 9 WoS citations included in Table C.3 that mentioned system size for Plains Minnow were not all utilized because many of the references were not specifically about system size (1), or if there were system size values, they did not present data in the format needed for predicting Plains Minnow distribution (3). Plains Minnow are reported to be found in small, medium, and large rivers (Cross and Moss 1987; Lehtinen and Layzer 1988; Page and Burr 2011). In Kansas, Plains

Minnow's ideal habitat is described as shallow, broad, sandy segments with braided flow (Cross 1967; Eberle et al. 1997). However, the literature reports varying measures of width and depth in association with this fish (Cross and Moss 1987; Ostrand and Wilde 2004; Quist et al. 2004; Kehmeier et al. 2007). There is no mention of catchment area reported in the literature for Plains Minnow. Therefore, our predictions for both stream order, width and catchment area, are slight increases as primarily larger measures are reported, while our prediction for depth is a slight decrease, as shallow measures are more frequently reported (Table C.6– Rows 3, 4A, 4B, 5). In summary, the literature says Emerald Shiner are big river fish, so our trend depicted an increase in presence as system sizes increased (Table C.4 – Rows 3, 4A, 4B, 5). The literature says Central Stoneroller are found in medium to smaller systems; thus, our trend illustrated a decrease in presence as system sizes increased (Table C.5 – Rows 3, 4A, 4B, 5). Finally, the literature says Plains Minnow are most commonly found in moderate to large sized rivers with shallow depths, so our trend depicted a slight increase in presence as stream order, width and catchment area sizes increased and a slight decrease in presence as depths increased (Table C.6– Rows 3, 4A, 4B, 5).

**Objective 3 – Results. Sinuosity (Ecological Category 6).** Few associations between fish taxa and sinuosity (curviness measured as the ratio of thalweg to valley lengths) are reported in the literature. Hence, there are no established expectations about this variable for any of our three fish. To examine the quantitative relationship between sinuosity and Emerald Shiner I utilized non-quantitative descriptions in all three of our data sources. There were no WoS sinuosity citations included in Table C.3 for Emerald Shiner as search terms, and further investigation, did not identify any studies in which it was mentioned or measured). However, Emerald Shiner are reported in runs and channels of rivers (Jenkins and Burkhead 1994), which

can lack sinuosity (Minnesota DNR 2006). Therefore, one expectation for this literature gap might be that Emerald Shiner presence could decrease as sinuosity values increase (Table C.4 – Row 6). To examine the relationship between sinuosity and Central Stoneroller I utilized non-quantitative descriptions in all three of our data sources. The 2 WoS citations included in Table C.3 that mentioned sinuosity for Central Stoneroller were not utilized because one of the references was not specifically about sinuosity (Waits et al. 2008), and the other did not present quantitative data on sinuosity (Slack et al. 1997). For Central Stoneroller, a resident of deep pools in small tributaries, presence may be expected to increase with sinuosity as this microhabitat type can be found in meandering waterways (Table C.5 – Row 6). To examine the relationship between sinuosity and Plains Minnow I utilized non-quantitative descriptions in all three of our data sources. The 1 WoS citation included in Table C.3 that mentioned sinuosity for Plains Minnow did not present quantitative data on sinuosity. Plains Minnow is associated with shallow prairie streams with braided flows (Eberle et al. 1997). It is also associated with large river sizes (Cross 1967; Cross and Moss 1987). In consideration of both of these factors, we believe Plains Minnow presence may slightly decrease as sinuosities increase, but less so than that of Emerald Shiner due to differences in microhabitat associations (Table C.6 – Row 6). In summary, the literature says Emerald Shiner are primarily found in microhabitats (i.e. runs, channels) that lack sinuosity, so our trend depicted a decrease in presence as sinuosities increased (Table C.4 – Row 6). The literature says Central Stoneroller are found in smaller tributaries with deep pools, which when compared to main channels of larger rivers, may exhibit more sinuosity; thus, our trend illustrated an increase in presence as sinuosities increased (Table C.5 – Row 4). Finally, the literature says Plains Minnow are found in larger, braided rivers, so

our trend depicted a slight decrease in presence as sinuositities increased, but this decrease across sinuositities is less intense than that of Emerald Shiner (Table C.6 – Row 4).

**Objective 3 – Results. Land Use Impacts (Ecological Categories 7-9).** To examine the quantitative relationship between land use and Emerald Shiner I utilized non-quantitative descriptions in all three of our data sources. The 3 WoS citations included in Table C.3 that mentioned land use for Emerald Shiner were not utilized because the references did not present quantitative data on land use (2), or if there were land use values, they did not present data in the format needed for predicting Emerald Shiner distribution (1). To examine the quantitative relationship between land use and Central Stoneroller I utilized these references: Blum et al. 2012 (#3), Dekar and Magoulick (#8), Fischer et al. 2010 (#11), Gerkin and Paukert 2013 (#13), Jacquemin and Doll 2013 (#20), and Palic et al. 2007 (#29). The 12 WoS citations included in Table C.3 that mentioned land use for Central Stoneroller were not all utilized because many of the references were not specifically about land use (Slack et al. 1997), did not present quantitative data on land use (Bouska and Whitley 2014, Braaten and Berry 1997, Maloney et al. 2013, Waits et al. 2008), or if there were land use values, they did not present data in the format needed for predicting Central Stoneroller distribution (Taylor et al. 2014). To examine the quantitative relationship between land use and Plains Minnow I utilized this WoS reference: Steffensmeier et al. 2022 (#12). The 2 WoS citations included in Table C.3 that mentioned land use for Plains Minnow were not each utilized because 1 of the references did not present quantitative data on land use. The conventional wisdom is that native prairie fish will be adversely affected by agricultural land use (Lange et al. 2014) and anthropogenic activity such as human developments (Jenkins and Burkhead 1994). Based on these generalities, we expect that Emerald Shiner presence in Kansas will decline as agricultural land use and developed land



cover increase (Table C.4 – Rows 7, 8). No data on Emerald Shiner and natural land use exists in the literature, but these common fish do occur in streams in heavily populated areas. For this reason, multiple outcomes could be possible for Emerald Shiner related to natural land use (Table C.4 – Row 9). The same conventional wisdom may be applied to Central’s Stoneroller association with developed cover-types, even though general tolerance is referenced (Cross 1967); thus, a declining presence trend as development increases is depicted (Table C.5 – Row 8). The Central Stoneroller’s association with agricultural cover bears further consideration, as they have been known to be found adjacent to pastureland (Holm and Crossman 2001). Due to this association and the overall commonness of agricultural covers within our study area, we predict a neutral relationship between agricultural covers and Central Stoneroller (Table C.5 – Row 7). The literature made very few mentions of natural cover associated with Central Stoneroller, and the estimates it reported were brief (Holm and Crossman 2001). In consideration of this estimate, and the conventional wisdom that anthropogenic covers (not natural) degrade streams, we predict a neutral outcome for Central Stoneroller in response to increasing natural covers (Table C.5 – Row 9). Plains Minnow are a threatened fish and have low tolerances to anthropogenic influences such as agricultural and developed land use (Cross and Moss 1987; The Northern Prairie Research Center 1995; Bonner and Wilde 2002); therefore, we predict a gradual decline in presence as agricultural covers increase, and a sharp decline in presence as development increases (Table C.6 – Rows 7, 8). The literature did not report estimates of natural land use in association with Plains Minnow, but based on their sensitivity to anthropogenic types, we predict their presence will increase as natural covers increase (Table C.6 – Row 9). In summary, the literature says that prairie fish are negatively impacted by anthropogenic land uses such as development and agriculture, so we depict a decrease in presence across increasing

anthropogenic covers for Emerald Shiner (Table C.4 – Rows 7, 8). Because of population trends in areas where Emerald Shiner are common in Kansas, and the lack of information surrounding natural land use responses in the literature for this fish, we predicted that there may be multiple possible responses to increasing natural land use (Table C.4 – Row 9). In further consideration of the negative impacts of anthropogenic land use on prairie fish, we again depicted a decrease in presence in response to increasing development and agricultural cover for Central Stoneroller (Table C.5 – Rows 7, 8). Little is known about the impacts of natural cover on Central Stoneroller; therefore, we illustrated a neutral trend for a possible response to increases of this cover type (Table C.5 – Row 9). Finally, the literature commonly reports sensitivities to anthropogenic land uses for our threatened fish, Plains Minnow; thus, we predicted decreases in presence across increasing agricultural and developed land use (Table C.6 – Rows 7, 8). In consideration of these negative associations with anthropogenic land uses, and the lack of information surrounding natural land use and Plains Minnow response, we predicted an increase in presence as natural covers increased (Table C.6 – Row 9).

**Objective 3 – Results. Dam Proximity (Ecological Category 10).** To examine the quantitative relationship between dams and Emerald Shiner I utilized these references: Allen et al. 2017 (#1), Catalano et al. 2007 (#11), Duncan et al. 2016 (#15), Roberts and Taylor 2008 (#33), Wilhite and Hubert 2011 (#40), and Winston et al. 1991 (#41). The 8 WoS citations included in Table C.3 that mentioned dams for Emerald Shiner were not all utilized because one of the references was not specifically about dams (1), while another did not present data in the format needed for predicting Emerald Shiner distribution (1). Dams adversely affect many stream fish (Barbarossa et al. 2020), but the literature on Emerald Shiner and dams is mixed. Dams are reported to create a negative reduction in flow and a positive reduction in turbidity

(Pflieger and Grace 1987; Cross and Collins 1995). As a result, we expect that Emerald Shiner presence and absence will not follow a consistent response to dam proximity (Table C.4 – Row 10). The literature on Central Stonerollers and dams is very thin. To examine the quantitative relationship between dams and Central Stoneroller I utilized these references: Braaten and Berry 1997 (#5), Gerkin and Paukert 2013 (#13), Husemann et al. 2012 (#19), Jacquemin and Doll 2013 (#20), and Quinn and Kwak 2003 (#32). The 6 WoS citations included in Table C.3 that mentioned dams for Central Stoneroller were not all utilized because one of the references did not present data in the format needed for predicting Central Stoneroller distribution (1). Impoundments have been known to reduce the overall abundance of this species (McKee and Parker 1982; McAllister 1987). We therefore predict a gradual increase in presence as the distance to a dam grows (Table C.5 - Row 10). To examine the quantitative relationship between dams and Plains Minnow I utilized these WoS references: Hoagstrom et al. 2010 (#4), Osborne et al. 2014 (#8), Quist et al. 2004 (#11), Taylor and Mayes 2022 (#13) and Winston et al. 1991 (#15). The 9 WoS citations included in Table C.3 that mentioned dams for Plains Minnow were not all utilized because many of the references did not present quantitative data on dams (1), or if there were dam values, they did not present data in the format needed for predicting Plains Minnow distribution (3). There are extensive records in the literature detailing the negative impact dams have on Plains Minnow populations (Winston et al. 1991; Patton and Hubert 1993; Eberle 2007). Therefore, we predict Plains Minnow to only be present at sites further away from dams (Table C.6 – Row 10). In summary, the literature reports variable responses for Emerald Shiner in regard to dams; thus, our prediction depicted an inconsistent response to dam presence, with multiple possible trends (Table C.4 – Row 10). The literature states that Central Stoneroller have previously experienced population decline due to dam proximity; therefore, our trend

illustrated a slight increase in presence as distance to a dam grows (Table C.5 – Row 10).

Finally, the literature on the negative impact of dams on Plains Minnow populations is plentiful, so our trend depicted an increase in Plains Minnow presence as distance to a dam grows (Table C.6 – Row 10).

**Objective 3 – Results. Gradient (Ecological Category 11).** To examine the quantitative relationship between gradient and Emerald Shiner I utilized these references: Brown and Coon 1994 (#8), Catalano et al. 2007 (#11). The 2 WoS citations included in Table C.3 that mentioned gradient for Emerald Shiner were both utilized because they presented data in the format needed for predicting Emerald Shiner distribution. In Kansas rivers, Emerald Shiner have been caught at low to moderate gradients (i.e., the change in longitudinal elevation per unit distance; Cross 1967; Jenkins and Burkhead 1994). Thus, we expect the trend line for this variable will decrease as gradients increase near higher values (Table C.4 – Row 11). To examine the quantitative relationship between gradient and Central Stoneroller I utilized these references: Braaten and Berry 1997 (#5), and Lynch and Magoulick 2016 (#25). The 4 WoS citations included in Table C.3 that mentioned gradient for Central Stoneroller were not all utilized because a couple of the references did not present quantitative data on gradient (2). Central Stoneroller is reported to be associated with primarily moderate gradients (Holm and Crossman 2001); thus, we predict an increase in presence as gradients increase (Table C.5 – Row 11). To examine the relationship between gradient and Plains Minnow I utilized non-quantitative descriptions in all three of our data sources. There were no WoS gradient citations included in Table C.3 for Plains Minnow as search terms, and further investigation, did not identify any studies in which it was mentioned or measured. Only low gradients are reported in association with Plains Minnow (NatureServe 2023), so we predict a sharp decline in presence as gradients with increase for this fish (Table

C.6 – Row 11). In summary, the literature says Emerald Shiner can be found in streams with low to moderate gradients, so our trend depicted a decrease in presence as stream gradient increased (Table C.4 – Row 11). The literature says Central Stoneroller are often found in streams with moderate gradient; thus, our trend illustrated an increase in presence as gradient increased (Table C.5 – Row 11). Finally, while the literature on Plains Minnow response to gradient is thin, there are few reports of associations with lower stream gradients; therefore, our trend depicted a sharp decrease in presence as gradient increased (Table C.6 – Row 11).

## Conclusion

Habitat and impacts are an important aspect of fish ecology and conservation. Many researchers have collected data and published results on the habitat use and response to impacts for fish in general and prairie stream fish in particular. Of course, it is not possible to review and integrate all of the literature on a wide array of taxa relative to many habitat-impact regressors. What we present here is not comprehensive, but we have shown that we made a strong effort to review a representative subset of the literature. For objective 1, we showed that relatively few papers define habitat and that many studies measure different habitat-impact variables. While it makes sense that different authors to collect different data for different studies, this lack of consistency in how habitat is conceptualized, defined, and measured across researchers makes broad comparisons across studies, sites, and time difficult.

For objective 2, for an objective sample of the literature, we identified the number of papers that examined each of our 11 ecological category for each fish taxa. Not surprisingly, some variables were frequently examined and others rarely and data on some fish was more common than on other fish. Although we do not report it here, the way these studies collected data on the same ecological variables also could differ.

For objective 3, for our three target taxa in Chapters 1 and 2, we summarized the expected or predicted trends that corresponded to the output of species distribution models, which are the most common tool for looking at large spatial scale conservation. The existing literature, although thoughtful and informative, is not always in the format needed to create and make testable predictions for multiple logistic regressions (and other statistical models). As a result, not all of the citations that examined a taxa-habitat variable could be generalized to the output format to make these links. Nevertheless, we tried to make predictions and then compare

those predictions to the model results (Chapters 2, 3). Habitat studies often do not have the data in a format where the profession can make predictions that can be tested with existing statistical tools. Without this match of the format of the literature predictions/expected with statistical model output, linking literature and data across the past present and future will be difficult and adaptive management will be limited. Therefore, we strongly recommend a major push for standardization for synthesis across the literature.

## Tables

**Appendix C Table C.1.** To organize WoS habitat papers per fish, and search each for evidence of empirical collection data, search terms were identified for each ecological category. Here we list the search terms used for each systematic search using the Web of Science database. The first column states the purpose of the search, as well as the bolded **location** of the searches results (Appendix C Table Number). The second column details the search terms utilized for each purpose stated in the previous column. "Quotations" are used to perform an exact search on a phrase. We include asterisks (\*) in many of our search terms to allow for any letters following or proceeding the word to appear in the results. For example, microhabitat, mesohabitat, habitats, or habitable would be included in the results in addition to studies including just "habitat."

| Purpose of WoS Search<br>(Location of Results) | WoS Search Terms                                                                                                                                                                                                                                                                |
|------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fish Papers ( <b>Table C.2</b> )               | "common name" OR "scientific name"                                                                                                                                                                                                                                              |
| Fish-Habitat papers ( <b>Table C.2</b> )       | "*habitat*" OR "ecosystem structure*" OR "ecosystem feature*" OR "abiotic variable*" OR "environmental condition*" OR "environmental driver*" OR "environmental factor*" OR "anthropogenic driver*" OR "anthropogenic factor*" OR "environmental variable*" OR "natural factor" |
| Flow papers ( <b>Table C.3</b> )               | "*flow*" OR "velocit*" OR "discharg*" OR "peak*" OR "flood"                                                                                                                                                                                                                     |
| Substrate papers ( <b>Table C.3</b> )          | "substrat*" OR "bottom characteristic*" OR "bottom habitat*" OR "cobbl*" OR "pebbl*" OR "bedrock*" OR "sand*" OR "mud*" OR "silt*" OR "rock*" OR "riprap*" OR "boulder*" OR "clay*" OR "sediment*" OR "embedded*" OR "gravel*" OR "*debris"                                     |
| System size papers ( <b>Table C.3</b> )        | "depth*" OR "deep*" OR "shallow*" OR "width*" OR "wide*" OR "stream order*" OR "Strahler*" OR "size*" OR "catchment size*" OR "watershed size*" OR "drainage area*" OR "catchment area*" OR "channel geometr"                                                                   |
| Sinuosity papers ( <b>Table C.3</b> )          | "sinuous*" OR "curv*" OR "oxbow*" OR "bend*" OR "meander"                                                                                                                                                                                                                       |
| Land use papers ( <b>Table C.3</b> )           | "land use*" OR "land cover*" OR "dewater*" OR "agricultur*" OR "pastur*" OR "developed" OR "development" OR "urbaniz*" OR "residential" OR "grassland*" OR "natural land*" OR "natural cover*" OR "forest*" OR "wetland*" OR "shrub"                                            |
| Dam papers ( <b>Table C.3</b> )                | "dam*" OR "impound*" OR "barrier*" OR "reservoir*" OR "fragment"                                                                                                                                                                                                                |
| Gradient papers ( <b>Table C.3</b> )           | "slope*" OR "grade*" OR "gradient*" OR "steep*" OR "elevat"                                                                                                                                                                                                                     |



**Appendix C Table C.2.** Fish-Habitat Literature Review Documentation (Web of Science [WoS] = blue, NatureServe = green, *Kansas Fishes* = red). Here we show the papers per database utilized in the review of habitat literature. Column 1 includes the common and scientific name of the species of interest, which also corresponds with the search terms used in WoS. Column 2 shows the number of papers available on WoS for each fish following the name search. Columns 3-5 show the number of studies in each source utilized (WoS, NatureServe, *Kansas Fishes*) that detail habitat parameters within our 11 ecological categories for our 15 fish. All citations corresponding with the results below can be found in the literature cited. The number of papers in the Fish-Habitat (WoS) column are considered in Table C.3. below. However, not all papers in Fish-Habitat (WoS) are in Table C.3. below because they may not include the ecological habitat categories we considered, but the number of papers in this column represent the maximum amount reviewed. Search terms for WOS papers can be seen in Table C.1.

| Fish (Common Name & Scientific Name):                | <u>Fish</u> Literature (WoS only) | <u>Fish-Habitat</u> Literature: |             |                      |
|------------------------------------------------------|-----------------------------------|---------------------------------|-------------|----------------------|
|                                                      |                                   | WoS                             | NatureServe | <i>Kansas Fishes</i> |
| Banded Darter ( <i>Etheostoma zonale</i> )           | 43                                | 10                              | 4           | 7                    |
| Blue Catfish ( <i>Ictalurus furcatus</i> )           | 447                               | 46                              | 3           | 14                   |
| Blue Sucker ( <i>Cycleptus elongatus</i> )           | 57                                | 28                              | 8           | 8                    |
| Brassy Minnow ( <i>Hybognathus hankinsoni</i> )      | 21                                | 11                              | 1           | 11                   |
| Bullhead Minnow ( <i>Pimephales vigilax</i> )        | 17                                | 11                              | 2           | 8                    |
| Central Stoneroller ( <i>Campostoma anomalum</i> )   | 124                               | 49                              | 4           | 12                   |
| Emerald Shiner ( <i>Notropis atherinoides</i> )      | 106                               | 41                              | 5           | 15                   |
| Freshwater Drum ( <i>Aplodinotus grunniens</i> )     | 175                               | 42                              | 3           | 13                   |
| Longnose Gar ( <i>Lepisosteus osseus</i> )           | 134                               | 16                              | 4           | 15                   |
| Neosho Madtom ( <i>Noturus placidus</i> )            | 17                                | 12                              | 10          | 25                   |
| Northern Plains Killifish ( <i>Fundulus kansae</i> ) | 39                                | 1                               | 1           | 14                   |
| Orangespotted Sunfish ( <i>Lepomis humilis</i> )     | 16                                | 8                               | 1           | 8                    |
| Plains Minnow ( <i>Hybognathus placitus</i> )        | 39                                | 15                              | 12          | 26                   |
| Red Shiner ( <i>Cyprinella lutrensis</i> )           | 142                               | 68                              | 4           | 13                   |
| Topeka Shiner ( <i>Notropis Topeka</i> )             | 33                                | 23                              | 14          | 21                   |

**Appendix C Table C.3.** We reviewed papers from our fish-habitat literature sources (Web of Science [WoS], NatureServe, and Kansas Fishes) for inclusion of variables that fall within the 11 ecological categories we assessed for each of our 15 fish. The results in this table are based on references in the Fish-Habitat (WoS) column in Table C.2. above. However, not all papers in Fish-Habitat (WoS) column in Table C2 are included below because not all Table C2 fish-habitat references address the 11 ecological habitat categories that we considered. Search terms for WoS papers can be found in Table C.1. The 6 columns below each source (WoS = blue, NatureServe = green, *Kansas Fishes* = red) represent these 11 ecological categories, or simplifications of them (i.e. system size includes measures of stream order, depth, width, or catchment size). Entries below represent the paper number in the appendix cited for each specific taxon. Note: the same numerical entries (1, 2, 3) are used within the literature review for each taxa.

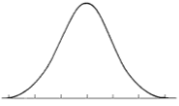
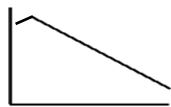
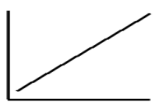
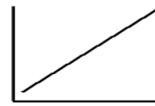
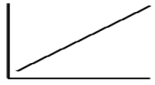
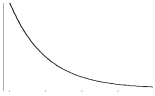
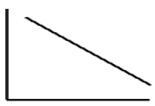
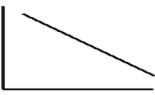
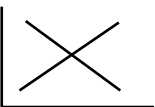
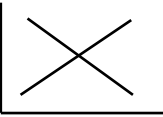
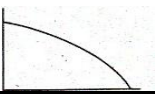
| Fish (Common Name & Scientific Name):           | WoS: Fish-Habitat Papers                   |                             |                                   |            |                 |                                     |          | NatureServe: Fish-Habitat Papers |           |             |           |          |      |          | Kansas Fishes: Fish-Habitat Papers |               |                 |           |          |         |          |
|-------------------------------------------------|--------------------------------------------|-----------------------------|-----------------------------------|------------|-----------------|-------------------------------------|----------|----------------------------------|-----------|-------------|-----------|----------|------|----------|------------------------------------|---------------|-----------------|-----------|----------|---------|----------|
|                                                 | Flow                                       | Substrate                   | System Size                       | Sinuosity  | Land-Use        | Dams                                | Gradient | Flow                             | Substrate | System Size | Sinuosity | Land-Use | Dams | Gradient | Flow                               | Substrate     | System Size     | Sinuosity | Land-Use | Dams    | Gradient |
| Banded Darter ( <i>Etheostoma zonale</i> )      | 1, 3, 5-10                                 | 1-7, 9                      | 2-10                              |            | 2, 6-8          |                                     | 7        | 4                                | 1, 2, 4   | 2-4         |           |          |      |          | 3-6                                | 4, 5, 7       | 4, 5, 7         |           | 2        | 3       |          |
| Blue Catfish ( <i>Ictalurus furcatus</i> )      | 1, 6, 9, 12, 18, 21, 23, 27-29, 40, 42, 44 | 23, 26, 37, 41, 42          | 7, 11, 23, 26, 28, 42, 44         |            | 19, 41, 44      | 4, 7, 8, 11, 16, 17, 24-26, 28, 29, |          |                                  | 1         |             |           |          | 2    |          | 6, 8, 12, 14                       | 6, 12, 14     | 2, 4, 6, 12, 14 |           |          | 4-9     |          |
| Blue Sucker ( <i>Cycleptus elongatus</i> )      | 1, 2, 5, 6, 11-17, 19, 25-27               | 2, 6, 12, 14-16, 18, 22, 28 | 2, 3, 6, 11, 14-16, 21-23, 26, 27 | 17, 26, 28 | 3, 12, 26       | 2, 5, 6, 11, 13, 16, 21, 22, 24-28  |          | 5, 6                             | 5, 6      | 5           |           | 8        | 6    |          | 1, 3, 4, 6-8                       | 2, 3, 5, 6, 8 | 1, 3, 6, 8      |           | 1, 4, 7  | 1, 4, 7 |          |
| Brassy Minnow ( <i>Hybognathus hankinsoni</i> ) | 1-5, 7-11                                  | 5, 7, 10, 11                | 3-5, 8-11                         | 11         | 2, 5, 8, 10, 11 | 7, 9                                | 9        |                                  | 1         | 1           |           |          |      |          | 2, 4, 6-8, 10, 11                  | 1, 2, 4, 10   | 1-5, 10, 11     |           | 4, 7, 8  | 4, 7, 8 |          |

|                                                       |                                                   |                                                             |                                                                |        |                                        |                                 |              |         |               |         |         |         |                   |                          |                    |               |                   |           |
|-------------------------------------------------------|---------------------------------------------------|-------------------------------------------------------------|----------------------------------------------------------------|--------|----------------------------------------|---------------------------------|--------------|---------|---------------|---------|---------|---------|-------------------|--------------------------|--------------------|---------------|-------------------|-----------|
| Bullhead Minnow<br>( <i>Pimephales vigilax</i> )      | 1, 3, 6, 7, 9, 11                                 | 6, 8, 9                                                     | 3, 6, 8, 11                                                    | 11     | 5, 8                                   | 1                               | 8            | 1, 2    | 1, 2          | 1, 2    | 2       | 2       | 1, 5, 6           | 1, 5-7                   | 1, 7               | 5, 7          |                   |           |
| Central Stoneroller<br>( <i>Campostoma anomalum</i> ) | 4-6, 8, 20, 24, 27, 31, 32, 36, 39, 41-44, 48, 49 | 4, 5, 7-9, 11, 13, 20, 22, 24-27, 31, 33, 34, 39, 43-46, 48 | 1, 3-5, 7, 8, 11-13, 15, 22, 24-27, 29, 31, 39, 45-48          | 39, 46 | 3-5, 8, 11, 13, 20, 26, 29, 39, 44, 46 | 5, 13, 19, 20, 32, 49           | 4, 5, 25, 26 | 1, 3, 4 | 1, 4          | 1, 3, 4 |         |         | 3, 6, 11          | 1-3, 7, 8                | 2, 3, 5, 9, 10, 12 | 11            |                   |           |
| Emerald Shiner<br>( <i>Notropis atherinoides</i> )    | 1, 8, 10, 15-17, 21, 23, 24, 30, 32               | 5, 8, 10, 11, 13, 14, 17, 19, 20, 22, 23, 27, 37            | 1, 6-8, 10, 13, 14, 16, 17, 20, 22, 23, 25, 27, 30, 34, 37, 38 |        | 7, 14, 20                              | 1, 11, 15, 24, 30, 33, 40, 41   | 8, 11        | 1, 3    | 1, 2          |         | 2, 4    | 2       | 3, 4              | 1-3, 6, 7, 9, 10, 12, 13 | 3, 7               | 4, 7, 9       | 1, 2, 4, 5, 10-12 | 3         |
| Freshwater Drum<br>( <i>Aplodinotus grunniens</i> )   | 1, 4-9, 13, 15, 21, 25, 27, 31-33                 | 6, 8, 9, 25, 29, 31                                         | 1, 2, 6-9, 17-19, 24, 25, 29, 31, 37, 38, 41                   | 38     | 6, 24                                  | 3, 5, 13, 18, 21, 27, 32-34, 37 | 1, 6, 8      | 2, 3    | 2, 3          |         |         |         | 1, 8, 13          | 2, 7-9, 11               |                    | 1, 5-10, 13   |                   |           |
| Longnose Gar<br>( <i>Lepisosteus osseus</i> )         | 5, 12                                             | 6                                                           | 12-14                                                          | 12     | 6, 12                                  | 7, 15                           | 13           | 1, 4    | 1, 4          |         |         |         | 2-5, 7, 8, 11, 12 | 6, 12, 15                | 2, 3, 5, 9, 12, 15 | 2, 3, 5, 6, 9 | 12, 15            |           |
| Neosho Madtom                                         | 4-8, 10-12                                        | 1, 4-8, 10-12                                               | 5-8, 11, 12                                                    | 6      | 6, 11, 12                              | 4, 8, 11, 12                    | 6            | 1, 2, 4 | 2, 5, 6, 8, 9 | 2, 5, 8 | 5, 6, 9 | 5, 6, 9 | 5, 8              | 2-5, 14, 15              | 6, 14, 15          | 8, 14, 17     | 1, 6, 12, 15      | 7, 10, 11 |

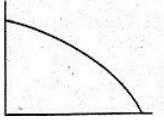
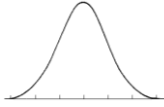
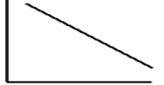
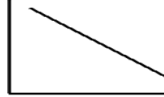
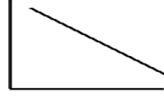
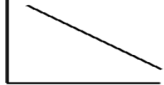
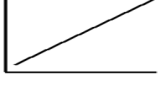
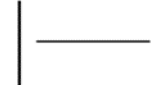
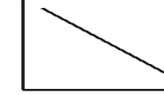
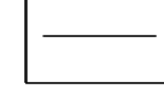
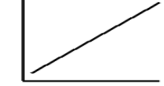
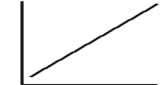
|                                                       |                                                                                        |                                                         |                                                                              |         |                              |                                                          |           |         |         |  |                    |  |                              |                                            |                                     |  |                 |                                        |
|-------------------------------------------------------|----------------------------------------------------------------------------------------|---------------------------------------------------------|------------------------------------------------------------------------------|---------|------------------------------|----------------------------------------------------------|-----------|---------|---------|--|--------------------|--|------------------------------|--------------------------------------------|-------------------------------------|--|-----------------|----------------------------------------|
| <i>(Noturus placidus)</i>                             |                                                                                        |                                                         |                                                                              |         |                              |                                                          | 5, 8, 9   |         |         |  |                    |  | 17, 19-21, 23                | 17, 22, 23                                 | 20, 23-25                           |  | 22, 23          | 15-23                                  |
| Northern Plains Killifish<br><i>(Fundulus kansae)</i> | 1                                                                                      |                                                         | 1                                                                            |         |                              |                                                          |           |         |         |  |                    |  | 1, 8, 11, 13                 | 1, 5, 6, 9-11                              | 1, 2, 6, 10, 11                     |  |                 | 8                                      |
| Orangespotted Sunfish<br><i>(Lepomis humilis)</i>     | 3, 4-6                                                                                 | 4-6, 8                                                  | 3-7                                                                          | 3, 5, 6 | 3, 5-7                       | 4, 7                                                     |           | 1       | 1       |  |                    |  |                              | 1, 2                                       | 2, 3, 6                             |  |                 | 1, 2                                   |
| Plains Minnow<br><i>(Hybognathus placitus)</i>        | 1, 4-6, 8, 10-15                                                                       | 2, 5, 11, 14                                            | 1, 3, 5, 6, 8, 9, 11, 12, 14                                                 | 1       | 8, 12                        | 1, 4, 6-8, 10, 11, 13, 15                                | 1-6, 8-11 | 5, 7, 9 | 5, 7    |  | 2, 4, 6, 8, 11, 12 |  | 1, 2, 4-9, 11, 18-23, 25, 26 | 1, 2, 4, 5, 10, 11, 16, 18, 19, 22, 25, 26 | 1, 4, 5, 10, 11, 18, 19, 22, 25, 26 |  | 2, 5, 9, 18, 21 | 1, 2, 5, 9, 11, 18, 19, 21, 22, 25, 26 |
| Red Shiner<br><i>(Cyprinella lutrensis)</i>           | 1, 2, 4, 6-8, 10, 11, 14, 17, 18, 22, 24-31, 33, 34, 36, 41-48, 51, 53, 56-58, 60, 62, | 6-8, 10, 11, 14, 28, 29, 31, 34, 42, 48, 54, 59, 60, 66 | 6, 8, 10, 11, 14, 19, 27, 28, 34, 36, 44, 50, 51, 55, 57, 58, 63, 65, 66, 68 |         | 6, 28, 36, 47-49, 58, 60, 63 | 1, 19, 21, 22, 25, 30-33, 36, 40, 41, 44, 49, 51, 53, 61 | 1, 2, 4   | 2, 4    | 1, 2, 4 |  | 3                  |  | 2, 3, 5, 7-11                | 2-4, 8-12                                  | 1, 2, 7, 9, 10                      |  | 6               | 2, 3, 5, 7                             |

|                                             |                                      |                                     |                                        |                                                    |                  |              |                                         |      |                              |           |                                               |                                         |                               |    |                                         |                                  |           |
|---------------------------------------------|--------------------------------------|-------------------------------------|----------------------------------------|----------------------------------------------------|------------------|--------------|-----------------------------------------|------|------------------------------|-----------|-----------------------------------------------|-----------------------------------------|-------------------------------|----|-----------------------------------------|----------------------------------|-----------|
| Topeka Shiner<br>( <i>Notropis Topeka</i> ) | 2, 6, 7,<br>10, 16,<br>17, 20-<br>23 | 2, 5, 6,<br>9, 10,<br>13, 19-<br>21 | 2, 6-8,<br>10, 12-<br>15, 17,<br>19-22 | 7,<br>12,<br>14,<br>16,<br>17,<br>20,<br>21,<br>23 | 2, 7-9,<br>12-23 | 9, 15,<br>19 | 1,<br>2,<br>4,<br>6,<br>7,<br>12,<br>13 | 7, 8 | 3,<br>8-<br>10,<br>12,<br>14 | 10-<br>12 | 1, 2,<br>8,<br>11,<br>12,<br>17,<br>18,<br>21 | 5, 9,<br>11-<br>13,<br>16-<br>18,<br>20 | 4,<br>11,<br>12,<br>17,<br>18 | 11 | 6, 7,<br>10,<br>11,<br>13,<br>17-<br>19 | 6, 7,<br>10,<br>13,<br>17-<br>19 | 11,<br>16 |
|---------------------------------------------|--------------------------------------|-------------------------------------|----------------------------------------|----------------------------------------------------|------------------|--------------|-----------------------------------------|------|------------------------------|-----------|-----------------------------------------------|-----------------------------------------|-------------------------------|----|-----------------------------------------|----------------------------------|-----------|

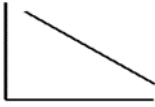
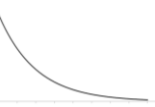
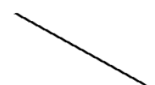
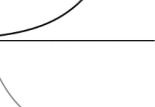
**Appendix C Table C.4.** Literature review for habitat and impact associations of Emerald Shiner. Included are ecological category, numerical value, description, expected trend from the literature and a possible trend noted by the authors. ? = no information for Kansas. Citation: Web of Science<sup>1</sup>, NatureServe<sup>2</sup>, *Kansas Fishes*<sup>3</sup>.

| #  | Ecological Category           | Emerald Shiner Literature                                                           |                                                                                                                    |                                                                                                              |                                                                                       |
|----|-------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|    |                               | Value                                                                               | Description                                                                                                        | Expected Trend                                                                                               | Possible Trend                                                                        |
| 1  | Flow (Discharge and Velocity) | Age 0 fish: (<0.6 m/s) <sup>1</sup>                                                 | Moderate current (but can thrive in lacustrine conditions) <sup>3</sup>                                            | <br>non reservoir sites   |                                                                                       |
| 2  | Substrates                    | ?                                                                                   | Sandy (but tolerant of many kinds) <sup>3</sup> , silt – rock <sup>1</sup> , typically sand or gravel <sup>2</sup> |                           |                                                                                       |
| 3  | Stream Order                  | ?                                                                                   | Large rivers <sup>3</sup> , medium-large <sup>2</sup>                                                              |                           |                                                                                       |
| 4A | Reach Measures - Stream Width | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |    |
| 4B | Reach Measures - Stream Depth | Age 0: Avg. <1.5, Range: 1-3 (m) <sup>1</sup> , Lake spawning: 2-6 (m) <sup>2</sup> | Can be found in shallow and deep water <sup>2,3</sup>                                                              |                          |                                                                                       |
| 5  | Catchment Area                | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |  |
| 6  | Sinuosity                     | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |  |
| 7  | Land Use - Agriculture        | ?                                                                                   | Sedimentation and water withdrawal (irrigation) cause declines <sup>3</sup>                                        |                         |                                                                                       |
| 8  | Land Use - Development        | ?                                                                                   | Pollution has led to imperilment in some populations <sup>3</sup>                                                  |                         |                                                                                       |
| 9  | Natural Land                  | ?                                                                                   | ?                                                                                                                  | ?                                                                                                            |  |
| 10 | Dams (Proximity)              | ?                                                                                   | Impoundments cause decline (flow regulation) or increase (reduce turbidity) <sup>2,3</sup>                         | <br>non reservoir sites |                                                                                       |
| 11 | Gradient                      | ?                                                                                   | Low gradient <sup>3</sup> , low-moderate <sup>2</sup>                                                              |                         |                                                                                       |

**Appendix C Table C.5.** Literature review for habitat and impact associations of Central Stoneroller. Included are ecological category, numerical value, description, expected trend from the literature and a possible trend noted by the authors. ? = no information for Kansas. Citation: Web of Science<sup>1</sup>, NatureServe<sup>2</sup>, *Kansas Fishes*<sup>3</sup>.

| #  | Ecological Category           | Central Stoneroller Literature                                           |                                                                                                                             |                                                                                       |                                                                                       |
|----|-------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|    |                               | Value                                                                    | Description                                                                                                                 | Expected Trend                                                                        | Possible Trend                                                                        |
| 1  | Flow (Discharge and Velocity) | 0.01-0.12 (m/s <sup>-1</sup> ), 19-757 (l/m <sup>-1</sup> ) <sup>1</sup> | Intermittent to short-term intermittency <sup>3</sup> , prefers slight current but is tolerant of fluctuations <sup>1</sup> |    |                                                                                       |
| 2  | Substrates                    | Rocky: ~ 80%, non-rocky: ~20% <sup>1</sup>                               | Rocky: Gravel, cobble, rubble <sup>1,3</sup> , tolerant of siltation but absent if high levels <sup>1,3</sup>               |    |                                                                                       |
| 3  | Stream Order                  | ?                                                                        | Small streams <sup>1,3</sup> (but can be found in moderate) <sup>1</sup>                                                    |    |                                                                                       |
| 4A | Reach Measures - Stream Width | Stream width (across sites): 0.7-60m, avg. 11m <sup>1</sup>              | ?                                                                                                                           |    |                                                                                       |
| 4B | Reach Measures - Stream Depth | 26.2-49.9, 3-60, 12-42 (cm) <sup>1</sup>                                 | Deep pools <sup>3</sup> , shallows (spawn) <sup>1</sup>                                                                     |   |                                                                                       |
| 5  | Catchment Area                | ?                                                                        | ?                                                                                                                           | ?                                                                                     |  |
| 6  | Sinuosity                     | ?                                                                        | ?                                                                                                                           | ?                                                                                     |  |
| 7  | Land Use - Agriculture        | ?                                                                        | "Mostly" pasture-cattle grazing, tolerant of ag. activity (siltation - to a point) <sup>1</sup>                             |  |                                                                                       |
| 8  | Land Use - Development        | ?                                                                        | Tolerant of urban development <sup>1</sup> , dewatering alters preferred flow regime <sup>3</sup>                           |  |                                                                                       |
| 9  | Natural Land                  | ?                                                                        | "Some" natural shoreline (meadow, woods) <sup>1</sup>                                                                       |  |                                                                                       |
| 10 | Dams (Proximity)              | ?                                                                        | Impoundments (reduced abundance) <sup>1</sup>                                                                               |  |                                                                                       |
| 11 | Gradient                      | 0.5-41 m/km (across sites) <sup>1</sup>                                  | Prefers moderate gradient <sup>1</sup> low-moderate <sup>2</sup>                                                            |  |                                                                                       |

**Appendix C Table C. 6.** Literature review for habitat and impact associations of Plains Minnow. Included are ecological category, numerical value, description, expected trend from the literature and a possible trend noted by the authors. ? = no information for Kansas. Citation: Web of Science<sup>1</sup>, NatureServe<sup>2</sup>, *Kansas Fishes*<sup>3</sup>.

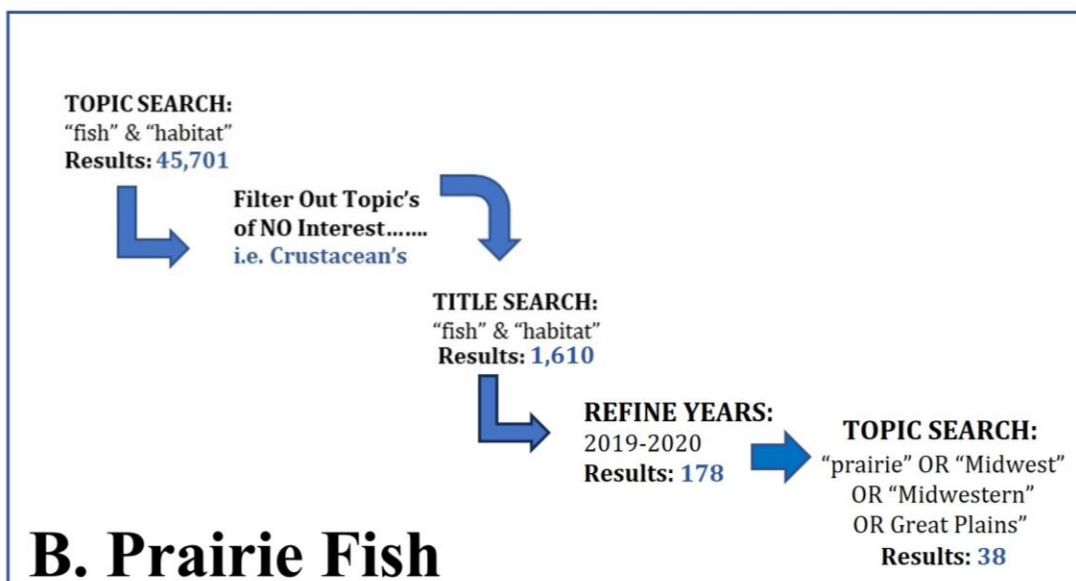
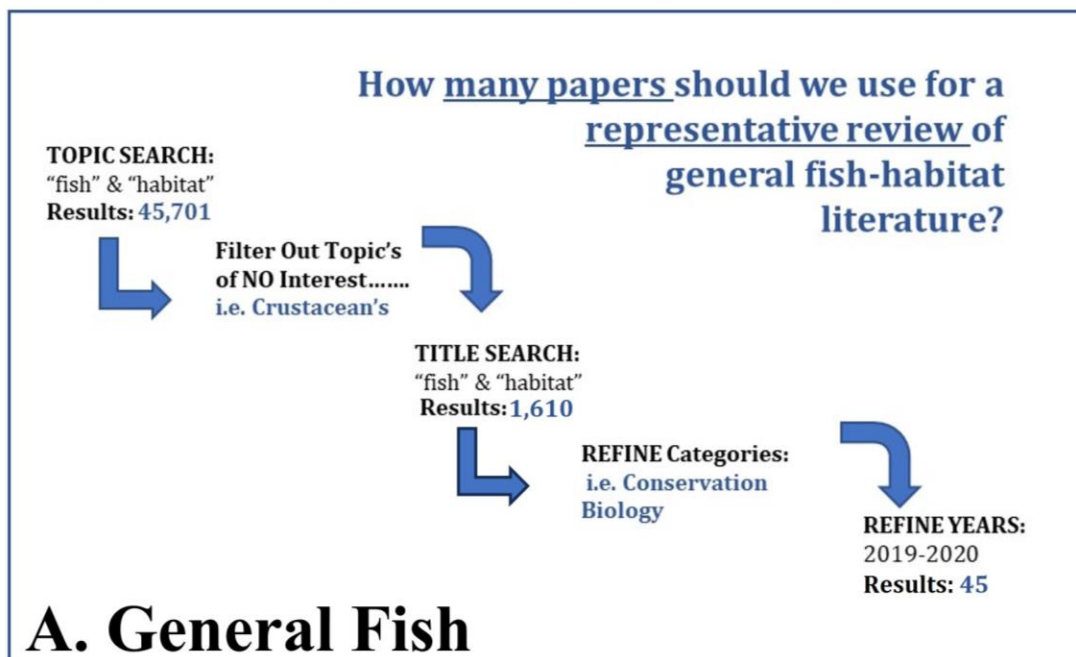
| #  | Ecological Category           | Plains Minnow Literature                                            |                                                                                                            |                                                                                       |                                                                                       |
|----|-------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|    |                               | Value                                                               | Description                                                                                                | Expected Trend                                                                        | Possible Trend                                                                        |
| 1  | Flow (Discharge and Velocity) | Velocity (across sites): 0.05–2.29 (m <sup>3</sup> /s) <sup>1</sup> | Little flow <sup>3</sup> , slower water, some current, slight to moderate erratic flows <sup>2</sup>       |    |                                                                                       |
| 2  | Substrates                    | Sample sites: 93% Fine, 6% Gravel, 1% Large <sup>1</sup>            | Sandy - sandbars, rarely over gravel, clay or high loads of silt <sup>3</sup> , silty streams <sup>2</sup> |    |                                                                                       |
| 3  | Stream Order                  | ?                                                                   | Small, medium, and large rivers <sup>1,2</sup>                                                             |    |                                                                                       |
| 4A | Reach Measures - Stream Width | Small river sites: <5m, large river sites: 200-500(m) <sup>1</sup>  | Broad segments <sup>3</sup>                                                                                |    |                                                                                       |
| 4B | Reach Measures - Stream Depth | ?                                                                   | Shallow water <sup>2,3</sup>                                                                               |   |                                                                                       |
| 5  | Catchment Area                | ?                                                                   | ?                                                                                                          | ?                                                                                     |  |
| 6  | Sinuosity                     | ?                                                                   | ?                                                                                                          | ?                                                                                     |  |
| 7  | Land Use - Agriculture        | ?                                                                   | Water withdrawal (irrigation) has altered needed flow regimes <sup>2,3</sup>                               |  |                                                                                       |
| 8  | Land Use - Development        | ?                                                                   | Dewatering and nonpoint source pollution cause declines <sup>2</sup>                                       |  |                                                                                       |
| 9  | Natural Land                  | ?                                                                   | ?                                                                                                          | ?                                                                                     |  |
| 10 | Dams (Proximity)              | CPUE was >3 higher in reaches with no dam <sup>1</sup>              | Dams: altered needed flow regimes/blocked migration leading to massive declines <sup>1,2,3</sup>           |  |                                                                                       |
| 11 | Gradient                      | ?                                                                   | Low gradients <sup>2</sup>                                                                                 |  |                                                                                       |



## Figures

**Appendix C Figure C.1.** Literature review methods for selecting papers used to address objective 1 of Olivia Rode's research. Throughout, two different literature datasets on fish habitat are considered: general fish (A), and prairie fish (B).

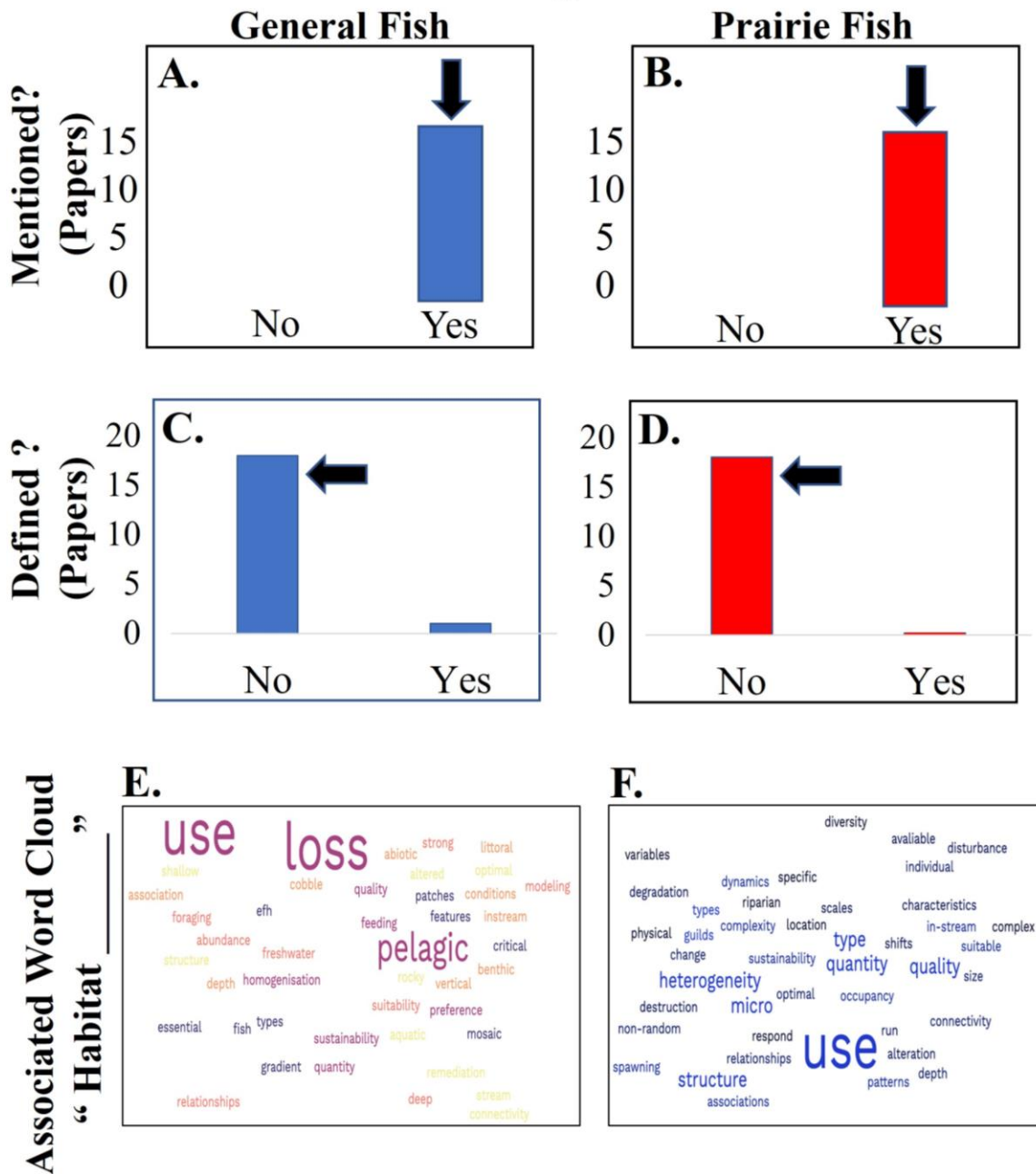
### Objective 1 - Methods General & Prairie Fish Literature



**Appendix C Figure C.2.** A problem related to inconsistency and ambiguity that exists in the fish habitat research related to whether habitat was mentioned (A, B), whether habitat was defined (C, D), and word associations for habitat (E, F) in databases that address general fish (A-E) and prairie fish (B-F) habitat. Mentioned is the use of the word “habitat,” and word association identifies the word(s) that immediately follow habitat in the abstract.

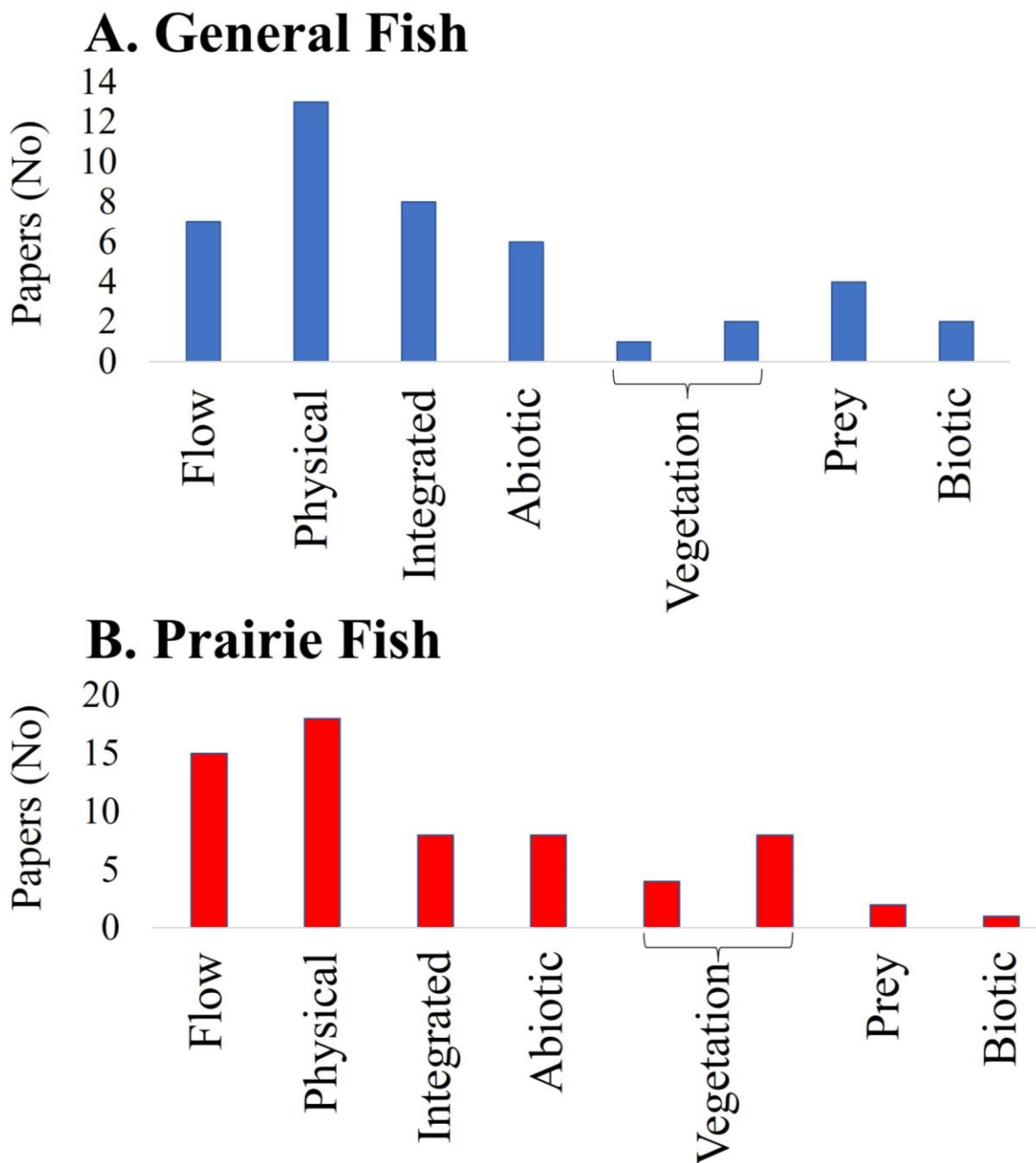
## Objective 1 Results – The Problem

### Defining Habitat



**Appendix C Figure C.3.** More details of the problem related to inconsistency and ambiguity that exists in fish habitat research related to the highly variable measurement of different variables, potentially because exactly what constitutes fish habitat is not clearly defined. Trends for two different literature datasets on fish habitat are shown [general fish (A) and prairie fish(B)].

## Objective 1 Results – The Problem Variables Measured



## References

### **Appendix C: What Literature Was Reviewed. Why, Results, and Next Steps**

Busch, M. H., Costigan, K. H., Fritz, K. M., Datry, T., Krabbenhoft, C. A., Hammond, J. C., Zimmer, M., Olden, J. D., Burrows, R. M., Dodds, W. K., Boersma, K. S., Shanafield, M., Kampf, S. K., Mims, M. C., Bogan, M. T., Ward, A. S., Perez Rocha, M., Godsey, S., Allen, G. H., ... Allen, D. C. (2020). What's in a Name? Patterns, Trends, and Suggestions for Defining Non-Perennial Rivers and Streams. *Water*, 12(7), 1980.

### General Fish Habitat Papers (Objective 1)

1. Akbaripasand, A., & Closs, G. P. (2018). Effects of food supply and stream physical characteristics on habitat use of a stream-dwelling fish. *Ecology of Freshwater Fish*, 27(1), 270-279.
2. Budnik, R. R., Conroy, J. D., Zweifel, R. D., Ludsins, S. A., & Marschall, E. A. (2021). Projecting future habitat quality of three midwestern reservoir fishes under warming conditions. *Ecology of Freshwater Fish*, 30(1), 31-47.
3. Carniatto, N., Fugli, R., Quirino, B. A., Cunha, E. R., & Thomaz, S. M. (2020). An invasive and a native macrophyte species provide similar feeding habitat for fish. *Ecology of Freshwater Fish*, 29(1).
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### **Prairie Fish Habitat Papers (Objective 1)**

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## Web of Science: All Papers (Objective 2 – Table C.2: Column 2, “WoS”)

### Banded Darter (*Etheostoma zonale*)

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**Web of Science: Fish-Habitat Papers (Objective 2 – Table C.3: Columns 1-7, “WoS: Fish-Habitat Papers”)**

Banded Darter (*Etheostoma zonale*):

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Brassy Minnow (*Hybognathus hankinsoni*):

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Freshwater Ecosystems, 29(10), 1735-1748. [Flow/Substrate/System Size/Land Use/Sinuosity]

Bullhead Minnow (*Pimephales vigilax*):

1. Cureton, J. C., & Broughton, R. E. (2014). Rapid morphological divergence of a stream fish in response to changes in water flow. *Biology Letters*, 10(6). [Flow/Dams]
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7. Stanley, C. E., Taylor, J. M., & King, R. S. (2012). Coupling Fish Community Structure with Instream Flow and Habitat Connectivity between Two Hydrologically Extreme Years. *Transactions of the American Fisheries Society*, 141(4), 1000-1015. [Flow]
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Central Stoneroller (*Campostoma anomalum*):

1. Angermeier, P. L. (1992). Predation by rock bass on other stream fishes: experimental effects of depth and cover. *Environmental Biology of Fishes*, 34(2), 171-180. [System Size]
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10. Knight, G. L., & Gido, K. B. (2005). Habitat use and susceptibility to predation of four prairie stream fishes: Implications for conservation of the endangered Topeka Shiner. *Copeia*(1), 38-47. [Flow/Substrate/System Size]

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13. Oakes, R. M., Gido, K. B., Falke, J. A., Olden, J. D., & Brock, B. L. (2005). Modelling of stream fishes in the Great Plains, USA. *Ecology of Freshwater Fish*, 14(4), 361-374. [Substrate/System Size/Land Use/Gradient]
14. Osterhaus, D. M., Leberg, S. S., Pierce, C. L., Stewart, T. W., & McCombs, A. (2022). Oxbow Restorations for Topeka Shiner (*Notropis topeka*) Recovery: Defining Success. *American Midland Naturalist*, 188(1), 56-73. [System Size/Sinuosity/Land Use]
15. Pfaff, P. J., Hase, K. J., & Gido, K. B. (2023). Community assembly of prairie farm ponds: build it and they will come, stock it and they won't. *Canadian Journal of Fisheries and Aquatic Sciences*. [Substrate/System Size/Land Use/Dams/Gradient]
16. Schilling, K. E., Wilke, K., Pierce, C. L., Kult, K., & Kenny, A. (2019). Multipurpose Oxbows as a Nitrate Export Reduction Practice in the Agricultural Midwest. *Agricultural & Environmental Letters*, 4(1). [Flow/Sinuosity/Land Use]
17. Schmolke, A., Bartell, S. M., Roy, C., Desmarteau, D., Moore, A., Cox, M. J., . . . Brain, R. (2021). Applying a Hybrid Modeling Approach to Evaluate Potential Pesticide Effects and Mitigation Effectiveness for an Endangered Fish in Simulated Oxbow Habitats. *Environmental Toxicology and Chemistry*, 40(9), 2615-2628. [Flow/System Size/Sinuosity/Land Use]
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20. Simpson, N. T., Bybe, A. P., Weber, M. J., Pierce, C. L., & Roe, K. J. (2019). Occurrence, abundance and associations of Topeka Shiners (*Notropis topeka*) in restored and unrestored oxbows in Iowa and Minnesota, USA. *Aquatic Conservation-Marine and Freshwater Ecosystems*, 29(10), 1735-1748. [Flow/Substrate/System Size/Sinuosity/Land Use]
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**NatureServe Habitat Papers (Objective 2 – Table C.3: Columns 8-14, “NatureServe: Fish-Habitat Papers”)**

Banded Darter (*Etheostoma zonale*)

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp. [Substrate]
2. Page, L. M., & B. M. Burr. (2011). Peterson field guide to freshwater fishes of North America north of Mexico. Second edition. Houghton Mifflin Harcourt, Boston. xix + 663 pp. [Substrate/System Size]
3. Trautman, M. B. (1981). The fishes of Ohio. Second edition. Ohio State University Press, Columbus, Ohio. 782 pp. [System Size]
4. Walters, J. P. (1994). Spawning behavior of *Etheostoma zonale* (Pisces: Percidae). Copeia 1994:818-821. [Flow/Substrate/System Size]

Blue Catfish (*Ictalurus furcatus*):

1. Manooch, C. S., III. (1984). Fisherman's guide. Fishes of the southeastern United States. North Carolina State Museum of Natural History, Raleigh. 362 pp. [Substrate]
2. Pflieger, W. L. (1997). The Fishes of Missouri, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Dams]
3. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). The fishes of New Mexico. University New Mexico Press, Albuquerque, New Mexico. 393 pp.

Blue Sucker (*Cycleptus elongatus*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp.
2. Boschung, H. T., & R. L. Mayden. (2004). Fishes of Alabama. Smithsonian Institution Press, Washington, D.C. 960 pp.
3. Coker, R. E. (1930). Studies of common fishes of the Mississippi River at Keokuk. Bulletin of the United States Bureau of Fisheries 45:141-225.
4. Mettee, M. F., P. E. O'Neil, & J. M. Pierson. (1996). Fishes of Alabama and the Mobile Basin. Oxmoor House, Birmingham, Alabama. 820 pp.

5. Moss, R. E., J. W. Scanlan, & C. S. Anderson. (1983). Observations on the natural history of the Blue Sucker (*Cycleptus elongatus* Le Sueur) in the Neosho River. *American Midland Naturalist*. 109:15-22. [Flow/Substrate/System Size]
6. Pflieger, W. L. (1997). *The Fishes of Missouri*, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Flow/Substrate/Dams]
7. Robison, H. W. & T. M. Buchanan. (1988). *Fishes of Arkansas*. The University of Arkansas Press, Fayetteville, Arkansas. 536 pp.
8. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). *The fishes of New Mexico*. University New Mexico Press, Albuquerque, New Mexico. 393 pp. [Land-Use]

Brassy Minnow (*Hybognathus hankinsoni*):

1. Becker, G. C. (1983). *Fishes of Wisconsin*. University of Wisconsin Press, Madison. 1,052 pp. [Substrate/System Size]

Bullhead Minnow (*Pimephales vigilax*):

1. Becker, G. C. (1983). *Fishes of Wisconsin*. University of Wisconsin Press, Madison. 1,052 pp. [Flow/Substrate/System Size]
2. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). *The fishes of New Mexico*. University New Mexico Press, Albuquerque, New Mexico. 393 pp. [Flow/Substrate/System Size/Dams/Gradient]

Central Stoneroller (*Campostoma anomalum*):

1. Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, & J.R. Stauffer, Jr. (1980). *Atlas of North American Freshwater Fishes*. North Carolina State Museum of Natural History, Raleigh, NC. 854 pp. [Flow/Substrate/System Size]
2. Matthews, W. J., & D. C. Heins, editors. (1987). *Community and evolutionary ecology of North American stream fishes*. Univ. Oklahoma Press, Norman. viii + 310 pp.
3. Page, L. M., & B. M. Burr. (2011). *Peterson field guide to freshwater fishes of North America north of Mexico*. Second edition. Houghton Mifflin Harcourt, Boston. xix + 663 pp. [Flow/System Size]
4. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). *The fishes of New Mexico*. University New Mexico Press, Albuquerque, New Mexico. 393 pp. [Flow/Substrate/System Size]

Emerald Shiner (*Notropis atherinoides*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp. [Substrate/System Size]
2. Burkhead, N. M., & R. E. Jenkins. (1991). Fishes. Pages 321-409 in K. Terwilliger (coordinator). Virginia's Endangered Species: Proceedings of a Symposium. McDonald and Woodward Publishing Company, Blacksburg, Virginia. [System Size/Dams/Gradient]
3. Page, L. M., & B. M. Burr. (1991). A field guide to freshwater fishes: North America north of Mexico. Houghton Mifflin Company, Boston, Massachusetts. 432 pp. [Substrate]
4. Pflieger, W. L. & T. B. Grace. (1987). Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-181 in W. J. Matthews and D. C. Heins (editors). Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma. [Dams]
5. Trautman, M. B. (1981). The fishes of Ohio. Second edition. Ohio State University Press, Columbus, Ohio. 782 pp.

Freshwater Drum (*Aplodinotus grunniens*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp.
2. Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, & J.R. Stauffer, Jr. (1980). Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh, NC. 854 pp. [Substrate/System Size]
3. Page, L. M., & B. M. Burr. (2011). Peterson field guide to freshwater fishes of North America north of Mexico. Second edition. Houghton Mifflin Harcourt, Boston. xix + 663 pp. [Substrate/System Size]

Longnose Gar (*Lepisosteus osseus*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp. [Substrate/System Size]
2. Goff, G. P. (1984). Brood care of Longnose Gar (*Lepisosteus osseus*) by Smallmouth Bass (*Micropterus dolomieu*). Copeia 1984:149-152.
3. Scott, W. B., & E. J. Crossman. (1973). Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184. 966 pp.

4. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). The fishes of New Mexico. University New Mexico Press, Albuquerque, New Mexico. 393 pp. [Substrate/System Size]

Neosho Madtom (*Noturus placidus*):

1. Cross, F. B., & Collins, J. T. (1995). Fishes in Kansas, second edition, revised. University of Kansas Natural History Museum, Public Education Series Number 14:1-315. [Flow]
2. Bulger, A.G., & Edds, D. R. (2001). Population structure and habitat use in Neosho Madtom (*Noturus placidus*). Southwestern Naturalist 46:8-15. [Flow/Substrate/System Size]
3. Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Díaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. Jacobo Schmitter-Soto, E. B. Taylor, & M.L. Warren, Jr. (2008). Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33(8):372-407.
4. Moss, R. E. (1981). Life history information for the Neosho Madtom, *Noturus placidus*. Report to Kansas Department of Wildlife and Parks. 38 pp. [Flow]
5. Pflieger, W. L. (1997). The Fishes of Missouri, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Flow/Substrate/System Size/Land Use/Dams/Gradient]
6. Pflieger, W. L. (Missouri Department of Conservation). (1997). Review and annotation of fish watershed distribution maps. Review requested by Ruth Mathews, TNC. April 1997. [Substrate/Land Use/Dams]
7. U.S. Fish & Wildlife Service (USFWS). (1990). Endangered and threatened species recovery program: report to Congress. 406 pp.
8. Wenke, T. L., M.E. Eberle, G. W. Ernsting, & W. J. Stark. (1992). Winter collections of the Neosho Madtom (*Noturus placidus*). Southwestern Naturalist 37:330-3. [Flow/Substrate/System Size/Gradient]
9. Wildhaber, M. (2008). Neosho Madtom: a small fish with complex problems. Endangered Species Bulletin 33(3):43-45. [Flow/Substrate/Land Use/Dams]
10. Wildhaber, M. L. (2006). The role of reproductive behavior in the conservation of fishes: examples from the Great Plains riverine fishes. The Conservation Behaviorist 4(1):15-19.

Northern Plains Killifish (*Fundulus kansae*):

1. Eberle, M., S. Hoofer, N. Mandrak, & T. Wenke. (1997). Assessment of fish communities in western Kansas streams during 1994-1996. Nongame Program Report, Kansas Department of Wildlife and Parks, Emporia and Pratt. 8 pp.

Orangespotted Sunfish (*Lepomis humilis*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp. [Substrate/System Size]

Plains Minnow (*Hybognathus placitus*):

1. Bonner, T. H., & Wilde, G. R. (2000). Changes in the fish assemblage of the Canadian River, Texas, associated with reservoir construction. *Journal of Freshwater Ecology*. 15(2):189-198. [Flow]
2. Cross, F. B. and R. E. Moss. (1987). Historic changes in fish communities and aquatic habitats in plains streams of Kansas. Pages 155-165 in W.J. Matthews and D.C. Heins (editors). *Community and evolutionary ecology of North American stream fishes*. University of Oklahoma Press, Norman, Oklahoma. [Flow/Land Use/Dams]
3. Cross, F. B., Moss, R. E., & Collins, J. T. (1985). Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron Rivers. University of Kansas Museum of Natural History, Lawrence, Kansas. 161 pp. [Flow]
4. Eberle, M. E. (1995). Status of the Plains Minnow (*Hybognathus placitus* Girard) in the Smoky Hill and Republican river basins of Kansas. Nongame Program Report, Kansas Department of Wildlife and Parks, Emporia and Pratt. 7pp. [Flow/Land Use/Dams]
5. Lehtinen, S. F. & Layzer, J. B. (1988). Reproductive cycle of the Plains Minnow, *Hybognathus placitus* (Cyprinidae), in the Cimarron River, Oklahoma. *Southwestern Naturalist* 33:27-33. [Flow/Substrate/System Size]
6. Northern Prairie Wildlife Research Center. (1995). North Dakota's federally listed endangered, threatened, and candidate species: Plains Minnow (*Hybognathus placitus*). Retrieved from: <http://www.npwrc.usgs.gov/resource/distr/others/nddanger/species/hyboplac.htm>. [Flow/Land Use/Dams]
7. Page, L. M., & Burr, B. M. (2011). Peterson field guide to freshwater fishes of North America north of Mexico. Second edition. Houghton Mifflin Harcourt, Boston. xix + 663 pp. [Substrate/System Size]
8. Rees, D. E., Carr, R. J., & Miller, W. J. (2005). Plains Minnow (*Hybognathus placitus*): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. [Flow/Land Use/Dams]

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#### Red Shiner (*Cyprinella lutrensis*):

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2. Page, L. M., & Burr, B. M. (2011). Peterson field guide to freshwater fishes of North America north of Mexico. Second edition. Houghton Mifflin Harcourt, Boston. xix + 663 pp. [Flow/Substrate/System Size]
3. Pflieger, W. L. & T. B. Grace. (1987). Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-181 in W. J. Matthews and D. C Heins (editors). [Dams]
4. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). The fishes of New Mexico. University New Mexico Press, Albuquerque, New Mexico. 393 pp. [Flow/Substrate/System Size]

#### Topeka Shiner (*Notropis topeka*):

1. Anonymous. (1975). Standard methods for the examination of water and wastewater (14th edition). American Public Health Association, Inc. New York. 769 pp. [Flow]
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13. Welch, P. S. (1948). Limnological methods. McGraw-Hill, New York, NY. 381 pp. [Flow]
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**Kansas Fishes Habitat Papers (Objective 2 – Table C.3: Columns 15-21, “Kansas Fishes: Fish-Habitat Papers”)**

Banded Darter (*Etheostoma zonale*):

1. Barron, J. N., & Albin, H. T. (2004). Reproduction in *Etheostoma zonale* across three breeding seasons in Ohio. *American Midland Naturalist*, 151(1), 1-14.
2. Chambers, D. K., Arruda, J. A., & Jaywardhana, A. A. (2005). A Synoptic Water Quality Survey of the Spring River and Its Tributaries. *Transactions of the Kansas Academy of Science* (1903-), 108(1/2), 47–56. [Land Use]
3. Conservation Committee, Kansas Academy of Science. (1974). Rare, Endangered and Extirpated Species in Kansas. I. Fishes. *Transactions of the Kansas Academy of Science* (1903-), 76(2), 97–106. [Flow/Dams]
4. Cross, F. B. (1967). Handbook of Fishes in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357. [Flow/Substrate/System Size]
5. Pflieger, W. L. (1997). The Fishes of Missouri, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Flow/Substrate/System Size]
6. Tsai, C. F., & Raney, E. C. (1974). Systematics of Banded Darter, *Ethostoma-zonale* (Pisces, Percidae). *Copeia*(1), 1-24. [Flow]
7. Walters, J. P. (1994). Spawning behavior of *Etheostoma zonale* (Pisces: Percidae). *Copeia* 1994:818-821. [Substrate/System Size]

Blue Catfish (*Ictalurus furcatus*):

1. Cross, F. B. (1967). Handbook of Fishes in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357.
2. Edds, D. R., Matthews, W. J., & Gelwick, F. P. (2002). Resource use by large catfishes in a reservoir: is there evidence for interactive segregation and innate differences? *Journal of Fish Biology*, 60(3), 739-750. [System Size]
3. Fischer, S. A., Eder, S., & Aragon, E. D. (1999). Movements and Habitat Use of Channel Catfish and Blue Catfish in a Small Impoundment in Missouri. Pages: 239-255 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. *Catfish 2000: proceedings of the international ictalurid symposium*. American Fisheries Society, Symposium 24, Bethesda, Maryland.



4. Glodek, G. S. (1980). *Ictalurus furcatus* (Lesueur), Blue Catfish. Pages 1–439 in D. S. Lee, C. Gilbert, C. Hocutt, R. Jenkins, D. E. McAllister, and J. R. Stauffer Jr., editors. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh. [System Size/Dams]
5. Goeckler, J., Quist, M., Reinke, J., & Guy, C. (2003). Population characteristics and evidence of natural reproduction of Blue Catfish in Milford Reservoir, Kansas. Transactions of the Kansas Academy of Science, 106, 149-154. [Dams]
6. Graham, K. (1999). A review of the biology and management of Blue Catfish. American Fisheries Society Symposium 24: 37–49. [Flow/Substrate/System Size/Dams]
7. Graham, K., and K. DeiSanti. (1999). The population and fishery of Blue Catfish and channel catfish in the Harry S Truman Dam tailwater, Missouri. Pages 361–376 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland. [Dams]
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9. Johnson, C. (2009). Progress and Management Report – El Dorado Reservoir. Kansas Department of Wildlife and Parks, Pratt. [Dams]
10. Kwak, T.J., Porath, M.T., Michaletz, P.H., & Travnichek, V.H. (2011). Catfish Science: Status and Trends in the 21st Century. Environmental Science.
11. Lagler, K. F. (1961). Freshwater fishery biology. William C. Brown Company, Dubuque, Iowa.
12. Pflieger, W. L. (1997). The Fishes of Missouri, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Flow/Substrate/System Size]
13. Timmons, T. J. (1999). Movement and exploitation of Blue and Channel Catfish in Kentucky Lake. Pages 187–191 in E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland
14. Trautman, M. B. (1981). The Fishes of Ohio: With Illustrated Keys: Ohio State University Press. [Flow/Substrate/System Size]

Blue Sucker (*Cycleptus elongatus*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp. [Flow/System Size/Land Use/Dams]
2. Boschung, H. T., and R. L. Mayden. (2004). Fishes of Alabama. Smithsonian Institution Press, Washington, D.C. 960 pp. [Substrate]
3. Cross, F. B. (1967). Handbook of Fishes in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357. [Flow/Substrate/System Size]
4. Edwards, R., Garrett, G., & Allan, N. (2004). Aquifer-Dependent Fishes of the Edwards Plateau Region. Chapter 13. Pages 253-268 in Aquifers of the Edwards Plateau. Texas Water Development Board, Austin. [Flow/Land Use/Dams]
5. Gilbert, C. R. (1980). *Cycleptus elongatus* (Lesueur), Blue Sucker. Page 396 in D. S. Lee, C. Gilbert, C. Hocutt, R. Jenkins, D. E. McAllister, and J. R. Stauffer Jr., editors. Atlas of North American freshwater fishes. North Carolina State Museum of Natural History, Raleigh. [Substrate]
6. Moss, R. E., J. W. Scanlan, and C. S. Anderson. (1983). Observations on the natural history of the Blue Sucker (*Cycleptus elongatus* Le Sueur) in the Neosho River. American Midland Naturalist. 109:15-22. [Flow/Substrate/System Size]
7. Trautman, M. B. (1981). The Fishes of Ohio: With Illustrated Keys: Ohio State University Press. [Flow/Land Use/Dams]
8. Vokoun, J., Guerrant, T., & Rabeni, C. (2003). Demographics and Chronology of a Spawning Aggregation of Blue Sucker (*Cycleptus elongatus*) in the Grand River, Missouri, USA. Journal of Freshwater Ecology - J FRESHWATER ECOL, 18, 567-575. [Flow/Substrate/System Size]

Brassy Minnow (*Hybognathus hankinsoni*):

1. Copes, F. A. (1975). Contributions to ichthyology, part III: ecology of the Brassy Minnow *Hybognathus hankinsoni* (Cyprinidae). Museum of Natural History, University of Wisconsin, Stevens Point, Reports of the Flora and Fauna of Wisconsin 10: 46-72. [Substrate/System Size]
2. Cross, F. B. (1967). Handbook of Fishes in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357. [Flow/Substrate/System Size]
3. Cross, F. B., & Collins, J. T. (1995). Fishes in Kansas, second edition, revised. University of Kansas Natural History Museum, Public Education Series Number 14:1-315. [System Size]

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6. Falke, J.A., Fausch, K.D., Bestgen, K.R., & Bailey, L.L. (2010). Spawning phenology and habitat use in a Great Plains, USA, stream fish assemblage: an occupancy estimation approach. *Canadian Journal of Fisheries and Aquatic Sciences*, 67, 1942-1956. [Flow]
7. Falke, J. A., Fausch, K. D., Magelky, R., Aldred, A., Durnford, D. S., Riley, L. K., & Oad, R. (2011). The role of groundwater pumping and drought in shaping ecological futures for stream fishes in a dryland river basin of the western Great Plains, USA. *Ecohydrology*, 4(5), 682-697. [Flow/Land Use/Dams]
8. Gido, K., Dodds, W., & Eberle, M. (2010). Retrospective analysis of fish community change during a half-century of landuse and streamflow changes. *Journal of The North American Benthological Society - J N AMER BENTHOL SOC.* 29. 970-987. [Flow/Land Use/Dams]
9. Haslouer, S. G., Eberle, M. E., Edds, D. R., Gido, K. B., Mammoliti, C. S., Triplett, J. R., Collins, J. T., Distler, D. A., Huggins, D. G., & Stark, W. J. (2005). Current status of native fish species in Kansas. *Transactions of the Kansas Academy of Science*, 108(1), 32-46, 15.
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11. Scheurer, J. A., Fausch, K. D., & Bestgen, K. R. (2003). Multiscale processes regulate Brassy Minnow persistence in a great plains river. *Transactions of the American Fisheries Society*, 132(5), 840-855. [Flow/System Size]

Bullhead Minnow (*Pimephales vigilax*):

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2. Cross, F. B., & Haslouer, S. G. (1984). *Pimephales vigilax* (Pisces, Cyprinidae) Established in the Missouri River Basin. *Transactions of the Kansas Academy of Science* (1903-), 87(3/4), 105–107.

3. Eberle, M. E., Wenke, T. L., & Welker, T. L. (1997). Selected Records of Stream Fishes from the Kansas River Basin in Kansas. *Transactions of the Kansas Academy of Science* (1903-), 100(3/4), 123–132.
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6. Pflieger, W. L. (1997). *The Fishes of Missouri*, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Flow/Substrate]
7. Robison, H. W. & T. M. Buchanan. (1988). *Fishes of Arkansas*. The University of Arkansas Press, Fayetteville, Arkansas. 536 pp. [Substrate/System Size/Dams]
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1. Berkman, H. E., & Rabeni, C. F. (1987). Effect of siltation on stream fish communities. *Environmental Biology of Fishes*, 18(4), 285-294. [Substrate]
2. Crevecœur, F. F. (1907). A New Species of *Campostoma*? *Transactions of the Kansas Academy of Science* (1903-), 21, 155–157. [Substrate/System Size]
3. Cross, F. B. (1967). *Handbook of Fishes in Kansas*. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357. [Flow/Substrate/System Size]
4. Matthews, W.J. (1987). Physicochemical tolerance and selectivity of stream fishes are related to their geographic ranges and local distributions. pp. 111–120. In: W.J. Matthews & D.C. Heins (ed.) *Community and Evolutionary Ecology of North American Stream Fishes*, University of Oklahoma Press, Norman.
5. Matthews, W.J., Power, M.E., & Stewart, A.J. (1986). Depth distribution of *Campostoma* grazing scars in an Ozark stream. *Environmental Biology of Fishes*, 17, 291-297. [System Size]
6. Metcalf, A. L. (1959). *Fishes of Chautauqua, Cowley and Elk Counties, Kansas*. University of Kansas, Lawrence, University of Kansas Publications, Museum of Natural History, Volume 11, Number 6: pages 345-400. [Flow]

7. Metcalf, A. L. (1966). Fishes of the Kansas River system in relation to zoogeography of the Great Plains. University of Kansas Publications Museum Natural History 17(3): 23-189. [Substrate]
8. Pflieger, W. L. (1997). The Fishes of Missouri, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [Substrate]
9. Power, M. E., & Matthews, W. J. (1983). Algae-grazing minnows (*Campostoma anomalum*), piscivorous bass (*Micropterus* spp.), and the distribution of attached algae in a small prairie-margin stream. *Oecologia*, 60(3), 328-332. [System Size]
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11. Spranza, J. J., & Stanley, E. H. (2000). Condition, growth, and reproductive styles of fishes exposed to different environmental regimes in a prairie drainage. *Environmental Biology of Fishes*, 59(1), 99-109. [Flow/Land Use]
12. Sublette, J. E., M. D Hatch, & M. Sublette. (1990). The fishes of New Mexico. University New Mexico Press, Albuquerque, New Mexico. 393 pp. [System Size]

Emerald Shiner (*Notropis atherinoides*):

1. Becker, G. C. (1983). Fishes of Wisconsin. University of Wisconsin Press, Madison. 1,052 pp. [Substrate/Dams]
2. Boschung, H. T., and R. L. Mayden. (2004). Fishes of Alabama. Smithsonian Institution Press, Washington, D.C. 960 pp. [Substrate/Dams]
3. Cross, F. B. (1967). Handbook of Fishes in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357. [Flow/Substrate/System Size/Gradient]
4. Cross, F. B., & Collins, J. T. (1995). Fishes in Kansas, second edition, revised. University of Kansas Natural History Museum, Public Education Series Number 14:1-315. [Flow/Land Use/Dams]
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6. Flittner, G.A. (1964). Morphometry and life history of the Emerald Shiner, *Notropis atherinoides* Rafinesque. Ph.D. thesis. University of Michigan, Ann Arbor, Michigan. [Substrate]

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11. Pflieger, W. L. & T. B. Grace. (1987). Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-181 in W. J. Matthews and D. C Heins (editors). Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma. [Dams]
12. Robison, H. W. & T. M. Buchanan. (1988). Fishes of Arkansas. The University of Arkansas Press, Fayetteville, Arkansas. 536 pp. [Substrate/Dams]
13. Ross, S. T. (2001). Inland Fishes of Mississippi. Mississippi Department of Wildlife, Fisheries and Parks, and University Press of Mississippi, Jackson. [Substrate]
14. Simon, T. (1998). Assessment of Balon's Reproductive Guilds with Application to Midwestern North American Freshwater Fishes. Pages 97-121 in T. P. Simon, editor.
15. Tomelleri, J. R., & Eberle, M. E. (2011). Fishes of the Central United States, second edition, revised and expanded. University Press of Kansas, Lawrence.

#### Freshwater Drum (*Aplodinotus grunniens*):

1. Cross, F. B. (1967). Handbook of Fishes in Kansas. University of Kansas Museum of Natural History. Miscellaneous Publication Number 45:1-357. [Substrate/Dams]
2. Cross, F. B., & Collins, J. T. (1995). Fishes in Kansas, second edition, revised. University of Kansas Natural History Museum, Public Education Series Number 14:1-315. [System Size]
3. Fremling, C. R. (1980). *Aplodinotus grunniens* (Rafinesque), Freshwater Drum. Page 756 in Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, & J.R. Stauffer, Jr., editors. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Raleigh.

4. Funk, J. L. (1957). Movement of Stream Fishes in Missouri. Transactions of the American Fisheries Society, 85(1), 39-57.
5. Gido, K. B., & Matthews, W. J. (2000). Dynamics of the Offshore Fish Assemblage in a Southwestern Reservoir (Lake Texoma, Oklahoma-Texas). Copeia, 2000(4), 917-930. [Dams]
6. Matthews, W. J. (1984). Influence of Turbid Inflows on Vertical Distribution of Larval Shad and Freshwater Drum, Transactions of the American Fisheries Society, 113:2, 192-198. [Dams]
7. Pflieger, W. L. (1997). The Fishes of Missouri, Revised Edition. Missouri Dept. of Conservation. Jefferson City, Missouri. [System Size/Dams]
8. Priegel, G. R. (1967). The Freshwater Drum: Its Life History, Ecology and Management. Wisconsin Department of Natural Resources Publication 236: 1-15. [Substrate/System Size/Dams]
9. Robison, H. W. & T. M. Buchanan. (1988). Fishes of Arkansas. The University of Arkansas Press, Fayetteville, Arkansas. 536 pp. [System Size/Dams]
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11. Rypel, A. L., & Mitchell, J. B. (2007). Summer nocturnal patterns in Freshwater Drum (*Aplodinotus grunniens*). American Midland Naturalist, 157(1), 230-234. [System Size]
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Longnose Gar (*Lepisosteus osseus*):

1. Alfaro, R. M., González, C. A., & Ferrara, A. M. (2008). Gar biology and culture: Status and prospects. Aquaculture Research, 39(7), 748-763.
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4. Ferrara A.M. (2001). Life-history strategy of Lepisosteidae: Implications for the conservation and management of alligator gar. PhD disseration, Auburn University, USA, 141pp. [Flow]
5. Haase, B. L. (1969). An ecological life history of the Long-nose Gar, *Lepisosteus osseus* (Linnaeus), in Lake Mendota and in several other lakes of southern Wisconsin. University of Wisconsin, Madison. PhD Thesis. 224 pp. [Flow/System Size/Dams]
6. Hoagstrom, C., Hayer, C.-A., Kral, J., Wall, S., & Berry, C. (2006). Rare and declining fishes of South Dakota: a river drainage scale perspective. Proc. South Dakota Acad. Sci., 85. [Substrate/Dams]
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9. Kelley, S. W. (2012). Age and Growth of Spawning Longnose Gar (*Lepisosteus osseus*) in A North Central Texas Reservoir. Western North American Naturalist, 72(1), 69–77. [System Size/Dams]
10. McGrath, P. E., Hilton, E. J., & Musick, J. A. (2012). Seasonal Distributions and Movements of Longnose Gar (*Lepisosteus osseus*) within the York River System, Virginia. Southeastern Naturalist, 11(3), 375–386.
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