USING MODELS AND ALTERNATIVE INFORMATION SOURCES TO INFORM A SPECIES STATUS ASSESSMENT FOR THE ROCKY SHINER (*NOTROPIS SUTTKUSI*)

by

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(Under the direction of Kelly F. Robinson and Brian J. Irwin)

ABSTRACT

Endangered Species Act (ESA) listing decisions can be guided by Species Status Assessments (SSA), which help describe a species' needs and life history, current condition, and potential future condition. When species are data limited it can be difficult to inform these documents, however alternative information sources and simple models can help describe what we currently know about a species and identify data gaps. The Rocky Shiner (*Notropis suttkusi*) is a data limited minnow in Oklahoma and Arkansas that was petitioned in 2010 for ESA listing and is scheduled for a Fiscal Year 2028 decision. To begin informing its SSA, I used species-specific information, surrogate species, and expert opinion to describe likely needs, life history, and influences for the species with simple visual and descriptive models. I also used this information paired with available spatial data and a Bayesian belief network to offer our understanding of the species' current condition.

INDEX WORDS: Species Status Assessment, Endangered Species Act, Data Limited, Modeling, Bayesian Belief Network

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DEDICATION

To my parents, who have always encouraged me, supported me, and believed in me.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The Endangered Species Act (ESA) recognizes that species have gone extinct in the past and that species today continue to face the threat of extinction (16 U.S.C. § 1531(a)). The purpose of the ESA is to conserve the ecosystems that support threatened and endangered species, while also promoting programs that conserve those species (16 U.S.C. § 1531(b)). Species Status Assessments (SSAs) were developed by the U.S. Fish and Wildlife Service (USFWS) to inform and guide ESA decisions for listing, recovery actions, status reviews, and critical habitat designations (USFWS 2016). Species Status Assessments include three components: 1) describing the species' life history and ecological needs, 2) assessing the species' current condition, and 3) forecasting the species' future condition and status (USFWS 2016; Smith et al. 2018). The SSA components are governed by the principles of resiliency, redundancy, and representation, known as the 3 Rs (USFWS 2016; Smith et al. 2018). Resiliency is the ability of a species to withstand stochastic disturbances, redundancy is the ability of a species to withstand catastrophic events, and representation is the ability of a species to adapt to a changing environment over time (USFWS 2016; Smith et al. 2018).

Overall, an SSA uses the best scientific information available and the 3 R's to conduct a biological risk assessment to anticipate how likely it is that a species can sustain its populations in the wild over time (i.e., species viability; USFWS 2016; Smith et al. 2018). Having adequate information on a species' abundance, distribution, genetics, population trends, and biological responses to negative influences is ideal for informing an SSA, but many species evaluated or petitioned for listing are data limited such that population trends or other basic information about the species may not be known (Woods and Morey 2008; Murphy and Weiland 2016; USFWS 2016; Smith et al. 2018; Dunn et al. 2024). For such species, conducting a preliminary evaluation that follows the SSA framework can aid in identifying important data gaps (USFWS 2016; Dunn et al. 2024).

Models are an important component of SSAs because they describe conceptual and quantitative relationships in order to both help decision makers understand the ecology of a species and identify important data gaps (Murphy and Weiland 2016; USFWS 2016; Dunn et al. 2024). Models used to inform SSAs can be complex, like stochastic simulation models, matrix projection models, and occupancy projection models (McGowan et al. 2017, 2020; Folt et al. 2022; Moore et al. 2022). More broadly, a model in an SSA can serve to organize information and make forecasts of potential future states, similar to how models are used to support decisions in other areas of natural-resource management (Irwin et al. 2011, 2024). When information on the focal species is limited, models may be informed by sources like expert opinion and surrogate species. Even so, relatively confident estimates for threats, habitat use, population sizes, distribution, and life history parameters are typically needed in order to make ecologically relevant conclusions for the focal species (Hernández-Camacho et al. 2015; McGowan et al. 2017, 2020; Long et al. 2019; Cummings et al. 2020; Folt et al. 2022; Moore et al. 2022). For example, Moore et al. (2022) used separate demographic parameter estimates, such as clutch size and survival, from both literature and expert opinion for the Wood Turtle (*Glyptemys insculpta*) across its life stages to create different matrix projection models for each of the two information sources. The authors found that literature estimates did not support a hypothesis for a shrinking, stable, or growing population, but that expert opinion produced results showing population decline, suggesting that the type of techniques used for expert elicitation in this context must be considered carefully. In both McGowan et al. (2017) and Folt et al. (2022) expert opinion was used to identify potentially important influences and stressors to the Sonoran Desert Tortoise (*Gopherus morafkai*) and Gopher Tortoise (*Gopherus polyphemus*), respectively. But in these studies, species-specific literature was already available for setting population estimates, demographic parameter estimates, and both the direction and magnitude of changes in these estimates, which allowed the authors to create complex population viability models. In another case, surrogate information was used for two populations of the California Sea Lion (*Zalophus californianus*), but this resulted in differences between observed and predicted trends for one of the populations of focus, which points to the possibility of choosing inappropriate surrogates (Hernández-Camacho et al. 2015).

When population-level information is lacking for a species, simple models in combination with expert opinion and surrogate species can still be informative to decision makers and can help organize what is known or unknown about a species (Murphy and Weiland 2016). Further, some simple models can be used to conduct sensitivity analyses, which can help identify the decision relevance of plausible values for various uncertainties (Murphy and Weiland 2016; Smith et al. 2018; Dunn et al. 2024). For example, simple modeling procedures like species needs tables, life history profiles, and influence diagrams have been used in SSAs for the Cape Fear Shiner (*Notropis mekistocholas*), Arkansas River Shiner (*Notropis girardi*), and Topeka Shiner (*Notropis topeka*) to aid in describing how these species interact with their environments (USFWS 2018a, 2018b, 2022). The Piebald Madtom (*Noturus gladiator*) has been identified as a species lacking requisite data for complex population modeling and has been used as an example for a simpler modeling procedure that requires less data and computational analysis for ESA decision making (Dunn et al. 2024). These types of simple models could be useful for data-limited species that require evaluation through an SSA, such as the Rocky Shiner (*Notropis suttkusi*).

The Rocky Shiner is a small minnow endemic to the Red River drainage in the Ouachita Uplands region of southeastern Oklahoma and southwestern Arkansas (Humphries and Cashner 1994). The Rocky Shiner has been identified as a Species of Greatest Conservation Need in both Oklahoma and Arkansas and was labeled as vulnerable by the American Fisheries Society's Endangered Species Committee (Jelks et al. 2008; Fowler and Anderson 2015; ODWC 2015). In 2010, the Rocky Shiner was petitioned for listing under the ESA by the Center for Biological Diversity (CBD) and in 2011, the USFWS confirmed in a 90-day finding that the species may warrant listing (CBS 2010; USFWS 2011). In 2023 and 2024, the Rocky Shiner was included on the USFWS's National Listing Workplan with an action plan for a 12-month finding on the petition to list the species, which is scheduled for Fiscal Year 2028. Much of the information commonly used or preferred in SSAs, such as up-to-date spatial and abundance data of known populations, details of a species' life history and life cycle, and responses to environmental and anthropogenic factors is not available for Rocky Shiner (Murphy and Weiland 2016; USFWS 2016; Smith et al. 2018).

The overarching goal of this thesis is to synthesize information sources about Rocky Shiner and provide the USFWS with a comprehensive initial assessment of the species across its range in Oklahoma and Arkansas. In Chapter 2, I consider multiple information sources, including species-specific published literature on Rocky Shiner, surrogate species, and expert opinion, to gain a better understanding of the species' needs, life history, and influences. Using this information, I construct species needs tables across the species' life stages, a life history profile using a Gantt chart, and an influence diagram to illustrate potential factors that affect the viability of Rocky Shiner populations. In Chapter 3, I combine available spatial and abundance data for Rocky Shiner as well as knowledge gained from Chapter 2 to assess the current condition of the species using a Bayesian belief network (BBN; Dunn et al. 2024). Using this model, I identify important data gaps and areas of possible future research that may be valuable to resolve. Also, I summarize potential future changes to the model that could be implemented once more is known about the effects of influential factors and stressors on Rocky Shiner specifically. Thus, this research could be updated as new research on Rocky Shiner reveals information that reflects a more biologically accurate representation of the species, both for its life history and condition.

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CHAPTER 2

USING SIMPLE MODELS TO ORGANIZE LIMITED INFORMATION ABOUT THE ROCKY SHINER (*NOTROPIS SUTTKUSI*)[1]

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ABSTRACT

Species Status Assessments (SSAs) are biological risk assessment documents that aid in Endangered Species Act (ESA) listing decisions, 5-year reviews, critical habitat designations, and recovery planning. These documents typically follow a framework that starts with describing the needs, life history, and anthropogenic and environmental influences on a species. The Rocky Shiner (*Notropis suttkusi*) is scheduled for a Fiscal Year 2028 ESA listing decision with an accompanying SSA document to inform it. This species has limited published literature available, so alternative information sources such as surrogate species and expert opinion are used in combination with available species-specific literature. From these information sources, three types of descriptive and visual models are informed: species needs tables, a life history profile Gantt chart, and an influence diagram. These models show the current understanding of how the Rocky Shiner interacts with its environment and provide details about where data gaps persist for the species.

INTRODUCTION

Under Section 4 of the Endangered Species Act (ESA), listing determinations are made based on five factors: negative changes to a species' habitat or range, overutilization of a species, disease or predation, inadequacy of regulatory mechanisms, and other negatively impactful natural or manmade factors (16 U.S.C. § 1533(a)(1)). Information on these five factors must come from the best available scientific and commercial data for the species of interest at the time of analysis (16 U.S.C. § 1533(b); Murphy and Weiland 2016). Section 4 ESA criteria can be met using information that describes a species' resource utilization, habitat, and stressors (CBD 2010; Murphy and Weiland 2016).

Species Status Assessments (SSAs) can be used to inform ESA listing decisions and consists of three stages: 1) describing the species' life history, ecological needs, and responses to environmental and anthropogenic factors, 2) assessing the species' current habitat and demographic conditions, and 3) making a forecast of potential trends of the species under different environmental and management scenarios to understand its status in the future (USFWS 2016a; Smith et al. 2018). Describing components during the first stage of the SSA process facilitates assessment during the subsequent stages of the document. Specific areas of emphasis for the first stage of SSAs typically are trophic niches, reproductive strategies, interactive behaviors, and habitat requirements that all contribute to growth, survival, and reproduction. These areas are then generally considered to influence how a species may respond to anthropogenic and environmental influences (USFWS 2016a; Smith et al. 2018). Conceptual ecological models that show relationships between species and their environment, as well as life cycle models that show variations in behaviors and needs across seasons and species life stages have been used for, and mentioned as best practices for, ESA decision making (Murphy and Weiland 2016). In the SSAs for the Cape Fear Shiner (*Notropis mekistocholas*), Arkansas River Shiner (*N. girardi*), and Topeka Shiner (*N. topeka*), biological and ecological information was presented using simple descriptive and visual models such as species needs tables, life history profiles in the form of Gantt charts, and influence diagrams (USFWS 2018a, b, 2022). However, species-specific data and information may not always be available to inform models; therefore, alternative information sources are sometimes considered to fill gaps when empirical information is lacking.

When developing an SSA, other potential sources of information include data on surrogate species and expert opinion. These sources are usually used for situations like those pertaining to the second and third stages of the SSA process for more complex models. This includes using surrogates and experts to inform probabilities of persistence of a species (Cummings et al. 2020; Fitzgerald et al. 2021), estimate demographic factors like fecundity, survival, and population growth (Wenger 2008; Banks et al. 2010; Hernández-Camacho et al. 2015; Moore et al. 2022), and inform distributions or occurrences of a species (Long et al. 2019; Crawford et al. 2020). However, even where data are lacking in the first stage of the SSA process, these two alternative information sources can still be useful and applied to inform simpler conceptual models to understand the system at hand (Murphy and Weiland 2014, 2016; USFWS 2016). For example, McGowan et al. (2017) and Folt et al. (2022), used expert opinion to identify potential threats or influences to their species of focus, respectively, the Sonoran Desert Tortoise (*Gopherus morafkai*) and the Gopher Tortoise (*G. polyphemus*). Expert judgements have also been used to identify ecological needs (McGowan et al. 2020) and create conceptual life cycle diagrams (McGowan et al. 2017) to understand and infer more complex relationships of the target species and its environment. Norman et al. (2022) used several surrogate species that had similar biology and ecology to a data limited listed species, the Cook Inlet Beluga (*Delphinapterus leucas*), to identify and prioritize possible threats. The best available science directive for the ESA, which refers to the most reliable information at a specific point in time, can be met using inferences from surrogate species and expert opinion (Murphy and Weiland 2014, 2016).

For this present study, my overarching goal is to synthesize information for a species to support an SSA document. Through communications with USFWS personnel, we identified the Rocky Shiner (*Notropis suttkusi*) as the focal species for this project. The Rocky Shiner is a small minnow species endemic to the Ouachita Uplands region of Oklahoma and Arkansas

(Humphries and Cashner 1994). This species was petitioned for ESA listing in 2010 and was confirmed in a 90-day finding by the USFWS that it may warrant listing (CBD 2010; USFWS 2011). The Rocky Shiner is currently scheduled for a Fiscal Year 2028 ESA listing decision, which will be informed by an SSA. The species is considered data limited, with few published sources on its life history, needs, and influences. The species is also considered to have a priority bin ranking of 4, meaning other species in higher ranked bins take priority for ESA listing determinations. Species that are known to be critically imperiled (i.e., bin 1), have strong data on their status (i.e., bin 2), or have emerging research underway (i.e., bin 3) include those species that have higher priority than the Rocky Shiner (USFWS 2016b).

The objective for my study is to improve the current understanding of the needs, life history, and influences for Rocky Shiner. To meet this objective, I consult species-specific literature and literature on possible surrogate species and seek expert opinion. From these three sources of information, I construct species needs tables for different life stages of the Rocky Shiner, a Gantt chart describing the Rocky Shiner's behavior temporally and ontogenetically, and an influence diagram showing possible mechanisms of cause-and-effect relationships with anthropogenic and environmental factors. These three simple models serve both to show where species-specific data gaps for Rocky Shiner exist and as a starting point for understanding the way in which the Rocky Shiner interacts with and can be influenced by its environment. As new information about the Rocky Shiner arises in the future, the models in this study can be updated to reflect a more biologically relevant view of the species that either confirms or refutes our current understanding. This research can also be used to determine the value of using surrogate species and expert opinion for filling information gaps for Rocky Shiner once more is known about the species itself.

METHODS

Information Sources

Three different sources of information are used in this study: species-specific literature, surrogate species, and expert opinion. The targeted gain of information from these three sources includes species needs, behaviors across life stages, and anthropogenic and environmental influences. Needs include types of physical habitat (i.e., in-stream structure and substrate), habitat quality (i.e., temperature, flow, and clarity), and food resources. Behaviors are those exhibited by the species for breeding, feeding, and sheltering (i.e., resource function) purposes across the species' life stages and at different times of the year. Influences are anthropogenic and environmental factors that could negatively affect the species, either through changes in habitat requirements or direct interactions with the species that affect resource functions or demographic needs.

Rocky Shiner Literature

Rocky Shiner-specific peer-reviewed and gray literature are used to obtain information on needs, behaviors, and influences for the species. The information sources used to inform these topics of interest include published journal articles, scholarly books, theses, dissertations, and government documents. A literature search was completed via Google Scholar in 2024 using the terms "Rocky Shiner" (n = 37 results) and "*Notropis suttkusi*" (n = 75 results). The literature was assessed and appropriate information regarding the Rocky Shiner's needs, behaviors, and influences was extracted. This included information from only nine literature sources.

Surrogate Species

Adequate surrogate species were selected using published genetic information available for Rocky Shiner, as provided from the species-specific literature search. These surrogates include Rosyface Shiner (*Notropis rubellus*) and Carmine Shiner (*N. percobromus*). Bielawski and Gold (2001) described the phylogenetic relationships between 16 species in the subgenus *Notropis* using maximum parsimony and maximum-likelihood analyses for cytochrome b gene sequences. Results from this study consistently supported the formation of a clade between the Rosyface Shiner and Rocky Shiner, suggesting a common ancestor between the two species (Bielawski and Gold 2001). Wood et al. (2002) conducted a phylogenetic analysis of 37 gene loci using allozyme data from 33 populations of the Rosyface Shiner species complex, which favored a hypothesis of a Rosyface Shiner, Carmine Shiner, and Rocky Shiner clade. Berendzen et al. (2008) used cytochrome b gene and allozyme datasets to examine the genetic variation and relationships among species in the Rosyface Shiner complex, resulting in a strongly monophyletic group including the reciprocally monophyletic groups of the Rocky Shiner, Rosyface Shiner, and Carmine Shiner. Because these genetic studies consistently reported relatedness and a common ancestor for the Rocky Shiner, Rosyface Shiner, and Carmine Shiner, these two latter species were chosen to serve as adequate surrogates of information where data gaps persisted for Rocky Shiner.

Like the Rocky Shiner literature search, Google Scholar was used to obtain information on the needs, behaviors, and influences for the Rosyface Shiner and Carmine Shiner in 2024. The terms "Rosyface Shiner," "*Notropis rubellus*," "Carmine Shiner," and "*Notropis percobromus*" were used in Google Scholar, resulting in both peer-reviewed and gray literature (respectively for terms: n = 1,100, n = 1,340, n = 224, n = 289). This includes, like the Rocky Shiner, published journal articles, scholarly books, theses, dissertations, and government documents. The available literature was sorted and information about each species' needs, behaviors, and influences was extracted. This information came from a total of 15 sources for the Rosyface Shiner and 19 sources for the Carmine Shiner.

Expert Opinion

Expert opinions are used as a source of information via input from a rapid prototyping workshop (RPW) hosted by the USFWS on August 1 and 2, 2024. This was a virtual workshop with 16 experts in attendance from a variety of state agencies, federal agencies, and academic institutions. Attendee affiliations include USFWS, U.S. Geological Survey, Arkansas Game and Fish Commission, Arkansas Natural Heritage, Arkansas Department of Transportation, Oklahoma Department of Wildlife Conservation, U.S. Forest Service - Ouachita National Forest, Arkansas Tech University, University of Arkansas, and University of Central Arkansas. The experts were briefed on the SSA framework and its structure, along with background information on Rocky Shiner by the Rocky Shiner SSA manager, Jessica Gilbert, and species lead, Dustin Booth. There were three breakout sessions that pertained to the three model objectives in this study, during which sessions the experts were split into two groups. In one breakout session, the experts reviewed and suggested changes to a preliminary Rocky Shiner life cycle diagram and life history profile in the form of a Gantt chart. In this same breakout session, experts were given blank resources needs tables and identified ecological requirements for the Rocky Shiner across life stages. In a second breakout session, experts identified important habitat and demographic needs, and conceptual models were developed to connect habitat qualities to demographic needs for resiliency. In a third breakout session, experts identified major anthropogenic and environmental influences using cause-and-effect tables to then add to the previously created conceptual model to create an influence diagram. The time spent in each of these workshop sessions ranged from 15 to 45 minutes.

Informed Models

I construct three descriptive and visual models to display the current understanding of the Rocky Shiner. These models include species needs tables, a life history profile using a Gantt chart, and an influence diagram.

Species Needs Tables

Species needs tables are assembled for the Rocky Shiner to characterize what conditions are likely needed by the species to promote functions of breeding, feeding, and sheltering by life stage. These conditions include aspects of water quality, habitat type, and food resources. These needs tables specify the resource or circumstance needed to complete the life stage, the function of that resource for the species (i.e., sheltering, feeding, or breeding), what information source was used (i.e., Rocky Shiner literature, surrogate species, or expert opinion), and the citation for the information presented. The life stages used for each table include eggs, larvae, juveniles, and adults.

Life History Profile Gantt Chart

Life history information is synthesized into a Gantt chart. In this chart, likely behaviors exhibited by Rocky Shiner are organized by life stage and month throughout a given year.

Behaviors described in the Gantt chart include those that each specific life stage likely exhibit at certain points during the year, such as breeding, feeding, and sheltering.

Influence Diagram

Using knowledge gained from the three information sources, the possible anthropogenic and environmental factors that may influence Rocky Shiner needs and behaviors are identified and then mechanisms by which those factors may affect Rocky Shiner are represented in an influence diagram. This diagram incorporates several levels of influence from anthropogenic and environmental sources: stressors in the form of changes in environmental conditions, species habitat requirements that may be affected by stressors, resource functions (i.e., sheltering, feeding, or breeding) that the habitat requirements serve for the species, and demographic needs that are influenced by resource functions (i.e., connectivity, abundance, growth, and survival). The flow of influence initially starts from anthropogenetic and environmental sources and connects in a downward trend to stressors, habitat needs, resource functions, demographic needs, and finally population resiliency.

The information presented in each of these categories is represented via boxes that are connected to each other by arrows. Arrows represent either causal or negative influences from one box to another. Causal influences represent a causal change in or contribution from one subject to another, while negative influences represent a negative change in one subject (i.e., habitat needs, resource functions, or demographic needs) by another (i.e., sources and stressors), specifically being a negative change that would affect Rocky Shiner. The outcome of interest in the influence diagram is Rocky Shiner resiliency, which is the ability of a species to withstand stochastic disturbances (USFWS 2016a; Smith et al. 2018). The influence diagram itself is assumed to represent an individual population, in which influential sources could affect population dynamics and health if present by affecting habitat and demographic needs, which help to define the level of resilience for that population. The influence diagram created in this study is modeled after those used in the SSAs for the Cape Fear Shiner and Arkansas River Shiner (USFWS 2018a, 2022).

RESULTS

Species Needs Tables

Eggs

Only surrogate species and expert opinion are used to inform the ecological requirements for the egg life stage of Rocky Shiner (Table 2.1) because species-specific Rocky Shiner literature describing the needs of eggs is not currently available.

Rocky Shiner eggs likely are deposited in shallow waters over or near riffles as observed in both Rosyface Shiner and Carmine Shiner, but eggs may also occur in pools like observed for some populations of these surrogates from Minnesota and Illinois (Raney 1940; Reed 1957a; Miller 1964; Eddy and Underhill 1974; Smith 1979; Trautman 1981; Baldwin 1983; Vives 1990; Macnaughton et al, 2020). Within or near riffles, eggs may occur in shallow depressions of substrate, which have been used as nests by Rosyface Shiners (Pfeiffer, 1955; Baldwin, 1983). Rosyface Shiner also commonly uses nests of other species to deposit eggs, such as nests of River Chub (*Nocomis micropogon*), Hornyhead Chub (*Nocomis biguttatus*), and Cutlips Minnow (*Exoglossum maxillingua*; Raney 1940; Pfeiffer 1955; Reed 1957a; Miller 1964; Trautman 1981; Baldwin 1983; Vives 1990; Pendleton et al. 2012). Carmine Shiner has been observed to spawn over other species' nests as well, including those of Hornyhead Chub, Chestnut Lamprey

(*Ichthyomyzon castaneus*), Central Stoneroller (*Campostoma anomalum*), Longnose Gar (*Lepisosteus osseus*), and redhorses (*Moxostoma* spp.; Pfleiger 1975). This may indicate that Rocky Shiner eggs may also occur within nests of other species in its own range in Oklahoma and Arkansas, similar to those species whose nests are used by Rocky Shiner surrogates.

Whether in depressions or nests within or near riffles, Rosyface Shiner eggs have been observed over gravel substrate (Raney 1940; Pfeiffer 1955; Reed 1957a; Trautman 1981; Baldwin 1983; Vives 1990; Etnier and Starnes 1993), whereas Carmine Shiner eggs have occurred over both gravel and rubble substrates in riffles and pools (Cross 1967; Eddy and Underhill 1974; Pfleiger 1975; Cross and Collins 1995). These substrates provide adequate interstitial spaces for eggs to settle (Pfeiffer 1955; Pfleiger 1975), which was also mentioned by experts in the RPW to be important for sheltering purposes. Both surrogate species deposit eggs over clean, silt-free substrate (Reed 1957a; Cross 1967; Smith 1979; Baldwin 1983; Vives 1990; Etnier and Starnes 1993; Cross and Collins 1995). Experts from the RPW mentioned that clean substrate and clean interstitial spaces are important for Rocky Shiner at the egg life stage because the presence of sediment on substrate can lead to reduced hatching success (Auld and Schubel 1978). Rosyface Shiner has been observed to spawn in portions of streams with faster flows, likely mitigating levels and effects of sediment loads (Baldwin 1983; Vives 1990).

On the first day of spawning for Rosyface Shiner, water temperatures have ranged from 20 to 24 °C (Pfeiffer 1955; Reed 1957a; Miller 1964; Baldwin 1983). For both Rosyface Shiner and Carmine Shiner, maximum temperatures recorded at the end of and during spawning have ranged from to 21 to 30 °C (Pfeiffer 1955; Baldwin 1983; Watkinson and Sawatzky 2013). These observations may suggest which temperatures Rocky Shiner eggs could be observed at across the species' range.

Larvae

Similar to the egg life stage, the needs for the Rocky Shiner larval life stage are only informed by surrogates and expert opinion due to a lack of literature available for the species of focus (Table 2.2). Only Rosyface Shiner is used as a surrogate for this life stage because literature is not available on larval Carmine Shiners currently.

After emerging from eggs, larval Rosyface Shiners have been observed to bury into the interstices of sand and gravel substrate (Pfeiffer 1955). Experts from the RPW mentioned that like eggs, clean interstitial spaces free of sediment are also likely important for larval Rocky Shiners, as sediment can coat the gills of larvae when present. A diet study of larval Rosyface Shiner revealed that this species at this stage largely consume algal masses at first but show a trend shifting towards a more insectivorous diet at the end of the life stage (Timbrook 1983). This transition towards insectivory included larval Rosyface Shiners initially starting to consume zooplankton and some dipteran larvae, then benthic arthropods, and then finally consuming mostly dipteran larvae along with a wider range of zooplankton and oligochaetes at the end of the larval stage (Timbrook 1983). In the RPW, experts mentioned that algae, diatoms, and zooplankton could all likely be food items used by larval Rocky Shiners.

Juveniles

Rocky Shiner juvenile ecological needs are only informed using surrogate species and expert opinion because there is currently a lack of information available on Rocky Shiner for this life stage (Table 2.3).

Juvenile Carmine Shiners have been found to be associated with reaches that have higher proportions of sand and gravel and lower proportions of silt (Carr et al. 2015). Stream reaches with lower turbidity levels have yielded more captures of juvenile Rosyface Shiners than those with higher levels of turbidity (Baldwin 1983). This suggests that juvenile Rocky Shiners may also be more associated with sand and gravel substrate and less associated with silted and turbid areas. Juvenile Carmine Shiners have been associated with lower gradient, more sinuous stream reaches that promote pool habitat formation, and juvenile Rosyface Shiners have been largely captured in pools (Baldwin 1983; Carr et al. 2015). Experts from the RPW suggested that deep pools are important for sheltering purposes for juvenile Rocky Shiners in terms of acting as thermal refuges. Experts from the RPW mentioned that in-stream vegetation such as Water Willow (*Justicia americana*) may also be important for sheltering purposes for juveniles.

Juvenile Rosyface Shiners have been observed to primarily consume algae and diatoms (65.5% of stomach content) and less so to consume insect larvae (28.8% of stomach content; Reed 1957b). Juvenile Carmine Shiners have been observed to consume insects such as coleopterans, dipterans, hemipterans, and hymenopterans as well as arachnids (Enders et al. 2020). Experts from the RPW suggested that zooplankton may also be an important diet item for juvenile Rocky Shiners.

Adults

Information about the Rocky Shiner adult life stage is available through all three information sources, including Rocky Shiner-specific literature, surrogate species, and expert opinion (Table 2.4). For this life stage, all three resource functions, including sheltering, feeding, and breeding, are informed.

Adult Rocky Shiners have been largely associated with and found near riffle habitats at shallow depths of 0.5 to 1.0 m (Humphries and Cashner 1994; Pratt 2000; Zbinden et al. 2021). Rosyface Shiners have also been found in or around riffles (Reed 1957b; Miller 1964; Lee et al. 1980) and Carmine Shiners have been found in both pools and riffles at shallow depths (Pflieger 1975; Smith 1979; Becker 1983; Cross and Collins 1995; Watkinson and Sawatzky 2013; Carr et al. 2015; Macnaughton et al. 2020). Adult Rocky Shiners occur over gravel, rubble, and cobble substrates with moderate water flows averaging from 0.19 to 0.29 m/s across the species' range (Humphries and Cashner 1994; Pratt 2000; Zbinden et al. 2021). Adult Rosyface Shiners and Carmine Shiners are usually also associated with clean gravel, rubble, and cobble substrates (Harlan and Speaker 1956; Reed 1957b; Pfleiger 1975; Smith 1979; Lee et al. 1980; Trautman 1981; Becker 1983; Watkinson and Sawatzky 2013). Rosyface Shiner and Carmine Shiner also occur in moderate to fast streams with permanent flow (Miller 1964; Pfleiger 1975; Smith 1979; Lee et al. 1980; Becker 1983; Macnaughton et al. 2020). The streams that Rocky Shiner occupy are generally clear and have moderate to high gradients (Humphries and Cashner 1994). Rosyface Shiner and Carmine Shiner have been observed to occupy clear streams with moderate to high gradients as well (Harlan and Speaker 1956; Cross 1967; Pfleiger 1975; Smith 1979; Trautman 1980; Becker 1983; Cross and Collins 1995; Watkinson and Sawatzky 2013; Carr et al. 2015).

Rocky Shiner has been found in areas with deep pools and Pratt (2000) suggested that the species may utilize pools deeper than 2 m as thermal refugia during the spring and summer. Experts from the RPW also suggested that Rocky Shiner adults may use deep pools as thermal refugia during the spawning season for sheltering purposes. Rosyface Shiner has been observed to exhibit this behavior, but during the winter from November to March, by moving to deeper pools, eddies, and riffles for thermal refugia (Reed 1957b; Trautman 1981). Experts from the RPW suggested that Rocky Shiner as adults may use Water Willow for sheltering purposes as well.

Across its range, Rocky Shiner have been found in temperatures as low as 6 °C in December and as high as 31 °C in August (Pratt, 2000). Matthews (1987) tested temperature tolerances of several *Notropis* species from Oklahoma and Arkansas, including Rocky Shiner, which was considered the Rosyface Shiner at the time, and found that Rocky Shiner exhibited a critical thermal maximum (CTM) via loss of equilibrium at a mean temperature of 34.56 °C. Carmine Shiner in its northern range has exhibited a temperature preference of 23.6 to 25.2 °C and a maximum avoidance temperature of 28.6 °C, even though temperatures do reach up to 30 °C in its northern range in the summer (Stol et al. 2013; Enders et al. 2019). Distributions of Rosyface Shiner has been found to be limited by temperature, with individuals avoiding temperatures that exceed 27.2 °C in Virginia (Stauffer 1975).

In a stomach content analysis for Rocky Shiner in Oklahoma, Hargrave (2005) found that the species is omnivorous, but primarily consumes terrestrial insects. In Arkansas, Rocky Shiner was found to consume adult dipterans, coleopterans, and odonates as well as some larval forms of insects (Robison and Buchanan 2020). Rosyface Shiner and Carmine Shiner adults have been observed to mostly consume both aquatic and terrestrial insects as well as some algae and diatoms (Pfeiffer 1955; Reed 1957b; Becker 1983; Hoover 1988; Watkinson and Sawatzky 2013; Enders et al. 2020).

Due to the paucity of information available on the Rocky Shiner's reproductive behavior or needs, information about surrogate species and expert opinion were used to inform expectations about needs for the breeding resource function of adults. Where the resource function “breeding” was specified for an ecological resource needed by adult Rocky Shiners in Table 2.4, both information sources and descriptions of why these resources are important to adults can be linked back to the egg life stage description above and in Table 2.1.

<u>Life History Profile Gantt Chart</u>

The life history profile of the Rocky Shiner is informed using all three information sources: Rocky Shiner-specific literature, surrogates, and expert opinion. An initial Gantt chart used in the August 2024 RPW, shown in Table 2.5, was reviewed by the experts in attendance, resulting in suggested changes that are discussed below. Using these expert opinions and literature gathered after the workshop, the representation of the Rocky Shiner’s species life history profile was updated (Table 2.6).

Adults

I did not find conclusive information regarding the frequency of spawning events for Rocky Shiner. However, in the RPW, experts questioned whether Rocky Shiners may spawn multiple times in a breeding season or if spawning was a single inconsistent event, in terms of timing, for individuals across its range. Carmine Shiner has been reported to be repeat spawners in its northern range in Canada, but these events have not been described in detail (Watkinson and Sawatzky 2013; Macnaughton et al. 2020). Rosyface Shiner has been observed to engage in breeding behaviors that lasted six days where groups of individuals moved to spawn over nests created by other species and then moved to rest in pools multiple times per day (Pfeiffer 1955; Reed 1957a). Groups of Rosyface Shiners have also exhibited nest fidelity, with individuals occurring over the same Cutlips Minnow or River Chub nest across multiple days (Miller 1964).

Rosyface Shiner, though in a short amount of time, displays repeat spawning behavior. Pratt (2000) studied ova stages in Rocky Shiner females in two rivers across the species' range and reported that multiple ova stages were present at the same time during the breeding season, but did not specify if these multiple stages were present in individual females rather than across individuals. However, with the evidence presented for its surrogates, the Rocky Shiner likely could be a repeat spawner as well. Based on the evidence presented, we conclude that repeat spawning within the duration of around six days could be possible during the species' breeding season (Table 2.6). Additionally, the breeding season for the Rocky Shiner across its range begins in late March and ends in mid-August (Pratt 2000). Rocky Shiner likely has a lifespan of around three years, like Rosyface Shiner and Carmine Shiner (Pfieffer 1955; Reed 1957b; Lee et al. 1980; Watkinson and Sawatzky 2013) and likely matures at around age 1 (Pfieffer 1955; Watkinson and Sawatzky 2013; Macnaughton et al. 2020).

Adult foraging behaviors was indicated by experts from the RPW as important topic for inclusion in the species' life history profile, as the inclusion of these behaviors was absent from the initial Gantt chart in Table 2.5. During their spawning season, Rosyface Shiners and Carmine Shiners were observed to consume much less food, with the majority of individuals' stomachs being empty (Pfeiffer 1955; Reed 1957b; Becker 1983). Within the same month before spawning began, Rosyface Shiners were found to increase foraging and feeding (Reed 1957b). Carmine Shiner in the Ozarks also had seasonal peaks in feeding, consuming more prey in late summer and fall as well as in early spring (Hoover 1988; Enders et al. 2020). From gut content analysis on 10 Rocky Shiners from the Little River in July, during the breeding season, mostly insect remains were found in stomachs (Robison and Buchanan 2020). These studies suggest that foraging likely takes place year-round for Rocky Shiner, but that peak foraging may occur at the beginning of the spawning season, such as in March and April, as well as at the end and right after the spawning season, such as in August and September (Table 2.6). As described in Table 2.4, insects are the likely prey items consumed by adult Rocky Shiners.

Rocky Shiner may exhibit behaviors of using refugia and is known to occupy similar habitat year-round. Sheltering behaviors, such using refugia and inhabiting year-round habitat, were not included in the initial life-history table (Table 2.5), which prompted experts to suggest inclusion of these non-breeding behaviors for adults. During the winter months in Pennsylvania and Ohio, Rosyface Shiner has been observed to move to deep pools, eddies, and riffles for thermal refugia (Reed 1957b; Trautman 1981). Pratt (2000) suggested that like Rosyface Shiner, Rocky Shiner likely uses deep pools for the same purpose, as refugia, but in late spring and summer months. In addition to the use of refuge habitat, Rocky Shiner has been reported to occur in streams with riffles and pools (Humphries and Cashner 1994; Pratt 2000; Zbinden et al. 2021), where it likely remains year-round (Table 2.6).

Eggs

Experts agreed that the incubation process for Rocky Shiner eggs was relatively quick (Table 2.5). Rosyface Shiner eggs have been reported to incubate for 57 to 59 hours, around 2.5 days, before larvae emerged (Table 2.6; Reed 1958). And Rocky Shiner eggs likely occupy interstitial spaces of substrate (Pfeiffer 1955; Pfleiger 1975).

Larvae

Experts agreed that Rocky Shiner larvae use interstitial spaces for habitat (Table 2.5). Rosyface Shiner larvae have been observed to bury into the interstices of substrate after emerging from eggs (Pfeiffer 1955). Experts also mentioned that larval Rocky Shiner likely drift downstream throughout the breeding season and may be of interest to include in the life history profile for this life stage. Three days after numerous larval Rosyface Shiners were observed to have emerged from eggs, only two were obtained from the same place, suggesting they had moved to a different part of the stream, likely downstream (Pfeiffer, 1955). Larval Rosyface Shiner foraging behaviors change throughout this life stage, showing a transition from algae to insects, zooplankton, arthropods, and oligochaetes (Timbrook 1983). The habitat use, drifting, and feeding behaviors were represented in Table 2.6 as occurring during the breeding season of adults because larvae likely quickly emerge from eggs and likely last in this stage for a little more than a month (Pfeiffer 1955; Pfleiger 1975; Timbrook 1983).

Juveniles

Knowledge from surrogate species, as well as expert opinion, suggest that after occupying interstitial spaces as larvae, Rocky Shiner juveniles may move to and occupy pool habitats (Table 2.6). For example, Carr et al. (2015) determined that Carmine Shiner juveniles occupied more sinuous, lower gradient stream reaches with more pool habitat formations and Baldwin (1983) was able to successfully capture juvenile Rosyface Shiners only in pool habitats. This behavior of juveniles occupying pools was shown in Table 2.6 as occurring across the entire year, as this transition would occur at some time during the juvenile stage, which the species is likely in for around a year before maturing (Pfieffer 1955; Watkinson and Sawatzky 2013; Macnaughton et al. 2020).

Experts agreed that the transition to insectivory is an identifying behavior for Rocky Shiner juveniles. As reported for juvenile Rosyface Shiners and Carmine Shiners, diets at this life stage consist of a combination of algae, diatoms, and insects (Reed 1957b; Enders et al. 2020). The use of and transition from algae to insects for the Rocky Shiner at the juvenile life stage likely occurs gradually throughout the whole life stage (Table 2.6).

Influence Diagram

The anthropogenic and environmental influential sources that experts mentioned for Rocky Shiner are climate change, impoundments and reservoirs, roads and road barriers, land use, and mining operations. The stressors induced by these influential sources include changes in connectivity, temperature, flow, turbidity, pollution and nutrients, and predation. Below, descriptions of the stressors induced by the influential sources are explained in terms of how they negatively affect species needs and respective resource functions mentioned in Tables 2.1 – 2.4 and how these sources also affect demographic needs as described by USFWS (2016a) and Smith et al. (2018), such as connectivity, abundance, growth, and survival, that are important to resiliency. The sources, stressors, habitat effects, and population-level effects are supported below in text by Rocky Shiner-specific literature, surrogate information, habitat literature, and studies describing individual effects from stressors on a variety of species. The visual representation of the descriptions below is shown in the influence diagram for the Rocky Shiner in Figure 2.1.

Connectivity

Rocky Shiner population connectivity may be impeded by impoundments and reservoirs, road-related barriers like culverts, and dewatering from climate change. Carmine Shiner has disappeared from and declined in streams where impoundment structures and reservoirs have been built, which has caused both stream obstruction and fragmentation (Smith, 1979; Cross and Collins, 1995; Falke and Gido 2006; Gido et al. 2010). Restricted movement because of fragmentation can cause restricted gene flow and genetic isolation in small bodied leuciscids, which can create genetically distinct clusters (Franssen 2012; Fluker et al. 2014). This could lead to inbreeding depression and reduced fitness in species where fragmentation occurs across their range (Zarri et al. 2022). Rocky Shiner commonly occurs in streams where there are impoundment structures and road related barriers, which may cause fragmentation through impaired movement abilities. The Rocky Shiner's range also may encounter more drought related events induced by climate change in the future, which could inhibit the species' ability to access habitat and other individuals if stream drying occurs (Bertrand and McPherson 2018).

Dams and reservoirs are barriers to movement and can prevent dispersal to and recolonization of areas with suitable habitat and therefore can fragment a once whole population (Winston et al. 1991; Mammoliti 2002). These fragmented populations can become vulnerable to even small, localized changes in climate conditions, perhaps causing extirpation of upstream populations due to spawning failure or mortality (Winston et al. 1991; Mammoliti 2002; Matthews and Marsh-Matthews 2003). Also, small fish upstream of reservoirs may be forced downstream into reservoirs due to stream drying, which increases exposure to predatory fish and decreases the ability to recolonize back upstream (Matthews and Marsh-Matthews, 2003). Road crossings, specifically when paired with structures like culverts that can constrict flow and act as bi-directional barriers, can cause impaired movement abilities of fish and fragmented populations (Warren and Pardew 1998; Matthews and Marsh-Matthews 2003). Climate change induced drought conditions in the Red River basin could also cause a loss of connectivity, especially if reaches are fully dewatered (Stanley et al. 1997; Magoulick and Kobza 2003; Bertrand and McPherson 2018).

Temperature

Climate change will likely have the biggest negative effect through increased water temperatures in the Rocky Shiner's range. Spatiotemporal trends in Rosyface Shiner distributions have been attributed to temperature, with individuals avoiding temperatures exceeding 27.2 °C in Virginia (Stauffer et al. 1975). Pandit et al. (2017) found that the distribution of Carmine Shiner across its range was predicted by summer temperatures and temperature seasonality. They suggested that the species in the future faces extirpations in its southern range because of decreased habitat suitability from climate change effects. Gill et al. (2018, 2020) used species distribution models to predict the potential future distributions of species in the Red River basin, including Rocky Shiner, under multiple climate scenarios and determined that the Rocky Shiner's distribution was most influenced by the mean temperature of the driest quarter and that the species showed large range contractions across all scenarios in the future.

Climate change indued droughts are possible throughout the Red River basin in the future and could increase stream temperatures, which has already been observed in rivers in the Rocky Shiner's range (Atkinson et al. 2014; Mosley 2015; Bertrand and McPherson 2018; DuBose et al. 2019). Carmine Shiner has been described as being likely unable to withstand high temperatures and faces significant increases in metabolic rates with increased temperatures, which decreases energy availability for both growth and reproduction (Smith 1979; Macnaughton et al. 2019). Matthews (1987) found that the Rocky Shiner's CTM was 34.56 °C, however rivers that the species is known to occupy, such as the Washita, Red, Kiamichi, Little, and Mountain Fork

Rivers, have been reported to exceed this temperature, some reaching over 40 °C (Zimmerman and Matthews 1990; Matthews et al. 2005; Atkinson et al. 2014). Also, decreased survival was observed in response to increased temperatures, in experimental streams, that approached or exceeded the CTM of three minnow species, the Red Shiner (*Cyprinella lutrensis*), Blacktail Shiner (*Cyprinella venusta*), and Central Stoneroller (*Campostoma anomalum*), that had similar CTM to the Rocky Shiner (Dekar et al. 2014).

With daily minimum and maximum temperatures predicted to increase by up to 7 °C by the end of the century in the Red River basin (Bertrand and McPherson 2019), and with temperatures already having been reported to exceed the Rocky Shiner's CTM in inhabited rivers (Matthews and Zimmerman 1990; Matthews et al. 2005; Atkinson et al. 2014), the species could face reductions in reproduction, growth, and survival. Aquatic species in the Southern Great Plains could also face the threat of extinction with possible increased future temperatures because in order to migrate away from these potentially harsh conditions, fish such as the Rocky Shiner would have to move south into the Red River, then to the Mississippi River Mainstem, and finally move northward, which is not only energetically demanding, but also impeded by the presence of many barriers (Matthews and Zimmerman 1990).

Flow

Climate change, impoundments and reservoirs, roads and road-related barriers, and land use can all potentially negatively affect flow conditions preferred by Rocky Shiner. Rocky Shiner and its surrogates are most commonly found in streams with moderate to high velocity flows (Table 2.4). Carmine Shiner in Kansas has declined and disappeared from areas where moderate and dramatic reductions in flow, regarding discharge, have occurred due to water use and impoundments, which has caused lotic conditions to exist in streams and rivers (Gido et al., 2010). Carmine Shiner has also been observed to use a wider range of habitats as water flows have increased and exhibit constricted habitat use with decreased water flows (Macnaughton et al. 2020). Humphries and Cashner (1994) stated that impoundments could threaten Rocky Shiner by degrading habitat that is commonly used by gravel and riffle dependent species. The Arkansas Wildlife Action plan by the Arkansas Game and Fish Commission (AGFC) identified hydrological alteration from water diversion as a threat to Rocky Shiner as well (Fowler and Anderson 2015).

Climate change is predicted to change patterns in precipitation and drought, and therefore flow, throughout the Red River basin, with a decrease in precipitation and an increase in droughts expected in western and central portions and an increase in precipitation expected in the eastern portion (Bertrand and McPherson 2018). During drought conditions in the Rocky Shiner's range, water flows have been observed to decrease, causing low or no flow with dried riffle habitat and shallow isolated pools (Galbraith et al. 2010; Atkinson et al. 2014). Though periodic droughts are common to the cyclical norms observed in the southern plains of the U.S., these conditions still have the potential to negatively affect species in these water systems especially when paired with poor water management practices such as changes in discharge from reservoirs (Matthews et al. 2005). Water releases by a reservoir in the Rocky Shiner's range have been observed to decrease during drought and already low-flow conditions, exacerbating negative effects of these conditions (Galbraith et al. 2010). Even without drought conditions, dam operations can eliminate or reduce natural periodic flows that maintain habitats downstream (Collier et al. 1996; Mammoliti 2002; Graf 2006; Poff et al. 2007). Maintenance of minimum flow values, which are environmental flows that set a baseline for streams, are important for maintaining aquatic habitat and are beneficial in larger streams to provide thermal refugia (Musselman 2014). Musselman (2014) analyzed changes in in-stream habitat in response to decreasing discharge in three streams in the Illinois River catchment in Oklahoma and found that backwaters, riffles, and runs had the greatest loss in areas as discharge decreased. Riffle habitat is likely important for Rocky Shiner and could be negatively affected by both climate change and water management associated with impoundment structures (Tables 2.1-2.4). Dams and reservoirs can also prolong increased flows, which can reduce species more adapted to intermittent conditions and cause erosion and deposition of sediments downstream (Collier et al. 1996; Mammoliti 2002).

Land use can also affect flow in rivers and streams. Roads, agriculture, urbanization, and forestry land use can all increase the amount of runoff into streams, due to the presence of impervious surfaces, which increases the frequency and intensity of high flows (Lenat and Crawford 1994; Jones et al. 2000).

When the flow regime of a stream is disrupted, it may negatively affect reproduction in fish that are adapted to certain conditions. Craven et al. (2010) reported that reproductive success in broadcast spawners, which included species that deposit eggs over substrate like Rocky Shiner, was negatively related to short-term high discharges that occurred during spawning. This is likely due to the fact that high flows occurred during and not before spawning events, meaning that eggs may have been exposed to sediment while incubating, which can decrease the success of hatching (Auld and Schubel 1978). For fish that likely use clean substrate as visual cues for spawning, like Rosyface Shiner and possibly Rocky Shiner, flows to produce this quality of substrate are likely needed prior to spawning (Reed 1957a). During extreme high flow conditions in a tributary of the Red River in Oklahoma, larval leuciscids were found to be susceptible to downstream displacement, with individuals found dead and physically damaged during and after high flow conditions (Harvey 1987). During low flow conditions, fish can become entrapped or stranded in pools, which can lead to death from thermal and oxygen stress and predation from predatory fish (Becker et al. 1981; Magoulick and Kobza 2003). Food resources, such as aquatic insects in riffles, have been shown to dramatically decrease in abundance, density, and biomass when low flow conditions exist (Schlosser and Ebel 1989; Walters and Post 2011). Both extreme high and low flows could negatively affect the Rocky Shiner via the mechanisms mentioned above, such as reproduction, survival, and feeding.

Turbidity, Sediment, Silt

A change in sediment loads in streams can be attributed to changes in flow from climate change, impoundment structures and reservoirs, roads and road barriers, and land use. Also, mining operations can directly increase turbidity, sediment, and silt in streams. A population of Rosyface Shiners in the Cumberland River in Tennessee was described to be at risk of extirpation from effects of surface mining activities (Etnier and Starnes 1993). Humphries and Cashner (1994) suggested that gravel mining operations could negatively affect Rocky Shiner because of the degradation of gravel and riffle habitat that are important to the species. Trautman (1981) reported decreased abundances and even extirpations of Rosyface Shiner in Ohio from areas with increased turbidity and siltation because the species is intolerant to these conditions. In tributaries of the Kansas River in Kansas, dams caused downstream habitat to become muddy and sandy, and therefore less suitable for Carmine Shiner (Cross and Collins 1995). Carmine Shiner are intolerant to turbidity and siltation, having been observed to disappear from streams with excessive siltation, occur less often in turbid streams, and occur in smaller numbers in silted streams (Harlan and Speaker 1956; Smith 1979; Hoagstrom et al. 2006). Habitat modification and destruction that causes changes in turbidity and siltation are thought to negatively affect eggs, larvae, food resources, and refuge habitat for Carmine Shiner (Watkinson and Sawatzsky 2013; Cross 1967). The AGFC reported that sedimentation from forest conversion and road construction could be a threat to Rocky Shiner (Fowler and Anderson, 2015). If Rocky Shiner encounters higher levels of turbidity, sediment, and silt, then the species may face negative effects on reproduction, survival, population growth, and feeding.

During conditions of low flow, like in the summer and during droughts, a large volume of fine sediment and decaying organic matter can settle onto the riverbed (Wood and Armitage 1997). In addition, when impoundments are poorly managed via low velocity discharges, sedimentation has been observed in downstream reaches that would normally be flushed away with constant or higher flows, leading to fine sediment deposition in the interstices of gravel substrate (Wood and Armitage 1997; Mammoliti 2002). A potential nonpoint source of pollution for the Lower Little River watershed includes streambank erosion due to reservoir management where banks of streams can often endure periods of high and low water conditions (FTN Associates, Ltd 2016).

During storm events that induce high flows in streams, suspended-sediment concentrations are greater in urban areas compared to forested and agricultural areas (Lenat and Crawford 1994). During low to moderate flow periods, sediment concentrations in streams have been greater at agricultural sites compared to both forested and urban areas (Lenat and Crawford, 1994). Vaughn (1997) observed siltation in the Blue River in Oklahoma due to riparian clearing and agriculture, which have led to the extirpation of mussels in this area. Riparian vegetation had been cut back to the riverbank, the soil was tilled up to the river's edge, and cattle grazed up to the river's edge, all causing the bottom of the river to be covered in silt (Vaughn 1997).

Forestry operations can introduce large amounts of sediment through the removal of trees, which can expose soil and sediment that had been previously stabilized by the trees and their roots (Wood and Armitage 1997). In the Little River, where there is an active timber industry, there have been observations of increased siltation in the past 30 years prior to 2005 (Matthews et al. 2005; Vaughn et al. 2023). Unpaved roads have also been identified as a possible source of turbidity in the Lower Little River watershed including country roads, National Forest roads and trails, and roads associated with the timber industry (FTN Associates, Ltd 2016). Finally, Galbraith et al. (2010) studied mussels in the Kiamichi River, in which the Rocky Shiner occurs, and observed siltation in the river due to use of terrestrial vehicles in shallow areas.

In three Ozark gravel bed streams that had gravel mining operations present, turbidity was significantly higher in disturbed and downstream reaches, transport of fine particulates from riffles to pools decreased, and silt-sensitive species were less abundant downstream of operations (Brown et al. 1998). In the Rocky Shiner's range, Galbraith et al. (2010) observed siltation in the Kiamichi River from gravel mining operations.

The flushing of sediments prior to spawning may be important for Rocky Shiner because clean interstitial spaces are likely needed for breeding, hatching success, and the survival of larvae (Tables 2.1, 2.4; Auld and Schubel 1978; Craven et al. 2010). A species that spawns in crevices or interstitial spaces like Rocky Shiner, the Tricolor Shiner (*Cyprinella trichroistia*), was found to exhibit decreased reproductive output and success, in the form of delays in spawning, fewer spawning events, and fewer eggs per event, when faced with increased levels of suspended sediment (Burkhead and Jelks 2001). Leuciscids labeled in the reproductive guild simple-lithophilus, which require clean gravel substrate for spawning, have been found to be more affected by increased siltation with a response of decreased abundances in those species (Berkman and Rabeni 1987). The abundance of stream fish that prefer riffle habitats have also been observed to decrease more than those species that occur in run or pool habitats in response to increased fine substrate (Berkman and Rabeni 1987). When sedimentation occurs, material settles in interstitial spaces of substrate, reducing porosity and permeability, which can reduce the amount of water and oxygen content in substrate (Wood and Armitage 1997). This can lead to negative responses in fish such as reduced growth rates, respiration efficiency, and feeding efficiency (Bruton 1985; Hoover 1988). High light levels have been shown to cause the diet breadth of Carmine Shiner to double in comparison with low light levels, suggesting that the species is a visual feeder and could be affected negatively by increased turbidity due to a loss of visual cues (Hoover 1988). A decrease in food availability can also occur in response to increased turbidity, which includes decreased photosynthetic aquatic vegetation and insects that have preferences for specific sizes and quality of substrate (Lauff and Cummins 1964; Lium 1974; Bruton 1985).

Pollution and Nutrients

Increased levels of pollution and nutrients could be attributed to increased runoff from climate change, roads, and forestry, urban, and agricultural land use (Lenat and Crawford 1994; Wood and Armitage 1997; Jones et al. 2000; Bertrand and McPherson 2018). Both forestry and agriculture are direct sources of these nutrients and pollutants. Agricultural pollution from livestock feedlots has been linked to decreased abundances and possible extirpations of Carmine

Shiner in Kansas (Cross and Collins 1995). Industrial pollution has been observed to limit the distribution of Rosyface Shiner in Pennsylvania (Reed 1957b). Rosyface Shiner have also been shown to exhibit avoidance of water pollutants (Cherry et al. 1977). Humphries and Cashner (1994) suggested that Rocky Shiner may be negatively affected by farmland runoff throughout its range. Pratt (2000) suggested that Rocky Shiner may be sensitive to pollution and noted a chicken processing plant on the Little River that could negatively affect the species. The AGFC reported that Rocky Shiner encounter chemical alterations of water from forestry activities and nutrient loading from agriculture (Fowler and Anderson 2015).

High nutrient loads in streams, including phosphorus and nitrogen, have been associated with areas where agriculture is the dominant land use practice (Lenat and Crawford 1994; Skoog et al. 2024). Abundances of leuciscid species, insectivorous species, and species labeled as intolerant are much lower in agricultural areas than in natural, forested areas (Skoog et al. 2024). Practices like clear cutting and fertilization in the forestry industry can also potentially introduce increased levels of nitrogen and phosphorus in receiving waterbodies (McBroom et al. 2008; Schilling et al. 2021; Shah et al. 2022). Inputs of nitrogen (N) and phosphorus (P) can lead to declines in invertebrate populations. A recent meta-analysis found that there was a significant decrease in abundance, biomass, and richness of terrestrial and aquatic insects in response to N alone and N and P together (Nessel et al. 2021).

A lack of food resources would likely lead to decreased survival, growth rates, and reproductive output from a lack of energy input required for these factors (Macnaughton et al. 2019). The presence of pollutants, specifically nitrates, from land uses has been shown to increase female associated hormone levels in male Fathead Minnows (*Pimephales promelas*), which could negatively affect males during breeding via reproductive failure (Kellock et al.

2018). Also, larvae of the same species that have experienced exposure to agricultural runoff have endured slower growth rates (Ali et al. 2016). Further, chemical runoff from pesticide use has been shown to cause damage in the DNA of fish via mutations (Whitehead et al. 2004). If faced with decreased water quality from increased nutrients and pollutants, Rocky Shiner may have decreased food resources, survival, growth rates, and reproductive output.

Predation

The risk of predation is a stressor that can be exacerbated by changes in flow from climate change, impoundments and reservoirs, roads and road barriers, and land use. Predation can also directly increase from management practices of reservoirs. After impoundment construction, predatory fish are usually introduced into reservoirs, which can result in increased predation and competition of native species upstream and downstream of the reservoir (Winston et al. 1991; Mammoliti 2002). After reservoir construction in Kansas, which changed stream dynamics above and below the structure, increasing the abundance of large predatory fish, Carmine Shiner was not found in the area even though the species was consistently reported there in the two years prior to reservoir construction (Layher 1993).

During events of low flow or drought, small fish that are upstream of reservoirs may be forced to move into reservoirs, which increases exposure to predatory fish (Matthews and Marsh-Matthews 2003). When predatory fish are present in streams, small fishes like leuciscids can be restricted to isolated and shallow refugia rather than deep pools in order to avoid these predators (Schlosser 1987a, b). However, when these smaller fish occupy less ideal refugia to avoid predation, they could endure harsher conditions that lead to stranding and mortality (Magoulick and Kobza 2003). In cases of drought, when low flows force smaller species into downstream reaches, small species may face predation due to limited and shared refugia with predators (Becker et al. 1981; Schlosser 1987b). Not only could survival be linked to predatory fishes but also feeding related behaviors. The diet breadth of Carmine Shiner has been shown to decrease by more than half in the presence of predatory fish, compared to when predators were absent, likely due to changing foraging behavior to reduce the risk of predation (Hoover 1988). When encountering native or stocked predaceous fish in their range, Rocky Shiner could have increased mortality and changes in feeding habits via the mechanisms described above.

DISCUSSION

In this present study, we use available information on Rocky Shiner as well as from surrogate species and expert opinion to describe needs, behaviors, and influences for Rocky Shiner. Not only did this synthesis of information provide a more comprehensive understanding of how the Rocky Shiner interacts with its environment, but also where data gaps persist for the species. Therefore, the information presented here could be used to inform both the first stage of the SSA document for Rocky Shiner and potential areas of research to fill information gaps that may be important to the species' listing decision. A lack of information currently persists for non-adult needs for the species, behaviors across the species' life span, and direct cause-and-effect relationships of possible negative influences. As a result, surrogate species and expert opinion largely comprise the sources used for informing what we understand about Rocky Shiner.

Overall, through our evaluation of existing data and literature, surrogate species information, and expert opinion, Rocky Shiner likely require moderate to high gradient, clear, shallow streams with riffle-pool structure, moderate to fast flows, clean gravel, rubble, cobble, and sand substrates, in-stream vegetation like Water Willow, shallow depressions or nests of other species with interstitial spaces, algae, zooplankton, and insects, and temperatures below 34.56 °C. These habitat qualities contribute to the ability of the species to shelter, feed, and breed across its life stages. Likely behaviors exhibited by Rocky Shiner adults include repeat spawning from March to August, year-round foraging on primarily insects with peak foraging at the beginning and end of the breeding season, occupying deep habitats for thermal refugia in late spring and summer, and occupying streams with riffle and pool structure year-round. Rocky Shiner eggs likely occur within the interstices of substrate and incubate for ~2.5 days, after which larvae emerge and likely occupy interstices of substrate as well, while drifting downstream and consuming algae, zooplankton, and arthropods. Juvenile Rocky Shiners likely move into and occupy pools, and transition to an insectivorous diet as they mature.

Identified sources of anthropogenic and environmental influences on Rocky Shiner include climate change, impoundments and reservoirs, roads and road barriers, land use, and gravel mining. These sources can cause stressors such as changes in connectivity, temperature, flow, turbidity, nutrients and pollutants, and predation, all of which can potentially negatively affect habitat and demographic requirements for Rocky Shiner and can affect the ability of the species to shelter, feed, and breed (i.e. its resource functions). These resource functions are necessary to factors that contribute to Rocky Shiner resiliency, or the ability of the species to withstand stochastic disturbances (USFWS 2016a; Smith 2018). The descriptions for Rocky Shiner's needs and behaviors primarily stemmed from surrogate species and expert opinion, with only the adult life stage being informed by species-specific literature. The influences portion of the Rocky Shiner description used species-specific literature, surrogate species, expert opinion, and inferences from habitat and other species' literature.

For other shiner SSAs, information presented for needs and life history has largely or strictly come from species-specific literature, with only a very limited amount of personal communication with experts. For example, SSA documents for Cape Fear Shiner and Arkansas River Shiner mainly drew from species-specific literature to describe needs and behaviors, but experts were consulted at times (USFWS 2018a, 2022). However, the experts either were currently conducting laboratory experiments on the species or had conducted expansive field studies on the species in the past. In the SSA for Topeka Shiner, needs and behaviors were entirely informed by species-specific literature because there were many field and laboratory experiments conducted on the species itself (USFWS 2018b). Most of the descriptions for influences in the SSAs for Cape Fear Shiner, Arkansas River Shiner, and Topeka Shiner were described by the presence or potential presence of influential sources in the species' ranges, inferring their possible negative effects on the species' habitat requirements, similar to our approach for Rocky Shiner. When information was available, like tolerances or observed declines and extirpations, it was mentioned but inferring influences from possible habitat and resource changes was largely used to describe this section. Some expert opinion was also used to identify and rank possible influences on Topeka Shiner (USFWS 2018b).

Collection of additional data directly connected to Rocky Shiner populations could occur prior to the compilation of its SSA document and ESA listing decision. This could be fostered through research on the species throughout its range, targeting perhaps needs and behaviors for non-adults, behaviors for adults, and tolerances to possible environmentally and anthropogenically induced stressors across all life stages. Conducting this research across the species' range may provide information on whether the species displays different needs, behaviors, or levels of tolerances across different locations. This could explain possible population trends or possible extirpations of the species in its range. By knowing and understanding more about Rocky Shiner needs, life history, and influences, the health and status of the species can be better observed and managed. And as future research is completed on Rocky Shiner, the three types of models produced in this present study, the species needs tables, life history profile Gantt chart, and influence diagram, can be updated to reflect species-specific empirical information that is less reliant on surrogates and expert opinion. However, since this information is currently unavailable, surrogate species and expert opinion both served well in aiding to describe possible needs of, behaviors exhibited by, and influences on Rocky Shiner.

Surrogate species are usually chosen based on genetic relatedness, ecological similarity, or disturbance response similarity (Caro et al. 2005). Rosyface Shiner and Carmine Shiner were both chosen as surrogates for Rocky Shiner based on available genetic data that showed close relatedness among all three species (Bielawski and Gold 2001; Wood et al. 2002; Berendzen et al. 2008). The Rosyface Shiner has also been used as a surrogate of information for Carmine Shiner in previous studies (Watkinson and Sawatkzy 2013; Macnaughton et al. 2020). When needs, life history traits, and influences from the surrogates were mentioned in this present study, it was assumed that the same, or very similar, needs and responses would be exhibited by Rocky Shiner as well. However, even for the surrogates used in this present study, information was lacking on direct estimates for changes in vital rates and population sizes in response to anthropogenic and environmental influences for the surrogates, which represents a limitation to describing exactly how Rocky Shiner may respond to changes in ecological requirements in its range.

The expert opinion used in this study was not as intensive or analytical as other methods used for informing SSA documents or ESA decisions such as eliciting probabilities of persistence

(Cummings et al. 2020; Fitzgerald et al. 2021) and life history parameters like survival and fecundity (Moore et al. 2022). However, when much information is lacking on a species, even expert opinions can be limited to simpler topics such as needs, behaviors, and influences, rather than eliciting exact estimates for the species. So, when we were faced with limited information available about Rocky Shiner's needs and responses to negative influences, we relied on surrogates and opinions of experts, though it is commonly stated that using species-specific information is always preferred (Banks et al. 2010; Murphy et al. 2011; Hernández-Camacho et al. 2015; Heeren et al. 2017; Horswill et al. 2021).

A beneficial way to show the information gained from this study was through conceptual and visual models. These types of models have been suggested to be useful when identifying needs that affect a species' survival and reproduction (i.e., species needs tables), showing how a species' needs may vary ontogenetically and temporally (i.e., Gantt chart life history profile), and describing possible relationships between stressors and anticipated responses of a species (i.e,. life history diagram; Noon and McKelvey 2006; Murphy and Weiland 2016; USFWS 2016a; Smith et al. 2018). Information used to inform these types of models can vary among species or across applications; however, the best available science directive for SSAs and ESA decisions can still be met using alternative information sources like surrogate species and expert opinion (16 U.S.C. § 1533(b); USFWS and NMFS 1994; Murphy and Weiland 2014; USFWS 2016a). As long as all relevant information is considered, citations of previous and peer-reviewed studies are included, and assumptions or uncertainties are identified, the best available science directive can still be met (Murphy and Weiland 2016). The purpose of the first stage of an SSA document is to understand, via life history and ecology, how the focal species can maintain itself (USFWS 2016a; Smith et al. 2018). In the simple models presented in this study, the first stage of the SSA process for Rocky Shiner was informed by the best available science at the time of analysis, however these models could benefit from more species-specific information to provide decision makers with a better understanding of how the species interacts with its environment to make a more comprehensive listing decision.

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TABLES

Table 2.1: Ecological requirements of Rocky Shiner during the egg life stage Only the sheltering resource function is relevant for this stage.

Resource Needed	Resource Function S Sheltering F Feeding B Breeding	Information Source A Rocky Shiner Literature B Surrogate Species C Expert opinion
Shallow waters	S	**B:** Reed 1957a; Miller 1964; Baldwin 1983; Vives 1990
Riffles	S	**B:** Raney 1940; Miller 1964; Trautman 1981; Baldwin 1983; Vives 1990; Macnaughton et al. 2020
Pools	S	**B:** Eddy and Underhill 1974; Smith 1979
Shallow depressions	S	**B:** Pfeiffer 1955; Baldwin 1983
Nests of other species	S	**B:** Raney 1940; Pfeiffer 1955; Reed 1957a; Miller 1964; Pfleiger 1975; Trautman 1981; Baldwin 1983; Vives 1990; Etnier and Starnes 1993; Pendelton 2012
Gravel and rubble substrate	S	**B:** Raney 1940; Pfeiffer 1955; Reed 1957a; Cross 1967; Eddy and Underhill 1974; Pfleiger 1975; Trautman 1981; Baldwin 1983; Vives 1990; Etnier and Starnes 1993; Cross and Collins 1995
Interstitial Spaces	S	**B:** Pfeiffer 1955; Pfleiger 1975 **C:** RPW 2024
Clean substrate	S	**B:** Reed 1957a; Cross 1967; Smith 1979; Baldwin 1983; Vives 1990; Etnier and Starnes 1993; Cross and Collins 1995 **C:** RPW 2024
Fast flows	S	**B:** Baldwin 1983; Vives 1990
Temperatures (20 – 30 °C)	S	**B:** Pfeiffer 1955; Reed 1957a; Miller 1964; Baldwin 1983; Watkinson and Sawatzky 2013

Table 2.2: Ecological requirements of Rocky Shiner during the larval life stage.

Resource Needed	Resource Function S Sheltering F Feeding B Breeding	Information Source A Rocky Shiner Literature B Surrogate Species C Expert opinion
Sand and gravel substrate	S	**B:** Pfeiffer 1955
Interstitial spaces	S	**B:** Pfeiffer 1955 **C:** RPW 2024
Clean substrate	S	**C:** RPW 2024
Algae, diatoms, insect larvae, zooplankton, arthropods, oligochaetes	F	**B:** Timbrook 1983 **C:** RPW 2024

Table 2.3: Ecological requirements of Rocky Shiner during the juvenile life stage.

Resource Needed	Resource Function S Sheltering F Feeding B Breeding	Information Source A Rocky Shiner Literature B Surrogate Species C Expert opinion
Sand and gravel substrate	S	**B:** Carr et al. 2015
Clear water	S	**B:** Baldwin 1983; Carr et al. 2015
Pool formations	S	**B:** Baldwin 1983; Carr et al. 2015 **C:** RPW 2024
Water willow (*Justicia americana*)	S	**C:** RPW 2024
Algae, diatoms, insects, zooplankton	F	**B:** Reed 1957b; Enders et al. 2020 **C:** RPW 2024

Table 2.4: Ecological requirements of Rocky Shiner during the adult life stage.

Resource Needed	Resource Function S Sheltering F Feeding B Breeding	Information Source A Rocky Shiner Literature B Surrogate Species C Expert opinion
Riffles	S, B*	**A:** Humphries and Cashner 1994; Pratt 2000; Zbinden et al. 2021 **B:** Reed 1957b; Miller 1964; Pflieger 1975; Smith 1979; Lee et al. 1980; Becker 1983; Watkinson and Sawatzky 2013; Carr et al. 2015
Shallow depths (0.5 to 1 m)	S, B*	**A:** Pratt 2000; Zbinden et al. 2021 **B:** Macnaughton et al. 2020
Shallow depressions, nests of other species	B*	**B:** See Table 2.1
Gravel, rubble, cobble substrates	S, B*	**A:** Humphries and Cashner 1994; Pratt 2000; Zbinden et al. 2021 **B:** Harlan and Speaker 1956; Reed 1957b; Pfleiger 1975; Smith 1979; Lee et al. 1980; Trautman 1981; Becker 1983; Watkinson and Sawatzky 2013
Clean substrate	S, B*	**B:** Smith 1979; Pfleiger 1975; Trautman 1981
Moderate to fast flows (0.19 - 0.29 m/s)	S, B*	**A:** Pratt 2000 **B:** Miller 1964; Pfleiger 1975; Smith 1979; Lee et al. 1980; Becker 1983; Macnaughton et al. 2020
Pools, deep habitat (> 2 m)	S, B*	**A:** Pratt 2000; Zbinden et al. 2021 B: Pflieger 1975; Trautman 1981; Becker 1983; Cross and Collins 1995 **C:** RPW 2024

* Refer to Table 2.1 for the breeding resource function’s information sources.

Table 2.4: Continued.

Resource Needed	Resource Function S Sheltering F Feeding B Breeding	Information Source A Rocky Shiner Literature B Surrogate Species C Expert opinion
Clear streams	S	**A:** Humphries and Cashner 1994 **B:** Pfleiger 1975; Smith 1979; Trautman 1980; Becker 1983; Cross and Collins 1995; Watkinson and Sawatzky 2013
Moderate to high gradients	S	**A:** Humphries and Cashner 1994 **B:** Cross 1967; Pfleiger 1975; Trautman 1980; Carr et al. 2015
Water willow (*Justicia americana*)	S	**C:** RPW 2024
Temperatures (6 to 31 °C, max 34.56 °C)	S, B*	**A:** Matthews 1987; Pratt 2000 **B:** Staufer 1975; Stol et al. 2013; Enders et al. 2019
Insects, algae, diatoms	F	**A:** Hargrave 2005; Robison and Buchanan 2020 **B:** Pfeiffer 1955; Reed 1957b; Becker 1983; Hoover 1988; Watkinson and Sawatzky 2013; Enders et al. 2020

* Refer to Table 2.1 for the breeding resource function's information sources.

Table 2.5: Preliminary Rocky Shiner life history profile in the form of a Gantt chart used in the rapid prototyping workshop by the U.S. Fish and Wildlife Service to receive expert suggestions.

<table>
<tr><th>Life Stage</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td>Adult</td><td></td><td></td><td colspan="6">Spawn</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Egg</td><td></td><td></td><td colspan="6">Incubate</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Larvae</td><td></td><td></td><td colspan="6">Occupy interstitial spaces</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Juvenile</td><td colspan="12">Forage (algae)</td></tr>
<tr><td></td><td></td><td colspan="6">Transition to insectivory</td><td></td><td></td><td></td><td></td></tr>
</table>

Table 2.6: Modified and updated Rocky Shiner life history profile in the form of a Gantt chart informed by Rocky Shiner literature, surrogates, and expert opinion.

<table>
<tr><th>Life Stage</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td rowspan="5">Adult (1-3 years)</td><td></td><td></td><td colspan="6">Spawning (possible repeat spawning lasting ~6 days)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="2">Peak Foraging (insects)</td><td></td><td></td><td></td><td colspan="2">Peak Foraging (insects)</td><td></td><td></td><td></td></tr>
<tr><td colspan="12">Year-Round Foraging (insects)</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">Occupy deep habitats (thermal refugia)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="12">Occupy streams with riffle and pool structure</td></tr>
<tr><td rowspan="2">Egg (~ 2.5 days)</td><td></td><td></td><td colspan="6">Incubation (~2.5 days)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">Occupy interstices of substrate (~2.5 days)</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Larvae (~ 1.5 months)</td><td></td><td></td><td colspan="6">Occupy interstices of substrate (~2 months)</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">Drift downstream</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">Foraging (algae, zooplankton, annelids, insect larvae)</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Juvenile (~ 1 year)</td><td colspan="12">Move into and occupy pools (~1 year)</td></tr>
<tr><td colspan="12">Foraging (algae and transition to insects)</td></tr>
</table>

FIGURES

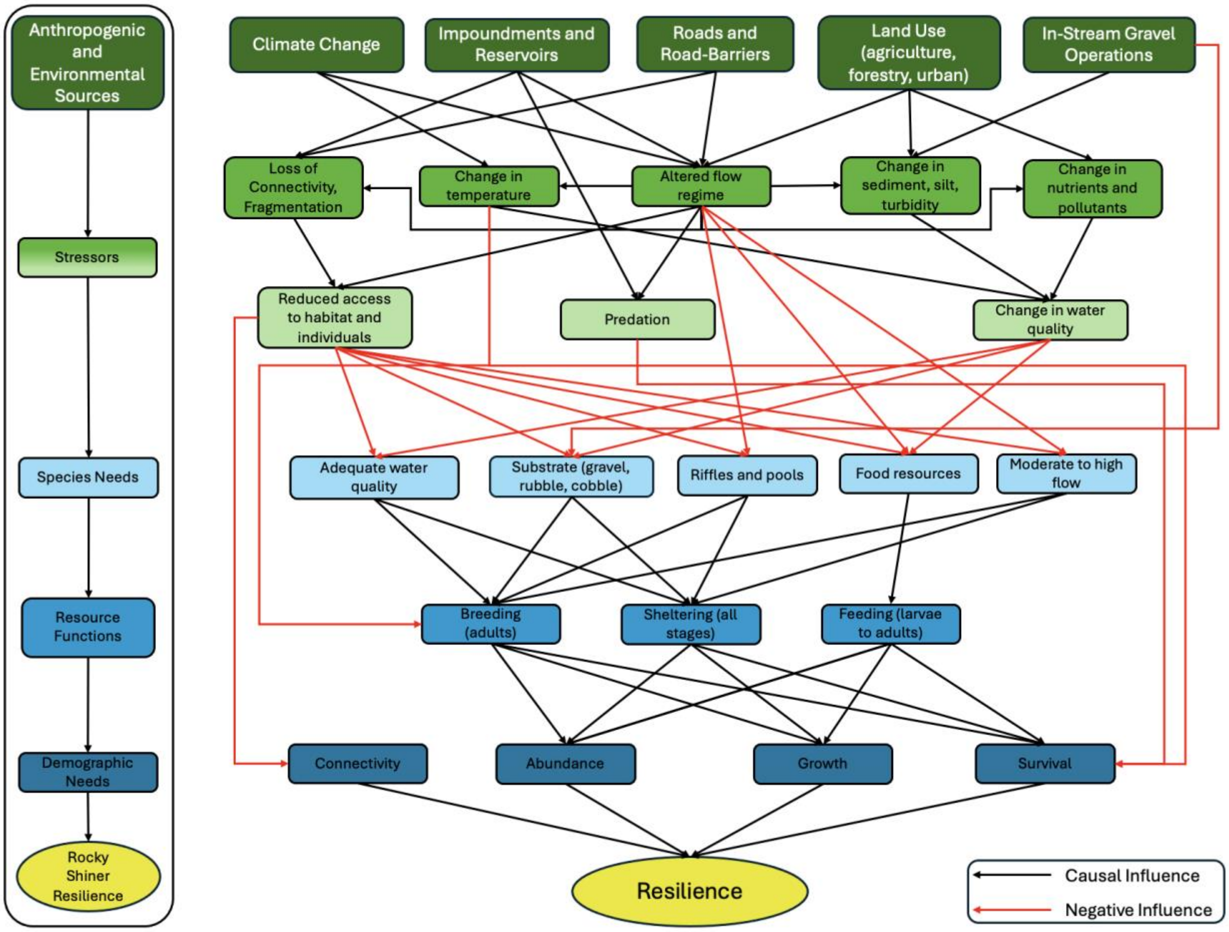

Figure 2.1: Influence diagram for the Rocky Shiner describing anthropogenic and environmental sources of influences (dark green), the stressors that sources cause to the environment (light green), the needs of the Rocky Shiner that are affected (light blue), the resource functions correlated with those needs (medium blue), and demographic needs (dark blue) important for the resilience (yellow) of the Rocky Shiner. Causal influences are depicted by black arrows and represent a causal change in or contribution from one subject to another. Negative influences are depicted by red arrows and represent a negative change in one subject by another.

CHAPTER 3

INFORMING AN INITIAL ASSESSMENT OF AND IDENTIFYING DATA GAPS FOR THE ROCKY SHINER (*NOTROPIS SUTTKUSI*) WITH A BAYESIAN BELIEF NETWORK[2]

[2] Bleau, T. R., Robinson, K. F., Irwin, B. J. To be submitted to a peer-reviewed journal.

ABSTRACT

A new application of a Bayesian belief network (BBN) has been proposed to more quickly and completely assess imperilments risks and identify data gaps for data-limited species that have been petitioned under or are candidates for the Endangered Species Act. The Rocky Shiner (*Notropis suttkusi*) is a data-limited candidate species that lacks spatial data, defined population structures, and known effects from threats. The new BBN application is used for this species to observe the effect of different population structures on imperilment risk and to identify uncertainties of importance to resolve for the species. Different information sources are used to suggest possible threats to include in the model for future assessments of the species. This research offers an initial evaluation of the Rocky Shiner's current condition, with the data available, while also highlighting possible areas of research or management for the species and suggesting future changes to the model.

INTRODUCTION

The Endangered Species Act (ESA) serves to protect threatened and endangered species by conserving the ecosystems on which these species depend (16 U.S.C. § 1531(b)). Listed species are protected through a variety of actions such as designated critical habitat, protective regulations, recovery plans, and monitoring, all of which are intended to recover species to the point such that they no longer require protection under the ESA (16 U.S.C. § 1532(3)). The U.S. Fish and Wildlife Service (USFWS) considers several factors when assessing if a species will be listed under the ESA. Because the number of species petitioned for listing is large, the USFWS currently uses a binning process by which listing-related actions for species are prioritized based on the availability of information that is needed for listing decisions. Species with more information are placed into higher bins associated with a higher priority that may lead to more timely decisions than lower binned species (USFWS 2016a; Smith et al. 2018). Species placed in lower bins are generally considered data limited and therefore need more information for listing decisions to be made. However, there is not a formal process accompanying binning that builds a species' information profile up to a certain target level of "readiness" for listing evaluations.

The USFWS informs listing decisions through Species Status Assessments (SSAs), which are biological risk assessments that help determine the probability that a species can sustain populations in the wild over time, or its viability (USFWS 2016b; Smith et al. 2018). This document is guided by the principles of the 3 Rs: resiliency, redundancy, and representation. Resiliency is the ability of a species to withstand stochastic disturbances, redundancy is the ability of a species to withstand catastrophic events, and representation is the ability of a species to adapt to a changing environment over time (USFWS 2016b; Smith et al. 2018). The complexity of models in an SSA document is typically case-dependent, influenced by the availability of data, the situational complexity, and the expertise of the modeling team (McGowan et al. 2017, 2020; USFWS 2018a, 2018b, 2022; Graves et al. 2020; Moore et al. 2022; Folt et al. 2022). Complex models are not able to be informed by empirical values when a species lacks spatial and temporal data, such as distribution and abundance, and lacks its own critical life history and demographic information, such as survival and fecundity. Complex models are also not well informed when this information is lacking from surrogate species and expert judgement. In these data-limited cases, it is not as clear as to what can be done to best inform listing decisions when more ideal information is extremely lacking.

Bayesian probability approaches may serve as an adequate method to use when uncertainty and a lack of data or information exists (Woods and Morey 2008; Murphy and

Weiland 2016; Kindsvater et al. 2018). Bayesian statistics reflect probability by incorporating the degree of belief that an event will occur (Krieg 2001; Heckerman 1998). Bayesian belief networks (BBNs) are graphical probabilistic models that use Bayesian inference and incorporate dependent relationships between variables via a directed acyclic graph (DAG; Krieg 2001; Pearl 1988; Heckerman 1998). A BBN is constructed of nodes, which represent variables, and edges, which show causal relationships between variables (Pearl 1988; Conroy and Peterson 2013). Node states are mutually exclusive and exhaustive, and nodes themselves exhibit a hierarchal structure where parent nodes influence child nodes (Krieg 2001; Pearl 1988). States of variables can be assigned with certainty or uncertainty using prior probabilities, which are stored at the level of the informed parent node (Krieg 2001; Pearl 1988). Conditional probabilities are represented by edges carrying weights between nodes that show how influential a parent node's state is to a corresponding child node's state and are stored in conditional probability tables (CPTs) in the child node in the form of all possible combinations of its parent node states (Pearl 1988; Krieg 2001; Marcot 2006; Conroy and Peterson 2013). The marginal probability of each child node, which is the likelihood that a parameter exists in a particular state, is calculated in a BBN using input prior probabilities and conditional probabilities (Marcot et al. 2001). Modeling ecological systems and aiding in natural resource decision making can be accomplished using BBNs because these models can predict responses in ecological variables at different spatial scales using influences from habitat, environmental, or species-specific predictor variables (Marcot et al. 2001, 2006). These models, specifically both the parent node states and CPTs, can be updated as new information on the ecological system of focus arises so the predictive capacity of the model best represents that system, given the current understanding of it (Marcot et al. 2006).

A BBN was recently developed for data-limited riverine fishes by Dunn et al. (2024) and presents a potential standardized approach for identifying important information gaps and informing SSAs for these species in a timely manner. This BBN can incorporate uncertainty and alternative information sources, while being updateable and adhering to the 3 Rs framework set forth by SSAs (USFWS 2016b; Smith et al. 2018; Dunn et al. 2024). The model estimates extirpation and imperilment risks specifically for riverine fish species in the southeastern U.S., as model components are informed by both opinions from conservation practitioners and literature (Dunn et al. 2024). The model is also parameterized for these types of species from expert judgement, literature, and empirical data from more informed species (Dunn et al. 2024). The use of this model with species other than the one used as an example in the paper, the Piebald Madtom (*Noturus gladiator*), may provide insight into how the model behaves under other forms of information availability and for other taxa.

The ESA petitioned Rocky Shiner (*Notropis suttkusi*), a data limited riverine fish endemic to southeastern Oklahoma and southwestern Arkansas, may be a good candidate for the BBN described above and may benefit from its use. The Rocky Shiner was petitioned for ESA listing in 2010 by the Center for Biological Diversity (CBD) under the notion that the species faced habitat destruction, inadequate regulatory mechanisms, and had a narrow, restricted range (CBD 2010). The USFWS determined, in a 90-day finding, that with the information presented for the species, it may warrant listing under the ESA (USFWS 2011). The Rocky Shiner was included on the 2023 and 2024 National Listing Workplans, which prioritize the USFWS's ESA workload for listing species, and the Rocky Shiner is currently set for a 12-month finding and accompanying critical habitat designation, if listing is warranted, for Fiscal Year 2028.

In this present study, I adapt Dunn et al.'s BBN (Dunn et al. 2024) to available spatial and temporal data, as well as available species-specific information, surrogate species, and expert opinion for the Rocky Shiner. Overall, I conduct an initial evaluation of the Rocky Shiner's current condition and identify pertinent data gaps and possible areas of future research. Two different spatial scales for population delineations are used in the BBN to explore if there were differences in model outputs, if the species is believed to exist in, overall, either larger or smaller populations. Several iterations of this model are performed per population spatial scale to assess how outputs of the model react to different levels of information. Sensitivity analyses are conducted for both spatial scales to assess which uncertainties and where in the Rocky Shiner's range could be prioritized for obtaining higher resolution data than currently exists. Future changes to the model's structure could include a more customized version for the Rocky Shiner in terms of evaluating identified species-specific threats once species-specific effects of possible threats are better known. In combination, this information could be used to inform the approaching Rocky Shiner's SSA document and listing decision. As new information about the species arises, the model can be readily updated to reflect a more accurate representation of the Rocky Shiner's imperilment risk. The model may provide an approach to quickly addressing the long list of species being petitioned and awaiting listing decisions in the Southeastern U.S. (Goode et al. 2023), especially data limited species that would otherwise continue to be subjected to long term listing decisions, like Rocky Shiner.

METHODS

A Bayesian Belief Network for the Data Limited Rocky Shiner

The influence diagram that represents the Dunn et al. (2024) BBN used in this study is shown in Figure 3.1. This model incorporates the 3 Rs (i.e., resiliency, redundancy, and representation) to assess extirpation and imperilment risks and characterizes species vulnerability as relevant to USFWS decisions.

Resiliency is represented at the individual population level, known as management units, and incorporates nine parent nodes and three child nodes to describe the ability of individual populations to withstand stochastic disturbances (Tables 3.1, 3.2). The parent nodes are used to describe the Local Distribution, Population Strength, and Other Threats child nodes. The Local Distribution child node, with states of "adequate" or "inadequate," is informed by parent nodes that describe the number of stream segments a species occupies, the recent length of stream habitat that the species occupies, and the complexity and locations of streams that the species occupies. The Population Strength child node, with states of "adequate" or "inadequate," is informed by the proportion of positive species detections for recently sampled stream segments, the change in species detections between recent and historically sampled stream segments, the highest reported abundance in a stream segment, and the number of years since the species was last encountered. The Other Threats child node, with states of "low risk" or "high risk," is informed by the presence of hybridization and nonnative species. The Individual Population Resiliency child node, with states of "secure" or "at risk," is calculated using probabilities from the previously mentioned three child nodes.

Redundancy in this model is represented at a multi-population scale, referred to as ecological settings, and integrates five parent nodes and one child node to describe the ability of the species to withstand catastrophic events by spreading risk over multiple resilient populations (Tables 3.2, 3.3). The one child node used to describe redundancy is Population Connectivity, which is represented by states of “adequate” or “inadequate,” and is informed by parent nodes that describe the distance between closest occupied segments in management units, the percentage of management unit connections uninterrupted by barriers, and a species’ dispersal capability. This child node and two other parent nodes that describe the proportion and number of extant populations are used to calculate the probabilities of the Ecological Setting Redundancy child node being “adequate” or “inadequate.”

Species vulnerability comprises the inherent qualities of a species that make it either more or less vulnerable to extirpation and integrates six parent nodes and one child node (Table 3.4). The one child node used for species vulnerability is Specialization, which uses parent nodes that describe the species’ adult trophic feeding level, lotic dependency, benthic dependency, and drift dependency to calculate the probability of the species being a “specialist” or “generalist” (Table 3.2). The Specialization child node along with two other parent nodes that describe the species’ life history strategy and maximum length are used to calculate the probability of the Species Vulnerability child node in terms of the species being “resistant” or “vulnerable.”

From the above three resulting child nodes, Individual Population Resiliency, Ecological Setting Redundancy, and Species Vulnerability, probabilities of the remaining child nodes in the model are calculated. Ecological Setting Resiliency is determined, in terms of being “secure” or “at risk,” by calculating the mean of all Individual Population Resiliency probabilities for all management units within an ecological setting (Table 3.2). The model assumes in the CPT for this child node that all management units have equal weight in each ecological setting. Using Ecological Setting Resiliency, Ecological Setting Redundancy, and Species Vulnerability probabilities, the Ecological Setting Extirpation Risk for each specific ecological setting is calculated in terms of being "secure" or "at risk" (Table 3.2). All Ecological Setting Extirpation Risks are used to characterize the concept of representation by equating their probabilities of being "secure" of extirpation to the ability of the species to maintain its adaptive capacity, habitat diversity, and behavioral diversity across its range. The terminal node in the model is Global Imperilment Risk, which is calculated, in terms of the species being "secure" or "at risk," using the mean of all Ecological Setting Extirpation Risk probabilities (Table 3.2). The CPT for this terminal node places equal weights on each ecological setting's contribution to Global Imperilment Risk.

Model Formulations: Spatial Scale and Uncertainty

Spatial Scale

I consider two spatial scales for Rocky Shiner populations to evaluate if there are differences in model child node outputs between the two delineations. This allows us to evaluate current uncertainty in population structure for Rocky Shiner. For the first spatial scale, Rocky Shiner experts from different academic institutions, state agencies, and federal agencies participated in a rapid prototyping workshop (RPW) hosted by the USFWS in August 2024. The experts used a map with Rocky Shiner occurrence records to delineate populations. From this, both management units in the form of populations and ecological settings at the multi-population level were described. Hydrologic unit codes (HUCs), both HUC10s and HUC8s, were adapted to fit the management units and ecological settings designated by experts. The second spatial scale was developed using recommendations from Dunn et al. (2024) to use HUC10s for all management units. Only HUC10s with at least one Rocky Shiner occurrence record were retained. This creates a more organized and standardized separation of units than those from expert opinion. The same ecological settings designated by experts are also used in this second spatial scale. By using the same ecological settings, but different management units, I examine the effects of changing only the population spatial scale on model predictions.

Evaluating Uncertainty in Node states

In addition to considering two population spatial scales, I also explore two levels of uncertainty per spatial scale regarding the parent node states in the BBN.

Complete Uncertainty

In this model iteration for both spatial scales, uniform parent priors are assigned to all states in all parent nodes for resiliency, redundancy, and species vulnerability to represent complete uncertainty. This means that for all parent nodes, Rocky Shiner could exist in any of the possible states with equal probability. For example, for the Occupied Segments parent node for resiliency, the species is set to equally exist in its three potential states of One, Rare, or Many. When a uniform probability is applied to this parent node, each state has a probability of 0.33. This shows what child node probability outputs the BBN would give when the priors for the model are completely uniform, providing insight into if the model favors certain child and terminal node states, serving as a baseline to observe how much key node probabilities change when the model is more informed.

Complete Certainty

For this model iteration, a probability of 1 is assigned to only one state in each of the parent nodes for resiliency, redundancy, and species vulnerability. The state chosen for each parent node was determined using results from measurements and observations described for each parent node in Tables 3.1, 3.3, and 3.4. This represents a scenario in which there is complete confidence in measured and observed states for all parent nodes. This reflects the current understanding, given available information and data, of the Rocky Shiner's condition across its range if we are confident that the data available are truly representative of the species' status. This iteration serves as a starting point for evaluating the current condition of the Rocky Shiner and any changes in key child node outputs could be tracked as updated information is incorporated into the model in the future.

Data Used

A set of spatial data, consisting of presence-only occurrence records, across the Rocky Shiner's range was assembled by the USFWS Rocky Shiner SSA lead biologist, Dustin Booth. This data came from several sources, including state agencies, citizen science data platforms, museum specimens, and researcher survey records. These sources are Arkansas Game and Fish Commission, Arkansas Natural Heritage Commission, Global Biodiversity Information Facility (https://www.gbif.org/), iDigBio (Integrated Digitized Biocollections; https://www.idigbio.org/), Fishnet2 (https://www.fishnet2.net/), Oklahoma Museum of Natural History, Oklahoma State University's collection of vertebrates, William J. Matthews (University of Oklahoma), and Savannah Wise (Arkansas Tech University). I screened these data to find coordinates that did not match locality descriptions. In cases of discrepancies, I contacted the sources for those data to obtain accurate spatial information. Where data could not be confirmed, those spatial data were not used for analysis. This consists of a 1950 record for the Little River and a 1992 record for the Glover River. I included more spatial data from updated records on iNaturalist (https://www.inaturalist.org/) and survey records from Brian Okwiri at Arkansas State University. The entire collection of spatial data for Rocky Shiner includes 313 unique data points spanning from 1947 to October 2024 (Figure 3.2).

For parent nodes that require measurement or observation of streams, the USGS National Hydrography Dataset Plus High Resolution (NHDPlus HR), was used for flowline and waterbody data (USGS 2018a, 2018b). The NHDPlus HR was downloaded from the National Map Downloader by HUC4 boundaries that encompass the Rocky Shiner's range, which includes HUC1113 and HUC1114. These data were last modified in March 2024. In Dunn et al. (2024), the authors used the NHDPlus V2, but we chose to use NHDPlus HR because it has more recently updated data for flowlines that are more representative of the current state of the region where Rocky Shiner occurs. The NHDPlus HR contains the USGS Watershed Boundary Dataset (WBD), which is used for its HUCs. This dataset is used for HUC8 and HUC10 boundaries for building and defining management units and ecological settings. Spatial analyses required for measuring specific spatial relationships for resiliency and redundancy parent nodes were accomplished using ArcGIS Pro Version 3.3.0 (ESRI/Redlands/CA). The programs R (Version 4.3.1; R Core Team 2023) and RStudio (Version 2023.06.1+524; Posit Team 2023) were used for calculating child node probabilities from assigned prior probabilities in Excel. Experts who had conducted research on Rocky Shiner, its range, and other species in its range were contacted via email and asked about their opinions on Rocky Shiner life history, behavior, and ecological needs. This helped to determine some parent node states in the complete certainty iteration for redundancy and species vulnerability, which are further described in the next section.

Assigning States to BBN Parent Nodes

The methods outlined below for measuring resiliency, redundancy, and species vulnerability parent nodes are applied to both spatial scales 1 and 2. These methods are used for assigning measured or observed states to parent nodes, which are then used in the certain iteration for each spatial scale to assign probabilities of 1 to those states.

Resiliency

The analysis of the observed resiliency for each management unit includes assessing the states of parent nodes for the Local Distribution, Population Strength, and Other Threats child nodes. This includes the Occupied Segments, Occupied Stream Length, and Network Complexity parent nodes for the Local Distribution child node, the Current Naive Occupancy, Naive Occupancy Trend, Qualitative Abundance, and Years Since Last Encounter parent nodes for the Population Strength child node, and the Hybridization and Nonnative Species parent nodes for the Other Threats child node (Table 3.1).

Local Distribution

The NHDPlus HR, hereafter NHD, flowline data were paired with available spatial data for Rocky Shiner to determine the number of occupied segments in each management unit for the Occupied Segments parent node. All Rocky Shiner occurrences, regardless of year, were used for this analysis. Flowline data and Rocky Shiner occurrence data points were displayed in

ArcGIS Pro. Occupied stream segments identified in management units were segments of a river or stream in between tributary junctions that contained at least one occurrence record. The number of unique segments occupied by Rocky Shiner within each management unit boundary was counted and was scored as having One, Rare, or Many occupied segments in each management unit (Table 3.1).

We identified the most upstream and downstream segments in each management unit for stream segments occupied by Rocky Shiner since the year 2000 to help score the Occupied Stream Length parent node. River mainstem and tributary segments were used for delineating upper bounds and only mainstem reaches were used for lower bounds. If a lower boundary segment was not on the mainstem, but on a tributary stream, the lower bound was chosen as the lowest point on the mainstem where the confluence between the mainstem and the tributary occurred. We then calculated the total sum length of the flowline between the upstream and downstream segments. Based on the lengths reported for management units, each management unit was scored as being Restricted, Moderate, or Widespread (Table 3.1). If a management unit only had one occupied segment, the length of that segment was used to represent the distance between the furthest upstream and downstream points. If a Rocky Shiner occurrence record had not been reported since 2000 in a management unit, that management unit was scored as having a Restricted Occupied Stream Length.

We used all NHD flowlines and Rocky Shiner spatial data points from the entire dataset to score the Network Complexity parent node for each management unit as Mainstem, Single Tributary, Multiple Tributary, or Complex (Table 3.1) based on where the species occurred. Node states correspond to occurrence only in the mainstem, only in a single tributary, in multiple tributaries, or in both the mainstem and tributaries within each management unit.

Population Strength

To measure the Current Naive Occupancy, the number of occupied stream segments since the year 2000 in a management unit was divided by the total number of stream segments that the species has been observed to occupy in the management unit, regardless of time. Each management unit was scored as being Potentially Extirpated, Rare, Uncommon, or Common (Table 3.1). If data were not available since 2000 in a management unit, then the unit was scored as Potentially Extirpated.

We scored the Naive Occupancy Trend parent node by first calculating the number of stream segments in each management unit that were occupied by the Rocky Shiner prior to 2000, as a measure of historical occupancy. We then divided this measure by the number of total occupied segments in the corresponding management unit, regardless of time. The naive occupancy trend in each management unit was then estimated by calculating the percent change between the current naive occupancy and historical naive occupancy. Based on percent changes in naive occupancy, each management unit was scored as being Relatively Stable, having a Moderate Decline, or having a Strong Decline (Table 3.1). When a management unit did not have any historical data available, that management unit was assigned a uniform probability to all states, since the trend was unknown. When there were no current, post 2000, occurrence data in a management unit, it was scored as having a Strong Decline.

The Qualitative Abundance parent node measured the maximum number of individuals captured in a single stream segment in a management unit on a given date. Some of the occurrence records provided for Rocky Shiner had accompanying abundance data, while other records did not, so only records where abundance data were available were used for analysis on this parent node. If multiple collections occurred on a single day in a single stream segment, the sum of those collections was retained as the maximum abundance recorded in that stream segment. Out of all abundances recorded and combined, if necessary, the highest total abundance in a single stream segment on a single date in each management unit was retained as the Qualitative Abundance value, with a score of Rare, Common, or Abundant for each management unit (Table 3.1).

We subtracted the most recent year of a Rocky Shiner occurrence record in each management unit from the year 2025 to calculate the Years Since Last Encounter parent node. Each management unit was scored as having Recent, Moderate, or Historical encounter records (Table 3.1).

Other Threats

Hybridization for Rocky Shiner in management units was determined by conducting a thorough literature search and communicating with experts. I did not find any reports in published literature of Rocky Shiner hybridizing with other co-occurring species. Experts who have collected this species and conducted research in streams of Oklahoma and Arkansas in the Rocky Shiner's range have also communicated that they have not observed any Rocky Shiner hybridization (William J. Matthews, University of Oklahoma, pers. comm., and Thomas M. Buchanan, University of Arkansas, pers. comm.). Therefore, the Hybridization state No was assigned to all management units for the complete certainty iteration. Because there was a lack of genetic data and literature on Rocky Shiner throughout its range reporting hybridization, hybrids could exist but have not been studied or reported. Reports of Rocky Shiner surrogate species, Rosyface Shiner (*Notropis rubellus*) and Carmine Shiner (*N. percobromus*), readily hybridizing with co-occurring species suggests this could be possible for Rocky Shiner as well (Pfeiffer 1955; Miller 1964; Raney 1940; Bailey and Gilbert 1960; Meuser 2023; Pfleiger 1975; Eddy and Underhill 1974). Therefore, for sensitivity analyses, described in the next section, hybridization was considered to be possible.

The number of nonnative fishes occurring in each management unit was determined using the U.S. Geological Survey's Nonindigenous Aquatic Species (NAS) database (USGS 2025). Data were filtered to only include nonnative fishes and were downloaded at a HUC 8 level, being the smallest scale available. Species were retained to include for analysis if they had been reported since the year 2000, were considered to be established, and have been reported within the defined boundaries of management units for each spatial scale. The number of unique species in each management unit was counted and management units were scored as having a Nonnative Species parent node state of Absent, Few, or Many (Table 3.1).

Redundancy

Analysis of redundancy for each ecological setting in this study is conducted by assessing parent node states for the Population Connectivity child node along with the Proportion Extant and Extant Populations redundancy parent nodes (Table 3.3). The Population Connectivity child node includes the Population Isolation, Network Connectivity, and Ranging Movements parent nodes.

Population Connectivity

The Population Isolation parent node for each ecological setting was measured using the mean shortest path distance between management units within each ecological setting. These distances were measured between the spatial midpoints of the two closest occupied segments, measured as NHD flowlines, between two management units in an ecological setting. Shortest path distances were determined for each individual management unit in an ecological setting, resulting in one shortest path distance per management unit in each ecological setting. The lengths of the closest occupied segments were divided by two to account for the midpoints being start and end points for this analysis, and these lengths were summed with the length of the flowline between these closest occupied segments to determine the shortest path distance. This was repeated for each management unit within an ecological setting and the mean of all shortest path distances in each ecological setting was calculated. Each ecological setting was scored as having Near, Moderate, or Far populations (Table 3.3). If an ecological setting only consisted of one management unit, then it was scored as having Far Population Isolation.

The Network Connectivity parent node was determined using the Southeast Aquatic Resource Partnership's (SARP's) Comprehensive Aquatic Barrier Inventory on pairwise shortest path connections between management units in each ecological setting (SARP 2024). This dataset was used to display dams and road-related barriers in ecological settings. The barrier data were downloaded at HUC8 and HUC10 scales across the Rocky Shiner's range, which resulted in 3,659 dams and 285 road and stream crossings, according to data version 3.15.0 published in January 2025. This list was filtered to only include those structures which have not been removed, those that were excluded from connectivity analysis due to field observations or reviews of aerial imagery, and those that were assessed to have passability scored as "unknown," "partial passability," or "complete barrier." This resulted in 3,659 dams and 111 roads/stream crossings. Shortest path pairwise connections were determined for every possible combination of shortest path management unit connections within an ecological setting. The midpoint of nearest occupied segments represents the start and end points between management units for these connections. The SARP barrier data were used to observe if any barrier existed along these shortest path connections. I selected barriers within 2 m of the shortest path distance flowlines in ecological settings. The percentage of uninterrupted shortest path connections in each ecological setting was calculated by dividing the number of uninterrupted connections by the total number of possible connections and multiplying by 100. If an ecological setting was made up of only one resiliency unit, it was scored as being Fragmented because it was separated from all other management units and ecological settings. The remaining ecological settings were scored as having High, Moderate, or Fragmented Network Connectivity based on percentages calculated (Table 3.3).

The Ranging Movements parent node, which describes the home range distance that adults will move in a given year, was determined for all ecological settings using expert opinion. I did not find data or literature that describes the movement range of adult Rocky Shiner or its surrogate species, Rosyface Shiner and Carmine Shiner, to the description or states outlined by this parent node. However, using expert opinion, Rocky Shiner was labeled as likely not being a long-distance migrator and not travelling a distance of more than 1 – 2 km throughout the year (Anthony Echelle pers. comm., Oklahoma State University). Therefore, Rocky Shiner in all ecological settings was retained to have a Short movement state (Table 3.3).

Proportion Extant and Extant Populations

The Proportion Extant parent node for ecological settings was calculated by dividing the number of management units in an ecological setting that had a current Naive Occupancy value greater than 0.05 by the total number of management units in that ecological setting. Ecological settings were scored as having a Low, Moderate, or High proportion of extant populations (Table 3.3). The number of Extant Populations in an ecological setting was calculated by summing the total number of management units in an ecological setting with a current naive occupancy greater than 0.05 since 2000. The Rocky Shiner was scored as having a Few, Moderate, or High number of Extant Populations.

Species Vulnerability

We use information from Rocky Shiner-specific literature, surrogate species literature, and expert opinion to inform the states of the species vulnerability parent nodes for Rocky Shiner (Table 3.4). The information gained from these sources was the same for both spatial scales and results for measured species vulnerability states did not change per spatial scale, since in this present study we assume that the species vulnerability parent nodes represent species-wide inherent traits that do not change across the Rocky Shiner's range or by spatial scale. The sources used for determining states in each species vulnerability parent node are in Table 3.5.

<u>Sensitivity Analysis</u>

In total, I conduct two sensitivity analyses per spatial scale to understand influential parent nodes on either extirpation or imperilment risks, described in more detail below. Overall, these sensitivity analyses were completed by creating a separate model iteration for the BBN to represent "informed uncertainty." This model iteration was re-run using modified input values to reflect the limited empirical information available on Rocky Shiner. Parent nodes were adjusted to reflect best- and worst-case scenarios of states, where best states were those that represent the species existing in the best condition for a parent node, while worst states are those that were designated to be the worst possible condition that the species could exist in, informed by lower bounds of measured and observed states and uncertainty in parent nodes. This included targeting each parent node at a time, across each appropriate level of ecological organization, being management units (resiliency parent nodes), ecological settings (redundancy parent nodes), and species-wide (species vulnerability parent nodes), to understand how uncertainty in those nodes may affect outputs for the key child nodes of interest, Ecological Setting Extirpation Risk and Global Imperilment Risk. Alternative states were explored for the following uncertain parent nodes: Occupied Segments, Occupied Stream Length, Network Complexity, Naive Occupancy, Naive Occupancy Trend, Qualitative Abundance, Years Since Last Encounter, Hybridization, Population Isolation, Population Connectivity, Ranging Movements, Proportion Extant, Extant Populations, and Benthic Dependency.

A Separate Model for Sensitivity Analysis: Informed Uncertainty

For sensitivity analyses, a separate iteration of the model was created, hereafter called the informed uncertainty iteration. For informed uncertainty, parent prior probabilities for states in the uncertain parent nodes mentioned above are informed to reflect a narrower confidence in states than the complete uncertainty iteration but still incorporate uncertainty unlike the complete certainty iteration. The informed uncertainty model was informed by measured or observed states assigned in the complete certainty iteration, which represented lower bound states, but reflected uncertainty by also assigning better conditioned states in the parent node.

Because there has not been long term monitoring or targeted surveys of Rocky Shiner across its entire range, uncertainty may exist in measured or observed states, so in this iteration multiple states were possible beyond the single measured state. For example, for the Occupied

Segments parent node in resiliency, if a management unit produced an observed value of 1 segment, there were equal parent prior probabilities (p = 0.33) assigned to the states One (1), Rare (2-5), and Many (>5). This is because it is not known if the species occupies more than one segment in the management unit. Another example includes if the Rocky Shiner had a highest reported Qualitative Abundance of 53 individuals for a management unit, which would characterize the species as Uncommon (10-75 individuals). The species in this management unit could exist at a higher abundance, so equal probability (p = 0.50) would be given to the states Uncommon (10-75 individuals) and Abundant (>75 individuals). When the Rocky Shiner was measured or observed in the best available state for a parent node, this value was retained as having a probability of 1, since it was known that the species already existed in the best condition for that node.

Two Levels of Parent Node Sensitivity Analysis

In this sensitivity analysis, each parent node that carried uncertainty was assessed one at a time across its appropriate level of ecological organization, similar to a one-way sensitivity analysis (Conroy and Peterson, 2013), but only for targeted nodes. A prior probability of 1 was assigned to the corresponding best-case scenario state for each parent node. Then, a prior probability of 1 was assigned to corresponding worst-case scenario states for each parent node. While the prior probabilities for one parent node were changed to certain states, all other parent nodes remained constant in their uncertain, yet informed states from the informed uncertainty iteration. Probabilities for both Global Imperilment Risk and Ecological Setting Extirpation Risks were evaluated to observe influential uncertain parent nodes.

For each parent node, the probability of being "at risk" in the best-case scenario was subtracted from the probability of being "at risk" in the worst-case scenario for extirpation and imperilment. This change in either Ecological Setting Extirpation Risk or Global Imperilment Risk shows how much the resulting probability of being "at risk" is influenced by the uncertainty in parent node states and how much better of a condition Rocky Shiner could be considered to be in, in terms of being "at risk," if targeted sampling and management efforts were to resolve specific parent node uncertainties and reveal or promote the species to exist in better states. For evaluating changes in Ecological Setting Extirpation Risks, this reveals the parent nodes that could contribute most to each specific ecological setting's condition for Rocky Shiner if the species exists in better states than the data currently shows. For evaluating changes in Global Imperilment Risk, this reveals the parent nodes that could contribute most, overall, to the Rocky Shiner's improvement in condition if it exists in better states.

Recommended Threat Nodes

I also describe potential Threat Nodes for Rocky Shiner based on Rocky Shiner-specific literature, surrogate species, and expert opinion. Expert opinion on threats came from experts who attended the same RPW where population delineations were made, as well as personal communication, via email, with experts who have conducted research on Rocky Shiner, its range, and other species in its range. Only four threats are selected because Dunn et al. (2024) limited parent nodes contributing to a single child node in the BBN to four to minimize complexity in CPTs. Possible data sources to evaluate these threats are also described. Currently, there is not enough information to support including these potential threats in the model due to a lack of evidence showing the degree of effects that the threats may have on Rocky Shiner, and even its surrogate species. Once there is evidence of direct effects from possible threats to Rocky Shiner, inclusion in the model would be appropriate.

RESULTS

Setting Spatial Scales

The experts at the RPW identified 13 total management units and six ecological settings throughout the Rocky Shiner's range for spatial scale 1 (Figure 3.3, Table A1). The ecological settings identified are the Washita Complex (WC), Blue Clear Muddy Complex (BCMC), Kiamichi Complex (KC), Little Complex (LC), Saline Complex (SC), and Red Complex (RC). From the management unit delineations created by experts, either HUC8s or HUC10s were matched to the outlined areas. If a HUC8 unit was too large or if a single HUC10 was too small to encompass a management unit, multiple HUC10s were used to combine into one unit. For spatial scale 2, strictly HUC10s were used to delineate populations, producing a total of 32 management units (Figure 3.4, Table A2). The same six ecological settings used in spatial scale 1 were used in spatial scale 2.

Evaluating Uncertainty in Node States

Complete Uncertainty

The purpose of this model iteration, under both spatial scales, is to observe what the model's child node outputs are when resiliency, redundancy, and species vulnerability parent nodes are completely uncertain, or under uniform parent priors. This shows what assumptions persist in the model that would need to be considered once the model is more informed. This means that under this model iteration, the probabilities of being "secure" or "at risk," "adequate" or “inadequate,” and “vulnerable” or “resistant” are observed for the Individual Population Resiliency, Ecological Setting Resiliency, Ecological Setting Redundancy, Ecological Setting Extirpation Risk, and Global Imperilment Risk child nodes. When observing the resulting probabilities of these child nodes under complete uncertainty, assumptions ingrained in the model’s CPTs that were parameterized using expert judgement, literature, and empirical data by Dunn et al. (2024) would show.

The Individual Population Resiliency and Ecological Setting Resiliency child nodes both produced equal probabilities of being “secure” and “at risk” ($p = 0.50$). For the probabilities of Ecological Setting Redundancy (p(“inadequate”) = 0.61), Species Vulnerability (p(“vulnerable”) = 0.55), Ecological Setting Extirpation Risk (p(“at risk”) = 0.58), and Global Imperilment Risk (p(“at risk) = 0.58), the model predicted higher probabilities towards the poorer conditioned states for these child nodes. This means that the parent node states (i.e. the moderate or poor conditioned states) for redundancy and species vulnerability hold a stronger directional weight in the CPTs for the Ecological Setting Redundancy and Species Vulnerability child nodes to exist more in their poorer conditioned states (i.e. “inadequate” or “vulnerable”) even when better conditioned parent node states are equally probable at the same time.

Complete Certainty

The assigned states used in this model iteration are based on measured and observed states for each spatial scale (Tables A3-A11). Using the designated states for resiliency parent nodes, Individual Population Resiliency was calculated for the 13 management units in spatial scale 1 and the 32 management units in spatial scale 2 (Tables 3.6, 3.7; Figure 3.5). For spatial scale 1, the projected probabilities of being “at risk” for Individual Population Resiliency for management units ranged from 0.05 (Muddy Boggy) to 0.70 (Red and Washita), with the Red and Washita being the only management units with probabilities of being more “at risk” than “secure”. For spatial scale 2, probabilities of being “at risk” for Individual Population Resiliency ranged from 0.05 (LC4) to 0.90 (WC2), with 28% of the management units predicted to be more “at risk” than “secure.” When looking at the distribution of more “secure” (i.e., p(“at risk”) < 0.50) management units for spatial scale 1, they were concentrated in the central portion of the Rocky Shiner’s range across the BCMC, KC, LC, and SC ecological settings (Figure 3.6b). While for spatial scale 2, more “secure” management units occurred in smaller pockets within the same ecological settings (BCMC, KC, LC, and SC; Figure 3.7b).

The Individual Population Resiliency probabilities for each management unit in an ecological setting were used to calculate the Ecological Setting Resiliency for both spatial scales (Table 3.8; Figure 3.5). For this node of interest in spatial scale 1, probabilities of being “at risk” ranged from 0.15 (BCMC) to 0.70 (RC and WC), with the RC and WC being the only ecological settings being more “at risk” than “secure.” For Ecological Setting Resiliency in spatial scale 2, the probability of being “at risk” ranged from 0.33 (BCMC) to 0.83 (WC), with 50% of the six ecological settings being more “at risk” than “secure.” For the Ecological Setting Resiliency of spatial scale 1, like its Individual Population Resiliency, more resilient ecological settings (BCMC, KC, LC, and SC) were concentrated centrally in the Rocky Shiner’s range (Figure 3.6c). However, for spatial scale 2, the more resilient ecological settings (BCMC and LC) were separated and surrounded by less resilient ecological settings (WC, KC, and RC; Figure 3.7c).

When considering the Ecological Setting Redundancy, the same two ecological settings in spatial scales 1 and 2, the LC and BCMC, were more “adequate” than “inadequate” with the probabilities of being “inadequate” in spatial scale 1 ranging from 0.22 (LC) to 0.39 (BCMC) and in spatial scale 2 being 0.17 for both the LC and BCMC ecological settings (Table 3.8;

Figure 3.5). In spatial scale 1, the remaining ecological settings (WC, KC, RC, and SC) all had probabilities of 1.00 for being “inadequate.” In spatial scale 2, the WC, RC, and SC ecological settings also had a probability of 1.00 of being “inadequate,” and the KC had a probability of 0.56 of being “inadequate.” In both spatial scales, the ecological settings that exhibited more redundancy, the LC and BCMC, were separated and surrounded by the less redundant ecological settings, the KC, SC, RC, and WC, across the Rocky Shiner’s range (Figures 3.6d, 3.7d).

The resulting probabilities for the Species Vulnerability child node were the same for both spatial scales 1 and 2 because the same information sources were used, and it was assumed that the Rocky Shiner’s inherent traits were species wide and did not change across its range or by spatial scale. The model predicted that the Rocky Shiner was more “vulnerable” ($p = 0.64$) than “resistant” ($p = 0.36$).

Ecological Setting Extirpation Risks for both spatial scales were calculated using Ecological Setting Resiliency, Ecological Setting Redundancy, and Species Vulnerability child node probabilities (Table 3.8; Figure 3.5). For spatial scales 1 and 2, the LC and BCMC were the only ecological settings that were more “secure” than “at risk” with their probabilities of being “at risk” ranging from 0.32 (LC) to 0.33 (BCMC) for spatial scale 1 and with both ecological settings having a probability of being “at risk” of 0.31 in spatial scale 2. In spatial 1, the ecological settings that were more “at risk” had probabilities that ranged from 0.64 (KC) to 0.84 (RC and WC). In spatial scale 2, the more “at risk” ecological settings, which were the same as those for spatial scale 1, had probabilities ranging from 0.58 (KC) to 0.90 (WC). Across the Rocky Shiner’s range for both spatial scales, ecological settings that were predicted to be of higher risk of extirpation by being more “at risk” than “secure,” such as the KC, SC, RC, and WC, split and surrounded the more “secure” ecological settings, the LC and BCMC (Figures

3.6a, 3.7a). Using the mean of all Ecological Setting Extirpation Risks, the Global Imperilment Risk of Rocky Shiner for each spatial scale was determined, of which was the same for both spatial scales, with a probability of being "at risk" of 0.62 and a probability of being "secure" of 0.38.

Sensitivity Analysis

This analysis uses the informed uncertainty iteration, where uncertainty was propagated throughout the model based on lower bound measured and observed values as well as the belief of uncertainty in other nodes. Only changes in targeted parent nodes are observed, simulating only resolving uncertainties one parent node at a time. The informed uncertainty iteration priors used for each spatial scale to represent uncertainty while at best- or worst-case scenarios are shown in Appendix A (Tables A12-A16).

Ecological Setting Extirpation Risk

The influence of uncertain parent nodes on Ecological Setting Extirpation Risk was evaluated for each ecological setting (Figure 3.8). For spatial scale 1, all but one ecological setting, the LC, showed the Extant Populations parent node being most influential on Ecological Setting Extirpation Risks. For spatial scale 2, this parent node was either much less influential or not at all influential for half of the ecological settings, being the BCMC, KC, and LC. For the WC, SC, and RC ecological settings, overlap persisted for the Extant Populations parent node being most influential for both spatial scales. More differences in influential nodes between spatial scales can be seen for the BCMC and KC ecological settings in Figure 3.8, where there is a visual split between overlapping influential nodes, particularly for spatial scale 2, which shows more uncertainty in resiliency parent nodes than spatial scale 1. The other ecological settings, the

WC, LC, SC, and RC, show similar patterns of what nodes are most influential for each spatial scale.

The magnitude of change in being at risk is also noteworthy. For the LC, under both spatial scales, a change to better states in all uncertain parent nodes does not elicit much change in extirpation risk, with each node only inducing a change in probability of being "at risk" of ~0.05 or less. Most of the uncertainty for this ecological setting rests in resiliency parent nodes, however with such small changes in Ecological Setting Extirpation Risk, the states in these parent nodes overall, likely already exist in better conditioned states. The WC, KC SC, and RC ecological settings have the potential to be greatly influenced, ranging in changes in probability of being "at risk" from 0.30 (WC) to 0.40 (KC), by the Extant Populations redundancy parent node. In the WC and RC ecological settings, the Proportion Extant redundancy parent node also shows a higher level of influence with a possible change in probability of being "at risk" of 0.10 if the state in this node were in better condition. All other nodes in these and the other ecological settings show smaller influential changes, less than 0.10, in Ecological Setting Extirpation Risk. These less influential nodes are largely resiliency parent nodes for all ecological settings. Overall, this sensitivity analysis shows that for different ecological settings, different uncertainties matter more and that some of these uncertainties are emphasized more under different spatial scales.

Global Imperilment Risk

Under both spatial scales, the Extant Population redundancy parent node had the most influence on Global Imperilment Risk because either half of or most ecological settings existed in moderate or poor states for worst-case scenarios (Figure 3.9). The influence of this parent node on the probability of being "at risk" of global imperilment ranged from 0.19 for spatial scale 1 to 0.25 for spatial scale 2. All other influential parent nodes show a similar smaller influence between spatial scales, with changes in being "at risk" of imperilment of ~0.05 or less. So, if uncertainties from the Extant Population parent node are resolved through targeted sampling and management for certain ecological settings, then we would see the greatest improvement for Global Imperilment Risk for Rocky Shiner. This has to do with both understanding the correct population spatial scales for the species as well as targeted sampling efforts and management to resolve uncertainties.

Recommended Threat Nodes

If a separate threat analysis for Rocky Shiner was to not be completed in its SSA, but rather be incorporated into this BBN, then several suggested changes to the model's threat node structure could be made. These threats could eventually be incorporated into the model once realized effects of these threats on Rocky Shiner are known. Using Rocky Shiner specific literature, surrogate species, and expert opinion, in combination with available datasets, four possible incorporable threats were selected.

Reservoirs were mentioned both in surrogate species literature as causes for declines, absences, and extirpations (Smith 1979; Cross and Collins 1995; Mammoliti 2002; RPW 2024) and by experts to be of concern for Rocky Shiner (Thomas M. Buchanan, University of Arkansas, pers. comm.). Reservoirs could threaten Rocky Shiner by changing habitat availability (Smith 1979; Cross and Collins 1995), altering quantity and timing of flows (Galbraith et al. 2010; Gido et al. 2010; RPW 2024), altering the species community (Mammoliti 2002), increasing turbidity and sedimentation (Wood and Armitage 1997; Mammoliti 2002; FTN Associates, Ltd 2016), and decreasing connectivity (Cross and Collins, 1995; Gido et al. 2010; RPW 2024). This threat could be measured using the presence and absence of reservoirs in management units. Resources and data that could be used to inform this possible node include the U.S. Army Corps of Engineers and the USGS NHD, which together provide descriptions of reservoirs and a visual representation of their bounds.

The presence of gravel mining operations has been linked to population declines and possible extirpations of Rosyface Shiner (Etnier and Starnes 1993) and may also pose a threat to Rocky Shiner (Humphries and Cashner 1994; RPW 2024). Mining operations can degrade and decrease riffle habitat and increase sedimentation, siltation, and turbidity (Humphries and Cashner 1994; Brown et al. 1998; Galbraith et al. 2010; RPW 2024). The presence or absence of mining operations could be used to determine the threat level in a Rocky Shiner management unit. For the state of Arkansas, the Arkansas Department of Energy and Environment – Division of Environmental Quality's permit data system could be used to determine if any mining operations currently occur within management unit bounds. This system allows the user to search for active gravel related mining permits by county in Arkansas and provides coordinates for those operations. For the state of Oklahoma, the Oklahoma Department of Mines can provide a list of all mining operations, with their associated mining products and coordinates.

Forestry related activities have been suggested to be of possible concern for Rocky Shiner (Fowler and Anderson 2015; RPW 2024). Forestry related activities such as road construction, fertilization, and clear cutting can increase runoff, erosion, siltation, sedimentation, turbidity, and pollutants in waterways (Matthews et al. 2005;Galbraith et al. 2010; FTN Associates, Ltd 2016; Vaughn et al., 2023; RPW 2024), all of which could negatively influence Rocky Shiner populations. The Forest Service Activity Tracking System database includes timber harvest data that are reported by U.S. Forest Service units. The U.S. Forest Service's advertised timber sales could also be used to infer future plans for forestry related activities. The

Oklahoma Forestry Service's spatial data on sawmill locations may also offer insight into forestry activities in the Rocky Shiner's range in this state. Global Forest Watch data, specifically for tree cover loss, could be used to suggest areas where silviculture activities have been recently active by using the loss of trees as a proxy for the forest industry being present. The presence or absence of forest activities in management units could be used to inform the overall threat level for Rocky Shiner.

Agricultural land use has been linked to the disappearance of Carmine Shiner (Cross and Collins 1995) and has been suggested to be a possible threat to Rocky Shiner (Humphries and Cashner 1994; Pratt 2000; RPW 2024). This land use can change suitable habitat for Rocky Shiner by both increasing runoff, nutrient loads, sedimentation, and siltation (Lenat and Crawford 1994; Cross and Collins 1995; FTN Associates, Ltd 2016; RPW 2024). Development and urban land use were mentioned by experts to also be of concern for Rocky Shiner (Pers. comm. W.J. Matthews, University of Oklahoma; Pers. comm. T.M. Buchanan, University of Arkansas; RPW 2024). This has the potential to decrease water quality in streams due to increased runoff, sedimentation, turbidity, and temperature (Lenat and Crawford 1994; RPW 2024). The National Land Cover Database could be used to represent total percentages of land use in Rocky Shiner management units, where higher percentages of agriculture and urban related land use would be associated with a higher threat level to the species.

Each of these four threats could be incorporated as parent nodes into the resiliency portion of the model to inform the Other Threats child node probabilities of being "high risk" or "low risk," which would influence a specific management unit's Individual Population Resiliency. If these suggested threats are confirmed to be representative of real-world threats to Rocky Shiner, either through direct experimentation, observation, or monitoring, then appropriate states for each could be selected and a new CPT for the Other Threats node could be developed (Figure 3.10). This serves as a starting point for how this model could be more customized to Rocky Shiner, so its calculated Ecological Setting Extirpation Risks and Global Imperilment Risk are more biologically relevant to the species.

DISCUSSION

In this present study, we evaluate the current condition of Rocky Shiner given available data, identify uncertainties within the BBN and in the available data for Rocky Shiner, and propose potential Rocky Shiner threat nodes to include in future iterations of the model. Rocky Shiner, under both spatial scales used in this study in the certain model iteration, showed higher probabilities of the species being "at risk" of global imperilment, in fact, the two spatial scales used produced the same probabilities. Though this result may appear to minimize the effect of population spatial scale in this BBN, both spatial scales resulted in the same Global Imperilment Risk probabilities via different pathways, particularly through resiliency and redundancy parent nodes.

Given that Rocky Shiner is data limited, the size of the units evaluated in the two spatial scales likely led to differences in the probabilities assigned to the different states of the parent nodes for resiliency. Spatial scale 1 included larger units of evaluation, and therefore more data per unit for evaluation, which could have led to Rocky Shiner existing in better conditioned states for each management unit in this spatial scale. For example, the KC ecological setting for spatial scale 1 was split amongst eight management units in spatial scale 2, which left less data available for use in each spatial scale 2 management unit, leading to poorer measured and observed states. This difference in resiliency between spatial scales is shown in the Ecological

Setting Resiliency child node where all ecological settings for spatial scale 1 were either equally or less "at risk" than those for spatial scale 2. On the other hand, the difference in the number of management units in the two spatial scales likely caused differences in the probabilities assigned to redundancy parent node states. Spatial scale 1 had, overall, fewer management units per ecological setting than spatial scale 2, which could have led to poorer conditioned states for each of its ecological settings. For example, the BCMC ecological setting had three management units in spatial scale 1, compared to nine in spatial scale 2, which not only decreased the number of populations available to be considered extant in spatial scale 1, but also increased the fluvial distance between those fewer management units, causing connectivity to be considered worse. Having fewer populations penalized the Ecological Setting Redundancy for spatial scale 1, which was shown by all of its ecological settings having higher or equal probabilities of being "inadequate" to those in spatial scale 2. With spatial scale 1 having higher resiliency than spatial scale 2, spatial scale 2 having higher redundancy than spatial scale 1, and both scales having the same species vulnerability probabilities, the Global Imperilment Risk for each spatial scale was the same.

Population structure delineation in SSAs has varied across species of shiners, with the Cape Fear Shiner (*Notropis mekistocholas*) and Topeka Shiner (*N. topeka*) being divided into subpopulations at a HUC10 scale and the Arkansas River Shiner (*N. girardi*) portioned into subunits using qualities like river length and the presence of impoundment structures (USFWS 2018a, 2018b, 2022). Understanding the population structure of a species is important to understanding how the species sustains itself and interacts with its environment. In SSAs, being able to describe a species at the correct population scale and then using population-specific quality and quantity of habitat, trends in abundance and distribution, and effects from environmental and anthropogenic factors allows for properly understanding the species' resiliency, or ability to withstand stochastic disturbances (USFWS 2016b; Smith et al. 2018). Knowing the number and distribution of these populations is also important for SSAs regarding a species' redundancy, or the ability of the species to withstand catastrophic events by spreading risk amongst many resilient populations (USFWS 2016b; Smith et al. 2018). As seen in this present study, these two important aspects of the SSA framework differ under the two spatial scales for Rocky Shiner, indicating that population structure may be of importance to resolve for Rocky Shiner's SSA document. Also, of importance to SSA documents is considering the current status of the species of interest.

Regarding the outcome of Global Imperilment Risk, this study showed that when using the data available for Rocky Shiner, the model predicted that the species was at greater risk of imperilment than not. In 2008, the American Fisheries Society Endangered Species Committee designated the status of Rocky Shiner as vulnerable, defined as being "in imminent danger of becoming threatened throughout all or a significant portion of its range" (Jelks et al. 2008). This species also has a NatureServe global status G3, or vulnerable, ranking which means that the species was designated to be at moderate risk of extinction (NatureServe 2025). Rocky Shiner is also a Species of Greatest Conservation Need in both Oklahoma and Arkansas (ODWC 2015; Fowler and Anderson 2015). Though the results of this present study for Global Imperilment Risk, with Rocky Shiner more "at risk" than "secure," do support these status designations for the species, the availability of data likely led to uncertainty that could influence its assigned status.

The ecological settings in this study that were more "at risk" than "secure" of extirpation had much less data. For example, the SC, WC, and RC ecological settings all had only three spatial data points each, which led to many of their parent nodes being assigned poor states. The KC ecological setting had 73 spatial data points and was still more “at risk” than “secure” of extirpation. The ecological settings that were more “secure,” the BCMC and LC, both had 115 spatial data points each. Because we are lacking targeted sampling efforts in some areas of Rocky Shiner’s range, we are unsure if the species is there and unaccounted for or if it is truly absent from these places. However, there could be environmental and anthropogenic influences on Rocky Shiner that may have contributed to poor conditions of the species, leading to limited data availability in the more “at risk” ecological settings.

Previous studies have shown that instream conditions in portions of the Rocky Shiner’s range have been degraded by a number of external factors. In the KC ecological setting, low flows, dried riffle habitat, shallow isolated pools, high temperatures, and siltation have all been observed and attributed to climate conditions, reservoir management, land use, and gravel mining (Galbraith et al. 2010; Atkinson et al. 2014; DuBose et al. 2019; Vaughn et al. 2023). In the SC ecological setting, high sediment conditions due to reservoir management, agricultural practices, and the forestry industry have been reported (FTN Associates, Ltd 2016) and in addition to this, the SC ecological setting is isolated from other ecological settings due to fragmentation from two reservoirs. The RC ecological setting has been reported to experience high water temperatures and increased concentrations of sediment (Zimmerman and Matthews 1990; Copeland 2002; Matthews et al. 2005). The WC ecological setting has been observed to exhibit high water temperatures, sedimentation, and isolation by reservoir construction (Zimmerman and Matthews 1990; Chappell 1995; Vaughn et al. 2023). All of these factors could have negatively affected Rocky Shiner populations in these areas, possibly causing the lack of reports of the species.

The results of this study highlight the importance of having adequate data prior to ESA listing decisions and species status evaluations, such that the species can be both evaluated in a timely manner and the listing decision be guided by the best information possible. Without adequate data, species listing decisions can be continuously delayed (Carden 2006; Robbins 2009; Goode et al. 2023). However, these listing decisions cannot be indefinitely postponed and must make do with the uncertainty at hand using the "best available science," as directed for use by the ESA and USFWS for listing decisions (16 U.S.C. § 1533(b); FWS and NMFS 1994; Carden 2006; Murphy and Weiland 2016). Though this best available science approach does not have a strict definition for ESA or SSA use, it has been suggested that it can be met with the most reliable information at the time of analysis, which can include expert opinion, surrogate species, and either a substantive or small amount of species-specific literature, whichever is available (Lowell and Kelly 2016; Murphy and Weiland 2016). In this study, the most reliable knowledge and data available for Rocky Shiner at the time of analysis were used, which included all known spatial data points for the species, species-specific literature, surrogate species, and expert opinion. As long as uncertainties are explicitly represented in data poor circumstances, it has been stated that the best available science requirement can be accomplished (Murphy and Weiland 2016).

In this present study, uncertainties in parent node states were explored, which revealed that sensitivity in model outputs came from the use of different spatial scales and the Extant Populations parent node. Changes in spatial scale caused differences in uncertain parent node influences for the KC and BCMC ecological settings. This was shown by the Ecological Setting Extirpation Risk for the KC and BCMC being influenced by changes in more redundancy parent nodes for spatial scale 1 and influenced by changes in more resiliency parent nodes for spatial scale 2. This was likely due to less available data for resiliency parent nodes, for spatial scale 2, and redundancy parent nodes, for spatial scale 1. For the remaining ecological settings, spatial scale did not cause as much variation in influential parent nodes. For the WC, RC, and SC ecological settings, both spatial scales showed the most uncertainty and influence from the Extant Populations redundancy parent node. For both the WC and RC ecological settings, this not only has to do with the small number of management units that Rocky Shiner has been reported in, but also that the species has not been reported in these ecological settings since 1993 in the WC and 1967 in the RC. For the SC ecological setting, the species has been recently reported, but due to the lack of connectivity to other potentially suitable habitats from reservoir construction, the species has been confined to one population under both spatial scales, which is why its extirpation risk could most greatly improve by gaining more Rocky Shiner populations in this ecological setting. The LC ecological setting showed the least sensitivity to changes in parent node states, confirming it is likely in good condition and at less risk of extirpation. Because the majority of ecological settings' extirpation risks were most sensitive to the Extant Populations parent node, Global Imperilment Risk was also most sensitive to changes in this node, likely pointing to possible improvements in the Rocky Shiner's current risk through research and management.

The uncertainties, limited data availability, and current understanding of Rocky Shiner's status, as described in this study may lead to informing possible targeted research and management efforts for Rocky Shiner. Ecological settings that showed higher uncertainties (i.e., KC, SC, RC, and WC) in parent nodes or spatial scale and had higher risks of extirpation may hold the most value towards improving the Rocky Shiner's current Global Imperilment Risk if targeted sampling efforts were to provide information of the species existing in better condition.

If targeted sampling efforts confirmed poor conditions, then management practices could be implemented to best improve the imperilment risk of Rocky Shiner. This includes possibly reintroducing the species into historically occupied ranges, which was successfully planned and completed for the endangered Topeka Shiner in Missouri, where reproduction, survival, and expansion of the species has been observed (USFWS 2013, Missouri Department of Conservation 2022, p. 8). It is also important to maintain Rocky Shiner in those ecological settings that are already considered to be in good standing, like the BCMC and LC, to preserve adaptive potential (i.e. representation), reduce effects from catastrophic events (i.e. redundancy), and increase the ability to withstand stochastic disturbances (i.e., resiliency; USFWS 2016b, 2020; Smith et al. 2018).

Other uncertainties that were explored in this study included those concerned with the BBN itself. By incorporating the complete uncertainty iteration, we explored uncertainties ingrained in the model, which revealed assumptions in the model's CPTs that resulted in a Global Imperilment Risk that was more "at risk" than "secure." This was likely from poorer conditioned states in redundancy and species vulnerability parent nodes having more weight in CPTs towards the direction of being in the higher risk child node state than the better conditioned parent node states had for being in the lower risk child node state. This shows that, perhaps, in the absence of data or in the presence of data with poor conditioned states, even if equally present to better conditioned states, that this does not lead to equal probability of a species being "at risk" or "secure" of global imperilment. This points to types of decision errors commonly associated with the ESA, which are Type I and Type II errors. Type I errors occur when a species is protected but does not need protection and Type II errors occur when the species needs protection but is not protected (Carden 2006; Woods and Morey 2008; Robbins 2009). In this case with the Dunn et al. (2024) BBN, Type II errors may be more readily avoided since this model favors higher risks of imperilment via its CPTs. This may be appropriate because the model is meant to work with data limited species that may not have much reliable information available.

This model proved convenient in the case of Rocky Shiner because when information is lacking for species, there is no guidance in the ESA that describes what specific analyses can be conducted with different levels of data availability (Carden 2006). With the available data on Rocky Shiner, gaining insight into the belief of its current condition was achievable using the Dunn et al. (2024) BBN. However, as with the best available science approach, there is no definition for what makes a species "data limited," so even though the BBN was developed to work with data limited species, the outputs are largely still dependent upon the data available for the species, as shown in the sensitivity analysis in this present study.

There is not a set amount and type of data that has been used for all listing decisions, in fact, ESA decisions have been noted to at times correlate with nonscientific factors such as species type, land ownership, the time a species was a candidate, the type of decision (i.e. single or multi-species), and political opinions (Laband and Nieswiadomy 2006; Harllee et al. 2009; Smith-Hicks and Morrison 2021). The data presented for listing decisions has also been shown to vary. For example, Smith-Hicks and Morrison (2021) found that in 143 ESA listing decisions from 2011 to 2014, the USFWS provided documentation of population size ranges only 31% of the time and population size estimates only 33% of the time.

Though the SSA format does help with defining some of the information needed for documentation, such as that for resiliency (i.e. abundance, survival, and growth rate), redundancy (i.e. the number of populations and connectivity), and the species' current condition (i.e. population trends and causes and effects of stressors; USFWS 2016b; Smith et al. 2018), the “best available science” varies across species, with information lacking for many species (Lowell and Kelly 2016). With variability in available data types across species and without a standardized methodology for evaluating species how do we approach situations when species are petitioned for listing that we do not know much about?

The Dunn et al. (2024) BBN may be a solution. A need for biological criteria to be developed that is both applicable across species and within species groups was called for by Easter-Pilcher (1996), specifically suggesting that “mutually exclusive quantitative ranges to apply to qualitative categories” be of focus for ESA decision making. Cape Fear Shiner, Arkansas River Shiner, and Topeka Shiner had different modeling approaches conducted for their SSAs, which included condition category tables and ranking mechanisms, which used specific scoring procedures per species. These models incorporated components that the Dunn et al. (2024) BBN already has built into it such as abundance, occupied habitat, connectivity, habitat complexity, occupancy, years since last reported, and the number of populations, which points to the information used in the BBN being transferrable across species. The Dunn et al. (2024) BBN could set the standard for informing SSA documents and ESA listing decisions, which could provide a more consistent approach for evaluations, tackle the backlog of species awaiting listing, allow comparisons amongst species, and identify data gaps to inform research and management prior to listing (Easter-Pilcher 1996; Carden 2006; Robbins 2009).

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TABLES

Table 3.1: Resiliency child and parent nodes for the Rocky Shiner BBN at the scale of singular management units. Notations in the parent node column reflect information and data sources used to determine management units existing in a state. Possible states for each resiliency parent node are adapted from Dunn et al. (2024). The description column describes how each parent node is measured, calculated, or determined.

Child Node	Parent Node	States	Description
Local Distribution	Occupied Segments[a, b]	One (1)	Number of unique stream segments, denoted by tributary junctions, occupied by the species regardless of time period.
		Rare (2-5)	
		Many (>5)	
	Occupied Stream Length (km)[a, b]	Restricted (<10 km)	The fluvial distance between the most upstream and downstream segments occupied by the species since 2000.
		Moderate (10-25 km)	
		Widespread (>25 km)	
	Network Complexity[a,b]	Mainstem	Type of stream segments occupied by the species.
		Single Tributary	
		Multiple Tributaries	
		Complex (mainstem and tributaries)	
Population Strength	Naive Occupancy (current)[a, b]	Potentially Extirpated (<=0.05)	Proportion of all stream segments occupied by the species since 2000.
		Rare (0.06-0.25)	
		Uncommon (0.26-0.50)	
		Common (>0.50)	
	Naive Occupancy Trend (%)[a, b]	Relatively Stable (Growth or <5% decline)	Percent change between historical (pre-2000) and current naive occupancy (post-1999).
		Moderate Decline (5%-30% decline)	
		Strong Decline (>30% decline)	

a – Rocky Shiner spatial data
b – NHDPlus High Resolution Dataset
c – Rocky Shiner literature
d – expert opinion
c – USGS Nonnative Aquatic Species Database

Table 3.1: Continued.

Child Node	Parent Node	States	Description
Population Strength	Qualitative Abundance[a, b]	Rare (<10 individuals)	Maximum number of individuals reported in a single stream segment on a single date.
		Uncommon (10-75 individuals)	
		Abundant (>75 individuals)	
	Years Since Last Encounter[a]	Recent (<10 years)	Number of years since the species was last reported.
		Moderate (10-30 years)	
		Historical (>30 years)	
Other Threats	Hybridization[c, d]	Yes	If hybridization is present or absent.
		No	
	Nonnative Species[b, e]	Absent (0 species)	Richness of nonnative fish species.
		Few (1-5 species)	
		Many (>5 species)	

a – Rocky Shiner spatial data
b – NHDPlus High Resolution Dataset
c – Rocky Shiner literature
d – expert opinion
c – USGS Nonnative Aquatic Species Database

Table 3.2: Child nodes for the Rocky Shiner BBN. Possible states for each child node are adapted from Dunn et al. (2024).

Resiliency Child Nodes	States
Local Distribution	Adequate
	Inadequate
Population Strength	Adequate
	Inadequate
Other Threats	Low Risk
	High Risk
Individual Population Resiliency	Secure
	At Risk
Ecological Setting Resiliency	Secure
	At Risk
Population Connectivity	Adequate
	Inadequate
Ecological Setting Redundancy	Adequate
	Inadequate
Specialization	Generalist
	Specialist
Species Vulnerability	Resistant
	Vulnerable
Ecological Setting Extirpation Risk	Secure
	At Risk
Global Imperilment Risk	Secure
	At Risk

Table 3.3: Redundancy child and parent nodes for the Rocky Shiner BBN at the scale of ecological settings (i.e., a multi-population scale). Notations in the parent node column reflect information and data sources used to determine management units existing in a state. Possible states for each redundancy parent node are adapted from Dunn et al. (2024). The description column describes how each parent node is measured, calculated, or determined.

Child Node	Parent Node	State	Description
Population Connectivity	Population Isolation (km)[a, b, c]	Near (<15 km)	Mean shortest path distance from the midpoint of an occupied segment to the closest midpoint of an occupied segment in a different management unit. One shortest path distance measured per management unit.
		Moderate (15-50 km)	
		Far (>50 km)	
	Network Connectivity (%)[a, b, c, d]	Fragmented (<25%)	Percentage of all shortest path connections among management units uninterrupted by SARP barriers. Shortest path connections are determined as the shortest fluvial path from the midpoint of a stream segment in one management unit to the midpoint of a stream segment in another management unit. All pairwise connections are used for all management units. Only one stream segment is used per pairwise connection per management unit.
		Moderate (25%-75%)	
		High (>75%)	
	Ranging Movements (km)[e]	Short (Local: <5 km)	Home-range size/travel distance for adults of the species of focus.
		Moderate (Ranging: >5km)	
		Long (Migration across discrete habitats)	

a – Rocky Shiner spatial data
b – NHDPlus High Resolution Dataset
c – USGS Watershed Boundary Dataset
d – SARP barriers
e – Expert opinion

Table 3.3: Continued.

Child Node	Parent Node	State	Description
Redundancy	Proportion Extant (count)[a, c]	Low (<0.34)	Proportion of management units with a current naive occupancy (post-1999) of >0.05.
		Moderate (0.34-0.67)	
		High (>67)	
	Extant Populations [a, c]	Few (0-1 management units)	Number of management units with a current naive occupancy (post-1999) of >0.05.
		Moderate (2-5 management units)	
		Many (>5 management units)	

a – Rocky Shiner spatial data
b – NHDPlus High Resolution Dataset
c – USGS Watershed Boundary Dataset
d – SARP barriers
e – Expert opinion

Table 3.4: Species vulnerability child and parent nodes for the Rocky Shiner BBN at the species-wide scale. Notations in the parent node column reflect information and data sources used to determine management units existing in a state. Possible states for each redundancy parent node are adapted from Dunn et al. (2024). The description column describes how each parent node is measured, calculated, or determined. Refer to Table 3.5 for descriptions of the different types of information used to inform these nodes and referenced in foot notes.

Child Node	Parent Node	States	Description
Specialization	Adult Feeding Guild[a, b]	Piscivore	Consume primarily fish
		Invertivore	Consume primarily invertebrates
		Other	Consumes lower trophic levels (algae, vegetation, detritus)
	Lotic Dependency[a, b, c]	Lotic	Obligate or prefers flowing streams or rivers
		Lentic	Prefers slow or no flow waterbodies
	Benthic Dependency[a, b]	Non-Benthic	Not an obligate benthic forager or spawner at any life stage
		Partially Benthic	Is an obligate benthic forager or spawner at any life stage
		Fully Benthic	Is both an obligate benthic forager and spawner at any life stage
	Drift Dependency[a, b]	Drift Dependent	Spawning dependent upon unfragmented rivers
		Other	Has other spawning mode that does not require drifting

a – Rocky Shiner literature
b – Surrogate species literature
c – Rocky Shiner range literature
d – Expert opinion

Table 3.4: Continued.

Child Node	Parent Node	States	Description
Species Vulnerability	Life History Strategy[a, b, c, d]	Opportunistic	Has a short life span and generation time, small number of eggs, low parental investment, and can withstand variable environmental conditions
		Periodic	Has a long life span and generation time, large number of eggs, low parental investment, and adapted to moderate changes in environmental conditions
		Equilibrium	Has a variable life span and generation times, small number of eggs, high parental investment, and cannot withstand changes in environmental conditions
	Maximum Length[a, b]	Small	TL < 250 mm
		Medium	TL between 250 – 500 mm
		Large	TL > 500 mm

a – Rocky Shiner literature
b – Surrogate species literature
c – Rocky Shiner range literature
d – Expert opinion

Table 3.5: Citations for information used to inform species vulnerability parent nodes for the Rocky Shiner.

Parent Node	a) Rocky Shiner Literature	b) Surrogate Species Literature	c) Rocky Shiner Habitat Literature	d) Expert Opinion
Adult Feeding Guild	Robison and Buchanan (1998) Hargrave (2005); Robison and Buchanan (2020)	Pfeiffer (1955); Reed (1957a); Hoover (1988); Watkinson and Sawatzsky (2013); Macnaughton et al. (2020); Enders et al. (2020)	NA	NA
Lotic Dependency	Pratt (2000); Zbinden et al. (2021)	Reed (1957a); Miller (1964); Pfleiger (1975); Smith (1979); Lee et al. (1980); Becker (1983); Watkinson and Sawatzky (2013); Macnaughton et al. (2020)	Galbraith et al. (2010); Atkinson et al. (2014); DuBose et al. (2019)	NA
Benthic Dependency	Hargrave (2005)	Pfeiffer (1955); Timbrook (1983); Macnaughton et al. (2020); Enders et al. (2020)	NA	NA
Drift Dependency	NA	Raney (1940); Pfeiffer (1955); Reed (1957b); Reed (1958); Cross (1967); Eddy and Underhill (1974); Pfleiger (1975); Baldwin (1983); Etnier and Starnes (1993); Cross and Collins (1995); Macnaughton et al. (2020)	NA	NA

Table 3.5: Continued.

Parent Node	a) Rocky Shiner Literature	b) Surrogate Species Literature	c) Rocky Shiner Range Literature
Life History Strategy	Robison and Buchanan (2020)	Raney (1940); Pfeiffer (1955); Reed (1957a); Miller (1964); Cross (1967); Pflieger (1975); Smith (1979); Lee et al. (1980); Baldwin (1983); Becker (1983); Vives (1990); Watkinson and Sawatzsky (2013); Macnaughton et al. (2020)	Chappell (1995); Galbraith et al. (2010); Atkinson et al. (2014); Atkinson and Cooper (2016); DuBose et al. (2019); Zbinden et al. (2021); Vaughn et al. (2023)
Maximum Length	Humphries and Cashner (1994); Pratt (2000)	NA	NA

Table 3.6: Rocky Shiner Individual Population Resiliency for management units of spatial scale 1 under the complete certainty model iteration for the BBN.

Management Unit	p(at risk)
Washita	0.70
Blue	0.32
Clear Boggy	0.10
Muddy Boggy	0.05
Kiamichi	0.18
Upper Little	0.35
Lower Little	0.18
Glover	0.35
Mountain Fork	0.27
Rolling Fork	0.48
Cossatot	0.23
Saline	0.46
Red	0.70

Table 3.7: Rocky Shiner Individual Population Resiliency for management units of spatial scale 2 under the complete certainty model iteration for the BBN.

Management Unit	p(at risk)
WC1	0.76
WC2	0.90
BCMC1	0.32
BCMC2	0.60
BCMC3	0.29
BCMC4	0.17
BCMC5	0.40
BCMC6	0.22
BCMC7	0.23
BCMC8	0.33
BCMC9	0.46
KC1	0.43
KC2	0.47
KC3	0.50
KC4	0.18
KC5	0.48
KC6	0.85
KC7	0.57
KC8	0.71
LC1	0.35
LC2	0.48
LC3	0.18
LC4	0.05
LC5	0.35
LC6	0.57
LC7	0.43
LC8	0.48
LC9	0.23
LC10	0.30
SC1	0.46
RC1	0.76
RC2	0.69

Table 3.8: Rocky Shiner Ecological Setting Resiliency, Ecological Setting Redundancy, Ecological Setting Extirpation Risk for each ecological setting for spatial scale 1 and 2 under the complete certainty iteration for the BBN.

Ecological Setting	Spatial Scale	Ecological Setting Resiliency p(at risk)	Ecological Setting Redundancy p(inadequate)	Ecological Setting Extirpation Risk p(at risk)
WC	1	0.70	1.00	0.84
	2	0.83	1.00	0.90
BCMC	1	0.15	0.39	0.33
	2	0.33	0.17	0.31
KC	1	0.18	1.00	0.64
	2	0.52	0.56	0.58
LC	1	0.31	0.22	0.32
	2	0.34	0.17	0.31
SC	1	0.46	1.00	0.75
	2	0.46	1.00	0.75
RC	1	0.70	1.00	0.84
	2	0.73	1.00	0.84

FIGURES

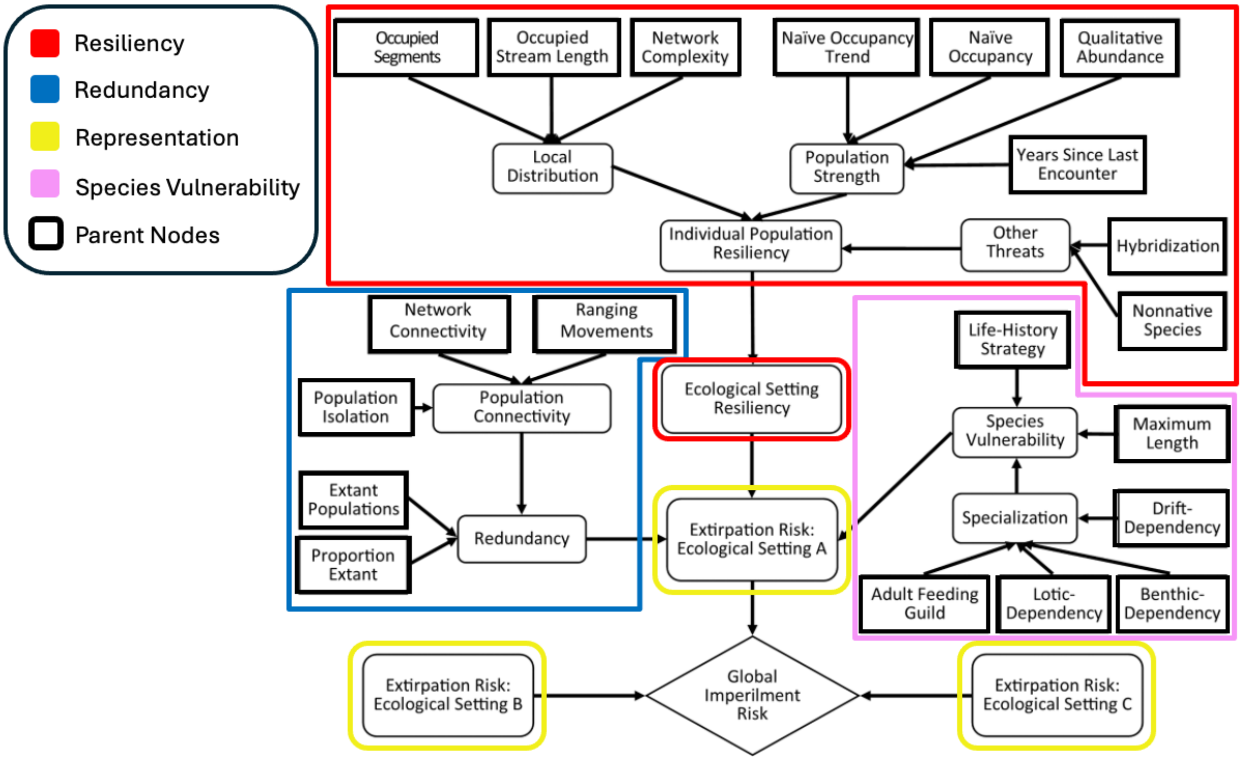

Figure 3.1: Influence diagram from Dunn et al. (2024) used for outlining the BBN with resiliency nodes in red, redundancy nodes in blue, representation nodes in yellow, species vulnerability nodes in pink, and parent nodes with bolded outlines.

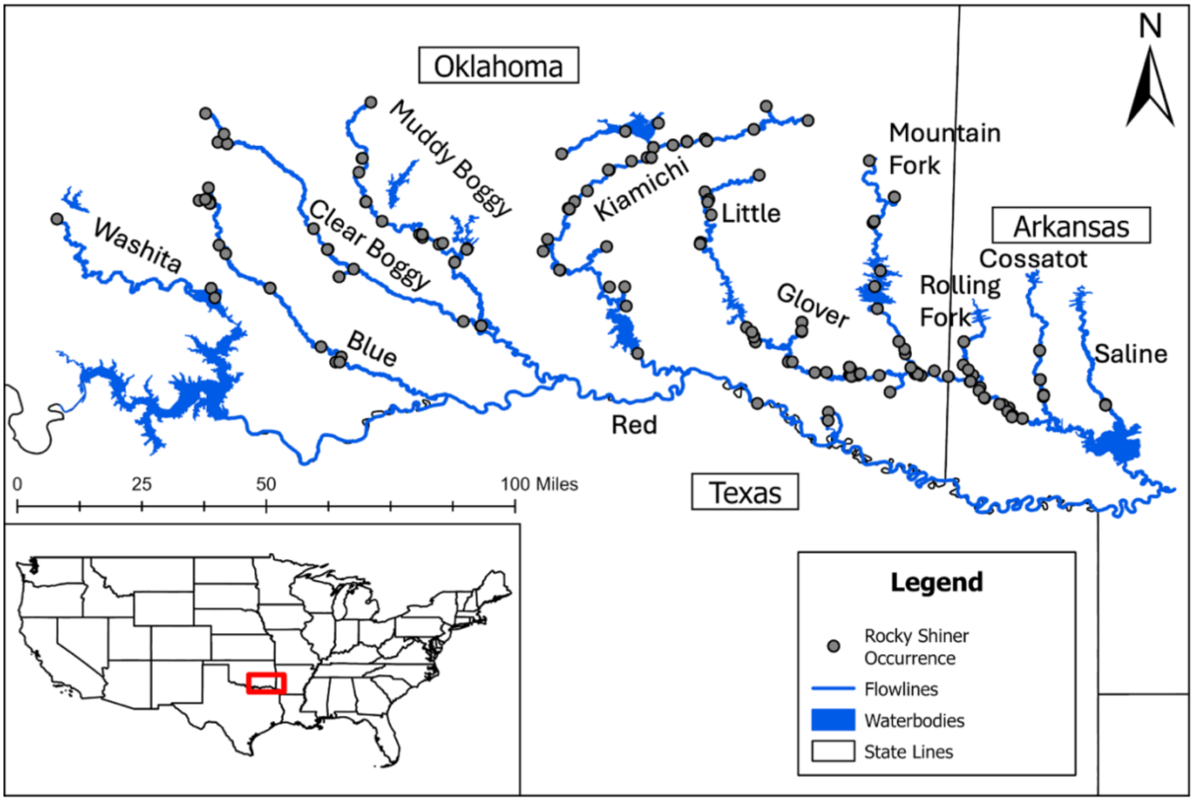

Figure 3.2: Rocky Shiner presence-only occurrence records mapped across the species' range in Oklahoma and Arkansas. Rocky Shiner occurrence records from 1947 to 2024 are shown in gray circles. Flowlines of rivers and streams where Rocky Shiner occurs are shown in in blue lines. Waterbodies are shown as blue polygons. State boundaries are shown as white polygons with black borders.

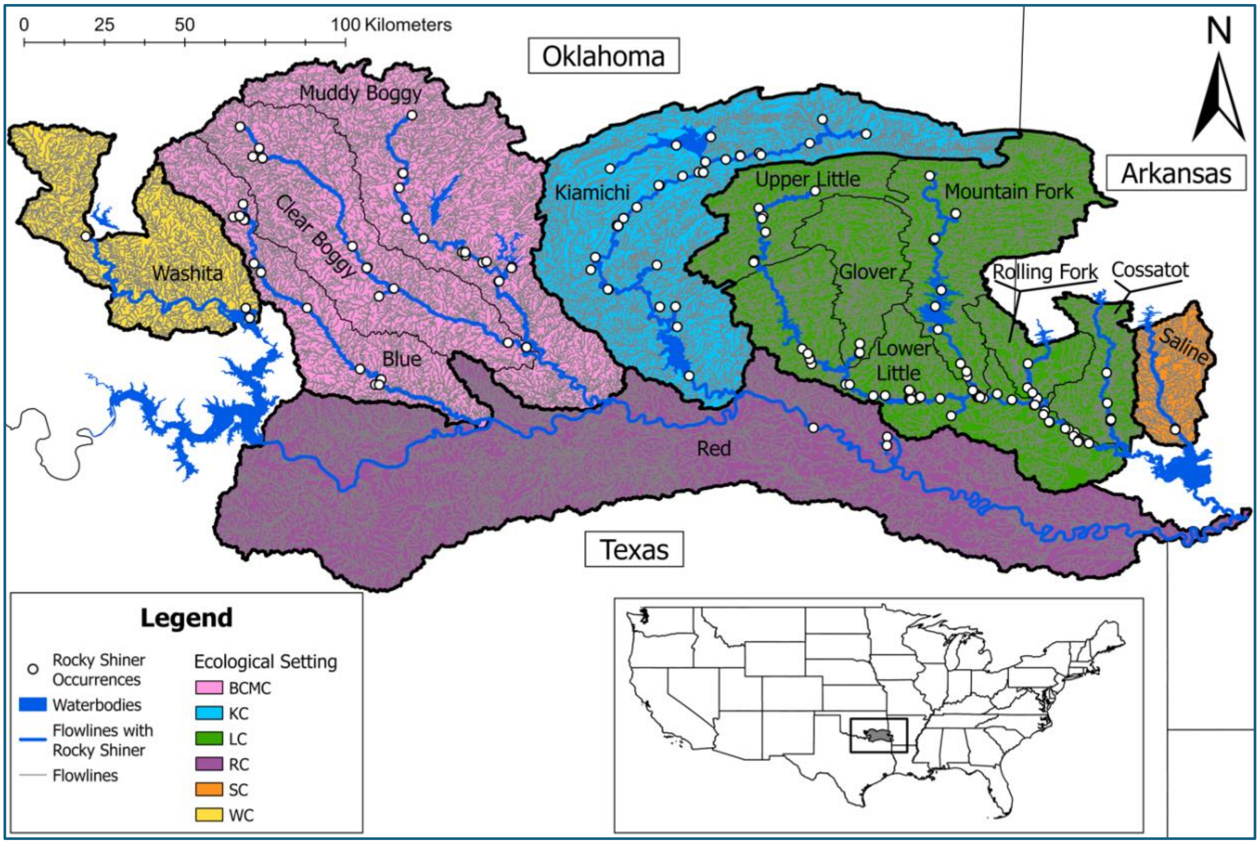

Figure 3.3: Spatial scale 1 of management units and ecological settings developed by expert opinion for the Rocky Shiner to evaluate the current probability that the species is at risk of imperilment, as part of a Species Status Assessment. Ecological settings are represented by different colors and thick borders. Management units in each ecological setting have smaller borders and are labeled. Waterbodies and flowlines were sourced from the USGS National Hydrography Dataset Plus High Resolution, hydrological boundaries in the form of Hydrological Unit Codes were sourced from the USGS Watershed Boundary Dataset, and US state boundaries were sourced from the US Census Bureau's Cartographic Boundary Files.

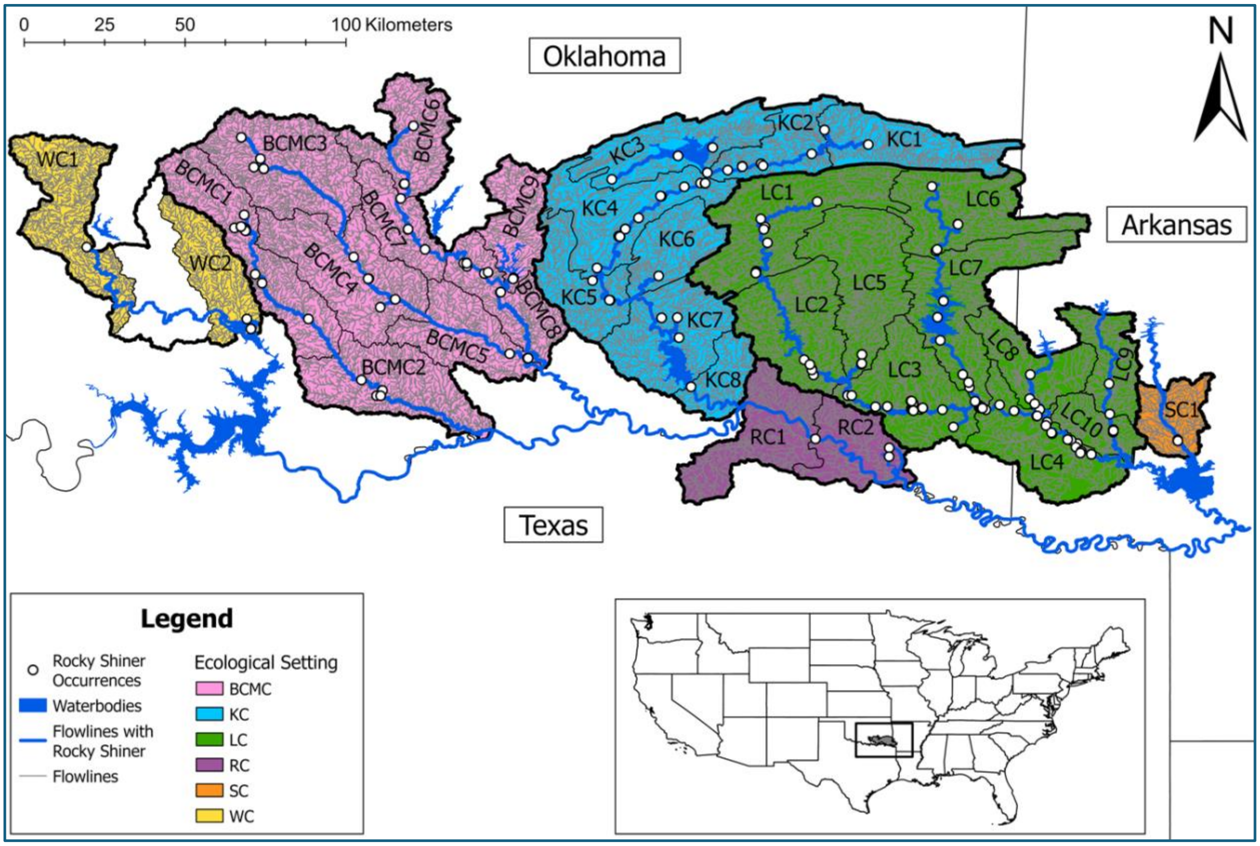

Figure 3.4: Spatial Scale 2 of management units and ecological settings developed using HUC10s for the Rocky Shiner to evaluate the current probability that the species is at risk of imperilment, as part of a Species Status Assessment. Ecological settings are represented by different colors and thick borders. Management units in each ecological setting have smaller borders and are labeled. Waterbodies and flowlines were sourced from the USGS National Hydrography Dataset Plus High Resolution, hydrological boundaries in the form of Hydrological Unit Codes were sourced from the USGS Watershed Boundary Dataset, and US state boundaries were sourced from the US Census Bureau's Cartographic Boundary Files.

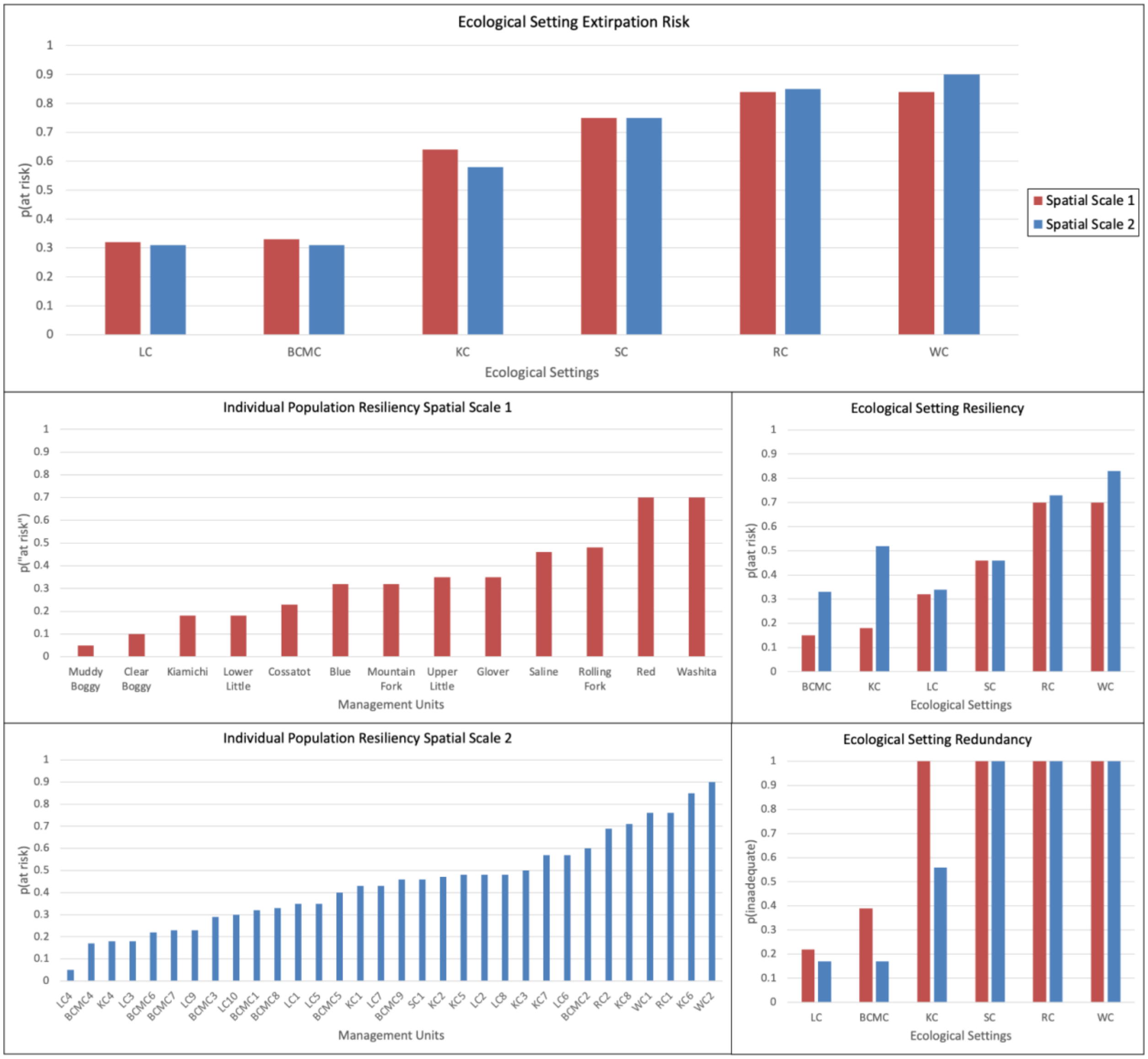

Figure 3.5: Graphical representations of the BBN child node probability outputs for spatial scale 1 and 2 under the complete certainty iteration for the Rocky Shiner. The red bars represent spatial scale 1 and the blue bars represent spatial scale 2.

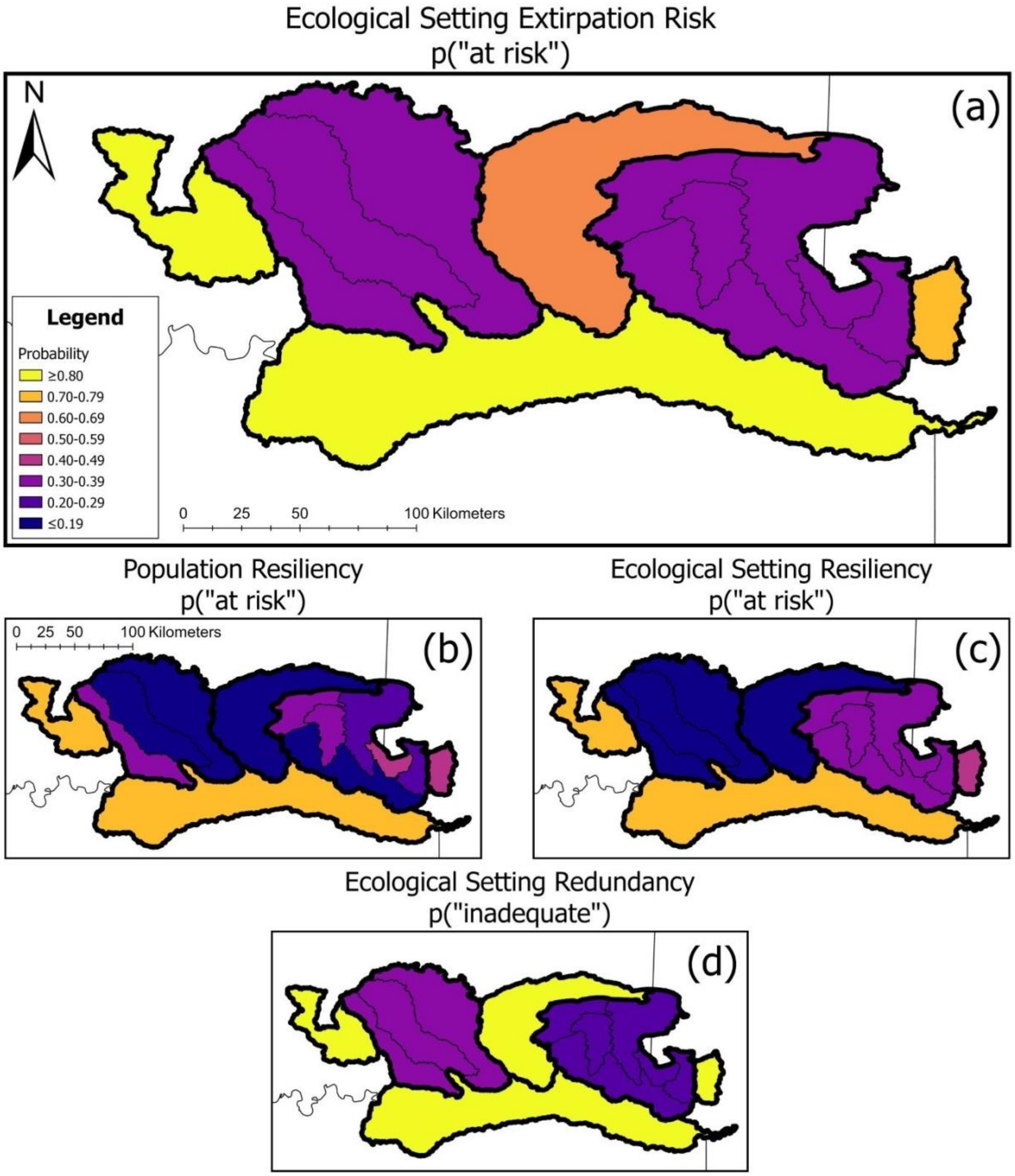

Figure 3.6: Maps for spatial scale 1 showing BBN child node probability outputs under the complete certainty iteration. (a) Probability that the Rocky Shiner in each ecological setting exists in an "at risk" state of extirpation. (b) Probability that populations, or management units, have an "at risk" Population Resiliency. (c) Probability that ecological settings have an "at risk" Ecological Setting Resiliency. (d) Probability that ecological settings have an "inadequate" Ecological Setting Redundancy.

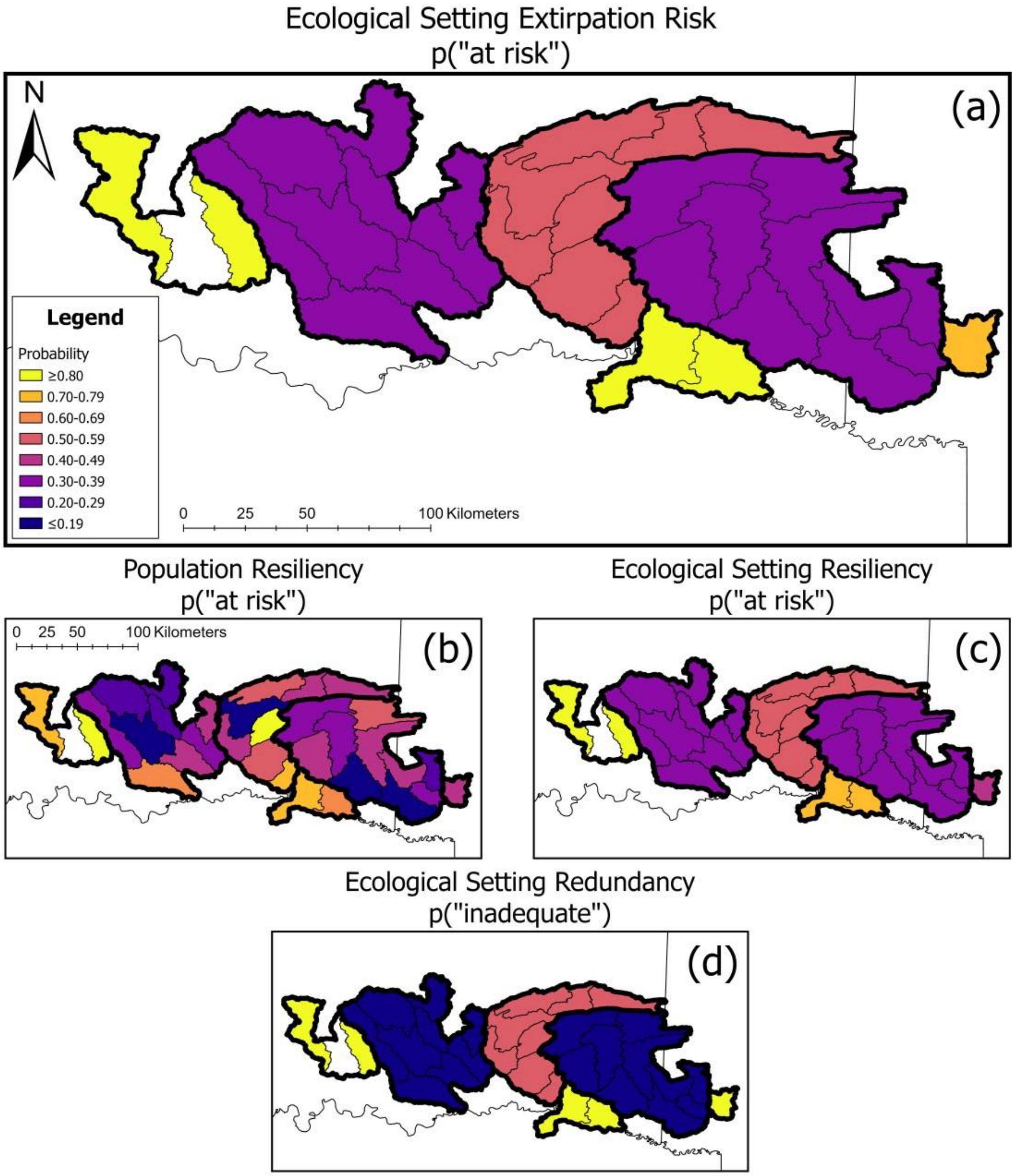

Figure 3.7: Maps for spatial scale 2 showing BBN child node probability outputs under the complete certainty iteration. (a) Probability that the Rocky Shiner in each ecological setting exists in an “at risk” state of extirpation. (b) Probability that populations, or management units, have an “at risk” Population Resiliency. (c) Probability that ecological settings have an “at risk” Ecological Setting Resiliency. (d) Probability that ecological settings have an “inadequate” Ecological Setting Redundancy.

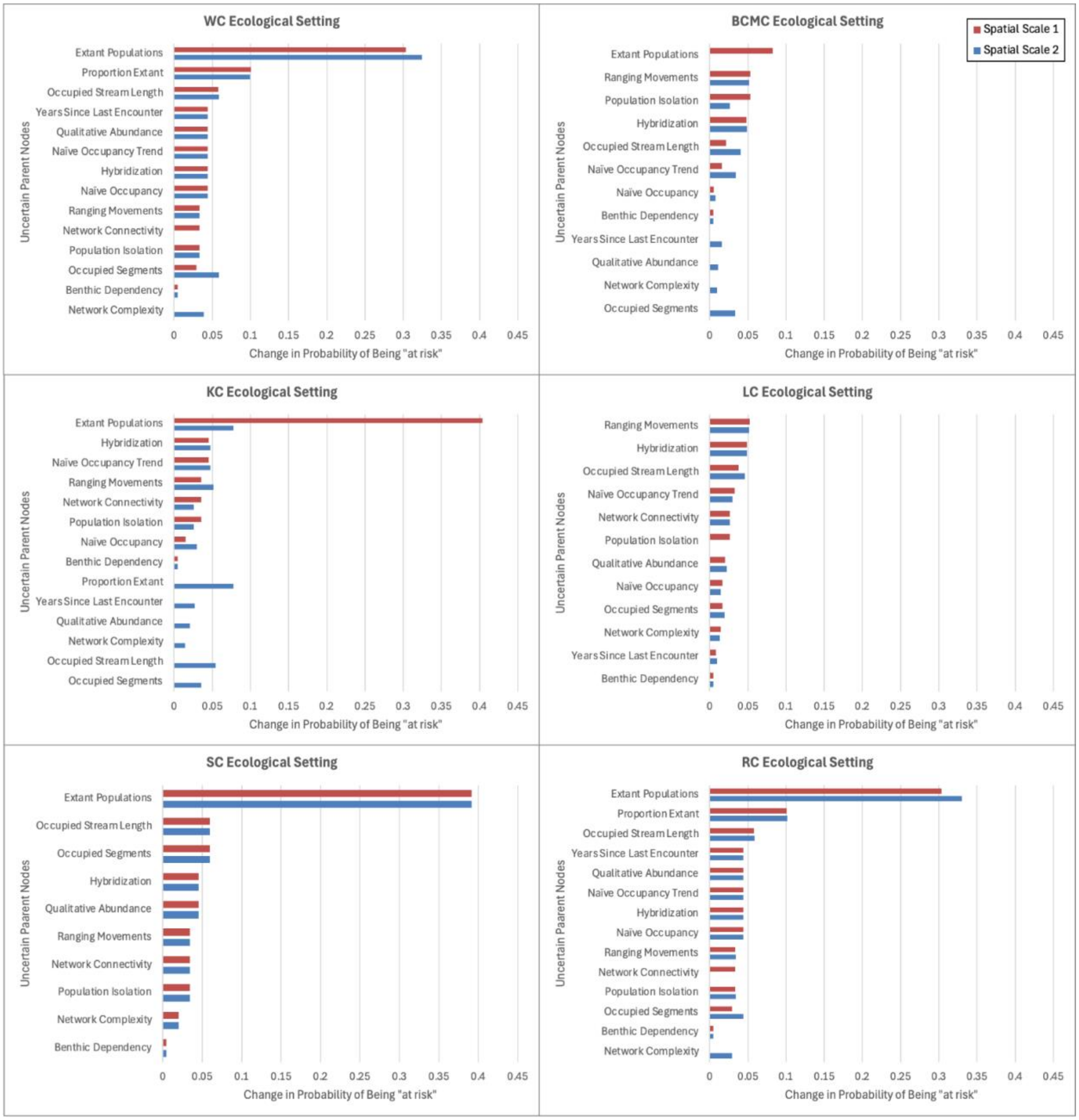

Figure 3.8: Sensitivity of Ecological Setting Extirpation Risk to changes in uncertain parent nodes for all Rocky Shiner ecological settings for spatial scale 1 and 2. Spatial scale 1 is represented as red bars and spatial scale 1 as blue bars. Ecological settings include the Washita Complex (WC), Blue Clear Muddy Complex (BCMC), Kiamichi Complex (KC), Little Complex (LC), Saline Complex (SC), and Red Complex (RC).

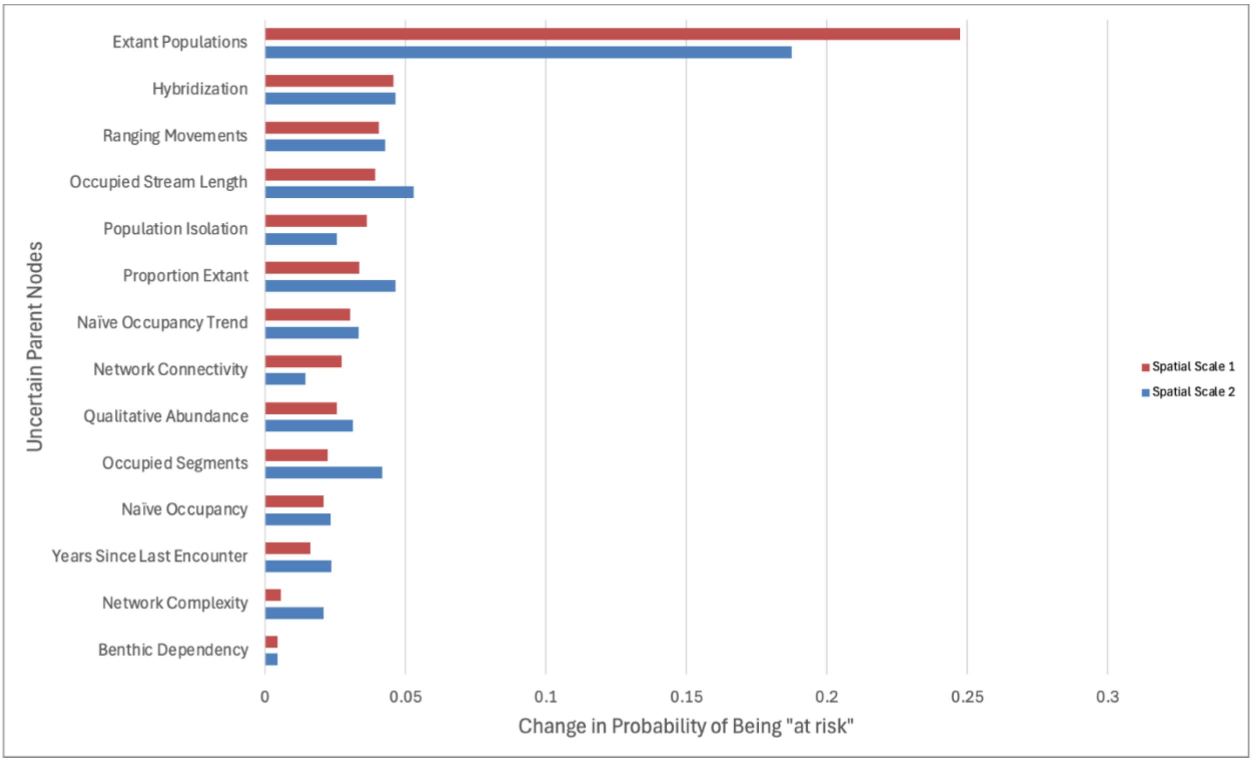

Figure 3.9: Sensitivity of Rocky Shiner Global Extirpation Risk to changes in all uncertain parent nodes under spatial scale 1 and 2. Spatial scale 1 is represented by red bars and spatial scale 2 by blue bars.

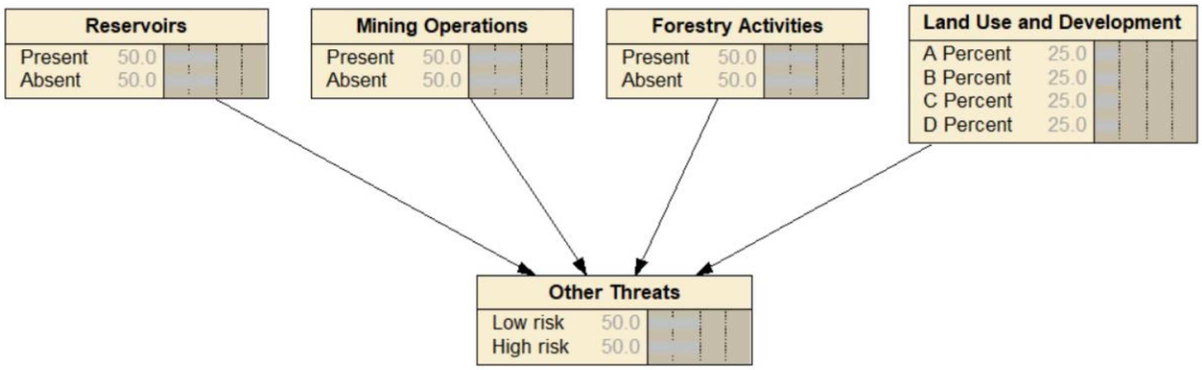

Figure 3.10: Example of what the Other Threats child node could look like, as formatted in Netica if the suggested Rocky Shiner threats were incorporated into the BBN for each management unit.

CHAPTER 4

CONCLUSIONS

In this thesis, I present an overview of our current understanding of the data-limited Rocky Shiner (*Notropis suttkusi*), regarding the species' needs, life history, influences, condition, and data gaps to inform a Species Status Assessment (SSA) that will be used to formulate an Endangered Species Act (ESA) listing decision for the species. The Rocky Shiner was petitioned in 2010 by the Center for Biological Diversity (CBD) for listing under the ESA because the species faces current or threatened destruction, modification, or curtailment of its habitat or range, has inadequate regulatory mechanisms, and faces other natural or manmade constraints such as its narrow, restricted range (CBD 2010). The U.S. Fish and Wildlife Service (USFWS), in a 90-day finding, stated that Rocky Shiner may warrant listing under the ESA (USFWS 2011). Rocky Shiner is now set for a Fiscal Year 2028 ESA listing decision.

The SSA framework follows three stages: 1) the description of the needs, life history, and sources of potential negative influence on the focal species, 2) the evaluation of the current condition of the species through assessing its demographic and habitat qualities, and 3) the projection of the species' future condition under alternative scenarios (USFWS 2016; Smith et al. 2018). This framework is also outlined by the principles of resiliency, redundancy, and representation (i.e., the 3 Rs). Resiliency is the ability of a species to withstand stochastic disturbances, redundancy is the ability of a species to withstand catastrophic events, and representation is the ability of a species to adapt to a changing environment over time (USFWS 2016; Smith et al. 2018). In this present study, we explore the first two stages of the SSA process and the 3 Rs framework for Rocky Shiner to start compiling and assessing information for its eventual SSA document.

In Chapter 2, we use alternative information sources such as surrogate species and expert opinion to better understand possible traits about the species and potential negative influences on the species, specifically by creating life history tables across life stages, a life history profile Gantt chart, and an influence diagram for Rocky Shiner. In Chapter 3, we use a new application of a Bayesian belief network (BBN) created by Dunn et al. (2024) that outlines the SSA framework. In this model, we use available spatial data for Rocky Shiner paired with information gained from Chapter 2 to assess the current condition of the species across its range regarding localized extirpation risks and overall species imperilment risk. We also use two different population spatial scales to assess BBN model outputs, and we perform sensitivity analyses on the model to highlight areas of possible future research and management.

Based on the synthesis of different sources of limited information, I expect that Rocky Shiner likely requires clear, shallow streams with riffle and pool structure, moderate to fast flows, rocky and sandy substrate, in-stream vegetation, depressions in the substrate or nests of other species with interstitial spaces, mostly algae and insects for feeding, and water temperatures below 35 °C. Further, Rocky Shiner adults likely repeat spawn across their range during the spring and summer, have increased foraging on insects at the beginning of and after the spawning season, and occupy deep habitats during the warmer months of the year. Rocky Shiner eggs likely incubate in interstitial spaces of rocky substrate for around 2.5 days, after which larvae emerge and occupy interstitial spaces of rocky and sandy substrate, while periodically drifting downstream and consuming algae, zooplankton, and insects. Juvenile Rocky Shiner likely occupy pools for sheltering and transition to insectivory as they mature into adults.

Potentially important negative influences on Rocky Shiner throughout its range include climate change, impoundments and reservoirs, roads and road barriers, land use, and gravel mining, which can cause changes in connectivity, temperature, flow, turbidity, nutrients and pollutants, and predation.

Although empirical data were scarce across multiple life stages of Rocky Shiner, we found that species-specific data gaps specifically persist for non-adult Rocky Shiners. As a result, in this present study, surrogate species and expert opinion were the best available information for non-adult life stages, both of which have been stated to satisfy the "best available science" directive for SSAs and the ESA (16 U.S.C. § 1533(b); USFWS and NMFS 1994; Murphy and Weiland 2014, 2016; USFWS 2016). Though these types of alternative information sources are more often used for more complex analyses or estimates such as for probabilities of persistence (Cummings et al. 2020; Fitzgerald et al. 2021), demographic variables like fecundity, survival, and population growth (Wenger 2008; Banks et al. 2010; Hernández-Camacho et al. 2015; Moore et al. 2022), and the distribution of a species (Long et al. 2019; Crawford et al. 2020), we had to rely on these sources even for simple biological descriptions of Rocky Shiner.

The areas where data gaps persisted for Rocky Shiner reflect potential future research areas. For example, the simple visual and descriptive models used to describe needs, life history, and influences (i.e., species needs tables, a Gantt chart, and influence diagram in Chapter 2) are useful when identifying these types of topics that are important to the SSA framework (Noon and McKelvey 2006; Murphy and Weiland 2016; USFWS 2016; Smith et al. 2018). Here, we present these models as our first comprehensive understanding of Rocky Shiner's life history and biological needs as well as potential threats to the species' persistence. Importantly, these models can be updated as more research is conducted on the species itself.

Although several uncertainties exist for populations of Rocky Shiner, we were able to use models to evaluate how these uncertainties could shape expectations for the species. For instance, when the BBN was used for Rocky Shiner under two different population spatial scales (Chapter 3), delineated by either expert opinion or strictly HUC10 units, we see that the model calculates the same imperilment risk for the species (p("at risk") = 0.62), showing that the species is currently believed to be at greater risk of imperilment than not. Although, these two spatial scales produced the same imperilment risk, they came to this same result in different ways. Under the spatial scale where populations were created by experts, populations were larger and there were fewer of them (n = 13) in comparison to the populations made using only HUC10s (n = 32). This caused resiliency and redundancy in the model to be represented oppositely of each other in each of the spatial scales, with the expert opinion population scale having overall higher resiliency and lower redundancy and the HUC10 population scale having overall lower resiliency and higher redundancy. This may point to the importance of setting the right population scales for Rocky Shiner across its range for its SSA document and ESA listing decision in order to represent the SSA framework principals appropriately.

Using the BBN, I conducted two sensitivity analyses to identify areas where changes to model inputs were most influential to extirpation risks and imperilment risk. These analyses indicate that the number of extant populations across Rocky Shiner's range may be of most importance for estimating imperilment risk. In certain areas, this variable in the model holds much uncertainty due to a lack of current occurrence records of Rocky Shiner available for use for model inputs. Determining the number of extant populations would likely require targeted sampling efforts in these areas, specifically in the Washita River and Red River to confirm if the species persists in these places. If populations are locally extirpated, it could also prompt management efforts such as captive rearing and reintroduction into historically occupied places in the Washita and Red Rivers or into other areas, such as in the Saline River, to improve the number of extant populations across the species' range and thereby decrease overall imperilment risk. As an example, the endangered Topeka Shiner (*Notropis topeka*) was successfully reintroduced in extirpated areas of Missouri (USFWS 2013, Missouri Department of Conservation 2022, p. 8), which suggests that this could be effectively accomplished for Rocky Shiner as well.

Regarding uncertainty in the BBN model's components, we further see that under uniform parent priors the model predicts a higher probability of imperilment risk from higher predicted inadequacy and vulnerability in redundancy and species vulnerability child nodes, respectively. This means that when data are absent, or when a species is conditioned on moderate to poor parent node states in the model, the conditional probability tables place more weight on these parent node states towards poorer conditioned child node states. When considering how the BBN could be more customized to Rocky Shiner, several potential threats could be included if new information is gained about Rocky Shiner responses to stressors. Influential factors could include the presence of reservoirs, the presence of gravel mining operations, the presence of various forestry practices, and the percent of agricultural and urban land use.

I believe that the Dunn et al. (2024) BBN offers a method that can be used that not only assesses the condition of Rocky Shiner but also allows for analysis and prioritization of uncertainties for the species for its SSA document and ESA decision. Although species-specific data are generally preferred for informing decisions, such information is not always available (Smith-Hicks and Morrison 2021). The Dunn et al. (2024) BBN allows for assessing a species' potential imperilment risk when this kind of information is absent. Also, the BBN makes use of limited spatial data to analyze a comprehensive set of topics that outline important concepts to the SSA framework (i.e., the 3 Rs). A call for a set of biological criteria that consists of "mutually exclusive quantitative ranges to apply to qualitative categories" across species was mentioned almost 30 years ago for potential use in ESA decisions (Easter-Pilcher 1996). Much of these criteria can be represented in the BBN, suggesting it may fill a remaining gap in the world of ESA decision making.

In conclusion, I conducted an initial assessment of Rocky Shiner to present what is known and unknown about the species, and where potential research efforts could be placed to improve understanding of the species. The models in this study could be updated as new knowledge about Rocky Shiner is gained. I also present and describe areas of uncertainty in the results of this study so that if some data or information about the species remain unavailable by the time of its ESA decision, these explanations for uncertainties could be considered and used. If parts of the models presented here are updated in the future, then comparisons could allow for an assessment of the benefits and costs of using alternative information sources as well as the value placed on the amount of spatial data used in SSAs and ESA decisions.

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APPENDIX A

SUPPLEMENTAL MATERIAL FOR CHAPTER THREE

Table A1: Management units and ecological settings for the Rocky Shiner across its range as adapted from expert opinion provided in a rapid prototyping workshop, referred to as spatial scale 1.

Redundancy Unit Name	Resiliency Unit Name	HUC8s or HUC10s Used Name	HUC8s or HUC10s Used Code
Washita Complex (WC)	Washita	City of Davis-Washita River	1113030308
		City of Ravia-Washita River	1113030401
		Pennington Creek-Washita River	1113030402
Blue, Clear Boggy, Muddy Boggy Complex (BCMC)	Blue	Blue	11140102
	Clear Boggy	Clear Boggy	11140104
	Muddy Boggy	Muddy Boggy	11140103
Kiamichi Complex (KC)	Kiamichi	Kiamichi	11140105
Little Compex (LC)	Upper Little	Upper Little River	1114010701
	Lower Little	Middle Little River	1114010703
		Lower Little River	1114010704
		Lower Rolling Fork	1114010903
	Glover	Glover River	1114010702
	Mountain Fork	Mountain Fork	11140108
	Rolling Fork	Upper Rolling Fork	1114010902
	Cossatot	Lower Cossatot River	1114010906
		Upper Cossatot River	1114010905
Saline Complex (SC)	Saline	Saline River-Millwood Lake	1114010909
		Messer Creek-Saline River	1114010908
Red (RC)	Red	Bois D'arc-Island	11140101
		Pecan-Waterhole	11140106

Table A2: Management units and ecological settings for the Rocky Shiner at a HUC10 scale across its range, referred to as spatial scale 2.

Redundancy Unit Name	Resiliency Unit Name	HUC10 Name	HUC10 Code
Washita Complex (WC)	WC1	City of Davis-Washita River	1113030308
	WC2	Pennington Creek-Washita River	1113030402
Blue, Clear Boggy, Muddy Boggy Complex (BCMC)	BCMC1	Upper Blue River	1114010201
	BCMC2	Lower Blue River	1114010202
	BCMC3	Upper Clear Boggy Creek	1114010401
	BCMC4	Middle Clear Boggy Creek	1114010402
	BCMC5	Lower Clear Boggy Creek	1114010403
	BCMC6	Upper Muddy Boggy Creek	1114010302
	BCMC7	Middle Muddy Boggy Creek	1114010304
	BCMC8	Lower Muddy Boggy Creek	1114010306
	BCMC9	McGee Creek	1114010305
Kiamichi Complex (KC)	KC1	Headwaters Kiamichi River	1114010501
	KC2	Dry Creek-Kiamichi River	1114010503
	KC3	Sardis Lake	1114010502
	KC4	Buck Creek-Kiamichi River	1114010504
	KC5	Beaver Creek-Kiamichi River	1114010506
	KC6	Cedar Creek	1114010505
	KC7	Hugo Lake-Kiamichi River	1114010507
	KC8	Outlet Kiamichi River	1114010508
Little Complex (LC)	LC1	Upper Little River	1114010701
	LC2	Middle Little River	1114010703
	LC3	Lower Little River	1114010704
	LC4	Lower Rolling Fork	1114010903
	LC5	Glover River	1114010702
	LC6	Middle Mountain Fork	1114010802
	LC7	Lower Mountain Fork	1114010803
	LC8	Upper Rolling Fork	1114010902

Table A2: Continued.

Redundancy Unit Name	Resiliency Unit Name	HUC10 Name	HUC10 Code
Little Complex (LC)	LC9	Upper Cossatot River	1114010905
	LC10	Lower Cossatot River	1114010906
Saline Complex (SC)	SC1	Saline River-Millwood Lake	1114010909
Red (RC)	RC1	Big Pine Creek-Red River	1114010601
	RC2	Whitegrass Creek-Red River	1114010603

Table A3: Measured and observed resiliency parent node states for each management unit in spatial scale 1 for the Rocky Shiner.

Resiliency Unit	Occupied Segments	Occupied Stream Length Post 1999 (km)	Network Complexity	Naive Occupancy (Post 1999)	Naive Occupancy Trend (%)	Qualitative Abundance	Years Since Last Encounter	Hybridization	Nonnative Species Richness
Washita	Rare	Restricted	Complex	Potentially Extirpated	Strong Decline	Rare	Historical	No	Many
Blue	Many	Restricted	Complex	Uncommon	Strong Decline	Abundant	Recent	No	Few
Clear	Many	Widespread	Complex	Common	Relatively Stable	Abundant	Recent	No	Many
Muddy	Many	Widespread	Complex	Common	Relatively Stable	Abundant	Recent	No	Few
Kiamichi	Many	Widespread	Complex	Uncommon	Strong Decline	Abundant	Recent	No	Few
Upper Little	Many	Restricted	Mainstem	Rare	Strong Decline	Abundant	Recent	No	Absent
Lower Little	Many	Widespread	Complex	Uncommon	Strong Decline	Abundant	Recent	No	Few
Glover	Rare	Restricted	Mainstem	Common	Relatively Stable	Uncommon	Moderate	No	Absent
Mountain Fork	Many	Widespread	Complex	Rare	Strong Decline	Uncommon	Moderate	No	Few
Rolling Fork	Rare	Restricted	Mainstem	Uncommon	Strong Decline	Rare	Recent	No	Absent
Cossatot	Rare	Moderate	Mainstem	Common	Relatively Stable	Uncommon	Recent	No	Absent
Saline	One	Restricted	Mainstem	Common	Relatively Stable	Rare	Recent	No	Few
Red	Rare	Restricted	Complex	Potentially Extirpated	Strong Decline	Rare	Historical	No	Many

Table A4: Measured and observed resiliency parent node values for each management unit in spatial scale 1 for the Rocky Shiner.

Resiliency Unit	Occupied Segments	Occupied Stream Length Post 1999 (km)	Network Complexity	Naive Occupancy (Post 1999)	Naive Occupancy Trend (%)	Qualitative Abundance	Years Since Last Encounter	Hybridization	Nonnative Species Richness
Washita	2	0.00	Mainstem and Tributaries	0.00	-100.00	1	32	No	7
Blue	12	1.77	Mainstem and Tributaries	0.33	-63.64	87	1	No	4
Clear	10	189.91	Mainstem and Tributaries	0.90	+350.00	179	1	No	6
Muddy	9	113.07	Mainstem and Tributaries	0.78	+16.67	489	1	No	2
Kiamichi	30	158.00	Mainstem and Tributaries	0.33	-62.96	553	1	No	5
Upper Little	7	0.60	Mainstem	0.14	-83.33	141	1	No	0
Lower Little	27	141.19	Mainstem and Tributaries	0.44	-40.00	518	1	No	3
Glover	3	3.11	Mainstem	0.67	0.00	53	10	No	0
Mountain Fork	13	86.78	Mainstem and Tributaries	0.23	-75.00	52	10	No	1
Rolling Fork	3	3.45	Mainstem	0.33	-50.00	9	2	No	0
Cossatot	5	19.20	Mainstem	0.80	+100.00	44	2	No	0
Saline	1	0.94	Mainstem	1.00	0.00	5	2	No	1
Red	3	0.00	Mainstem and Tributaries	0.00	-100.00	4	58	No	9

Table A5: Measured and observed redundancy parent node states for each ecological setting in spatial scale 1 for the Rocky Shiner.

Redundancy Unit	Population Isolation (km)	Network Connectivity (%)	Ranging Movements (km)	Extant Populations (Post 1999)	Proportion Extant
WC	Far	Fragmented	Short	Few	Low
BCMC	Far	High	Short	Moderate	High
KC	Far	Fragmented	Short	Few	High
LC	Moderate	Moderate	Short	Many	High
SC	Far	Fragmented	Short	Few	High
RC	Far	Fragmented	Short	Few	Low

Table A6: Measured and observed redundancy parent node values for each ecological setting in spatial scale 1 for the Rocky Shiner.

Redundancy Unit	Population Isolation (km)	Network Connectivity (%)	Ranging Movements (km)	Extant Populations (Post 1999)	Proportion Extant
WC	> 50.00	0.00	2	0	0.00
BCMC	92.14	100.00	2	3	1.00
KC	> 50.00	0.00	2	1	1.00
LC	18.07	66.67	2	6	1.00
SC	> 50.00	0.00	2	1	1.00
RC	> 50.00	0.00	2	0	0.00

Table A7: Measured and observed resiliency parent node states for each management unit in spatial scale 2 for the Rocky Shiner.

Resiliency Unit	Occupied Segments	Occupied Stream Length Post 1999 (km)	Network Complexity	Naive Occupancy (Post 1999)	Naive Occupancy Trend (%)	Qualitative Abundance	Years Since Last Encounter	Hybridization	Nonnative Species Richness
WC1	One	Restricted	Mainstem	Potentially Extirpated	Strong Decline	Rare	Historical	No	Few
WC2	One	Restricted	Single Tributary	Potentially Extirpated	Strong Decline	Rare	Historical	No	Many
BCMC1	Many	Restricted	Complex	Uncommon	Strong Decline	Abundant	Recent	No	Few
BCMC2	Rare	Restricted	Complex	Potentially Extirpated	Strong Decline	Rare	Moderate	No	Few
BCMC3	Rare	Moderate	Complex	Common	All States*	Uncommon	Recent	No	Few
BCMC4	Rare	Widespread	Complex	Common	Relatively Stable	Abundant	Moderate	No	Few
BCMC5	Rare	Restricted	Mainstem	Common	All States*	Abundant	Moderate	No	Few
BCMC6	Rare	Widespread	Complex	Common	All States*	Abundant	Moderate	No	Few
BCMC7	Rare	Moderate	Mainstem	Common	Relatively Stable	Abundant	Moderate	No	Absent
BCMC8	Rare	Moderate	Mainstem	Common	Moderate Decline	Abundant	Moderate	No	Few
BCMC9	One	Restricted	Mainstem	Common	All States*	Uncommon	Recent	No	Few
KC1	Rare	Restricted	Complex	Uncommon	Strong Decline	Uncommon	Moderate	No	Absent
KC2	Rare	Restricted	Complex	Rare	Strong Decline	Abundant	Moderate	No	Few
KC3	Rare	Restricted	Complex	Potentially Extirpated	Strong Decline	Uncommon	Moderate	No	Absent
KC4	Many	Widespread	Complex	Uncommon	Strong Decline	Abundant	Recent	No	Few
KC5	Rare	Restricted	Complex	Uncommon	Strong Decline	Uncommon	Moderate	No	Few
KC6	One	Restricted	Single Tributary	Potentially Extirpated	Strong Decline	Rare	Historical	No	Few
KC7	Rare	Restricted	Multiple Tributaries	Uncommon	Strong Decline	Uncommon	Moderate	No	Few
KC8	One	Restricted	Mainstem	Potentially Extirpated	Strong Decline	Uncommon	Historical	No	Few
LC1	Many	Restricted	Mainstem	Rare	Strong Decline	Abundant	Recent	No	Absent
LC2	Rare	Restricted	Complex	Uncommon	Strong Decline	Uncommon	Moderate	No	Few
LC3	Many	Widespread	Complex	Uncommon	Strong Decline	Abundant	Recent	No	Few
LC4	Many	Widespread	Complex	Common	Relatively Stable	Abundant	Recent	No	Few

Table A7: Continued.

Resiliency Unit	Occupied Segments	Occupied Stream Length Post 1999 (km)	Network Complexity	Naive Occupancy (Post 1999)	Naive Occupancy Trend (%)	Qualitative Abundance	Years Since Last Encounter	Hybridization	Nonnative Species Richness
LC5	Rare	Restricted	Mainstem	Common	Relatively Stable	Uncommon	Moderate	No	Absent
LC6	Rare	Restricted	Complex	Rare	Strong Decline	Rare	Moderate	No	Few
LC7	Many	Moderate	Mainstem	Rare	Strong Decline	Uncommon	Moderate	No	Few
LC8	Rare	Restricted	Mainstem	Uncommon	Strong Decline	Rare	Recent	No	Absent
LC9	Rare	Moderate	Mainstem	Common	Relatively Stable	Uncommon	Recent	No	Absent
LC10	Rare	Restricted	Mainstem	Common	Relatively Stable	Uncommon	Recent	No	Absent
SC1	One	Restricted	Mainstem	Common	Relatively Stable	Rare	Recent	No	Few
RC1	One	Restricted	Mainstem	Potentially Extirpated	Strong Decline	Rare	Historical	No	Few
RC2	Rare	Restricted	Multiple Tributaries	Potentially Extirpated	Strong Decline	Rare	Historical	No	Absent

* Assigned to all possible states in a node due to a lack of data to allow measurement or calculation for existing in a parent node state

Table A8: Measured and observed resiliency parent node values for each management unit in spatial scale 2 for the Rocky Shiner.

Resiliency Unit	Occupied Segments	Occupied Stream Length Post 1999 (km)	Network Complexity	Naive Occupancy (Post 1999)	Naive Occupancy Trend (%)	Qualitative Abundance	Years Since Last Encounter	Hybridization	Nonnative Species Richness
WC1	1	0.00	Mainstem	0.00	-100.00	1	77	No	4
WC2	1	0.00	Single Tributary	0.00	-100.00	1	32	No	6
BCMC1	8	1.77	Mainstem and Tributaries	0.50	-42.86	87	1	No	2
BCMC2	4	0.00	Mainstem and Tributaries	0.00	-100.00	6	26	No	3
BCMC3	4	21.92	Mainstem and Tributaries	1.00	Unknown	11	1	No	3
BCMC4	4	26.48	Mainstem and Tributaries	0.75	+50.00	76	10	No	3
BCMC5	2	8.21	Mainstem	1.00	Unknown	179	10	No	5
BCMC6	2	32.60	Mainstem and Tributaries	1.00	Unknown	158	10	No	1
BCMC7	3	13.27	Mainstem	0.67	0.00	291	11	No	0
BCMC8	3	20.87	Mainstem	0.75	-25.00	489	10	No	1
BCMC9	1	3.38	Mainstem	1.00	Unknown	40	1	No	1
KC1	2	1.40	Mainstem and Tributaries	0.50	-50.00	15	11	No	0
KC2	5	0.50	Mainstem and Tributaries	0.20	-80.00	123	18	No	2
KC3	4	0.00	Mainstem and Tributaries	0.00	-100.00	31	29	No	0
KC4	11	35.12	Mainstem and Tributaries	0.46	-44.44	553	1	No	2
KC5	3	0.45	Mainstem and Tributaries	0.33	-66.67	37	11	No	3
KC6	1	0.00	Single Tributary	0.00	-100.00	1	52	No	1
KC7	3	1.62	Multiple Tributaries	0.33	-50.00	69	11	No	1
KC8	1	0.00	Mainstem	0.00	-100.00	15	52	No	4
LC1	7	0.60	Mainstem	0.14	-83.33	141	1	No	0
LC2	3	1.53	Mainstem and Tributaries	0.33	-66.67	29	10	No	2

Table A8: Continued.

Resiliency Unit	Occupied Segments	Occupied Stream Length Post 1999 (km)	Network Complexity	Naive Occupancy (Post 1999)	Naive Occupancy Trend (%)	Qualitative Abundance	Years Since Last Encounter	Hybridization	Nonnative Species Richness
LC3	12	30.06	Mainstem and Tributaries	0.33	-63.64	144	1	No	2
LC4	12	52.31	Mainstem and Tributaries	0.58	+16.67	518	7	No	2
LC5	3	3.11	Mainstem	0.67	0.00	53	10	No	0
LC6	4	0.57	Mainstem and Tributaries	0.25	-75.00	8	10	No	1
LC7	9	11.99	Mainstem	0.22	-75.00	52	10	No	1
LC8	3	3.45	Mainstem	0.33	-50.00	9	2	No	0
LC9	2	11.39	Mainstem	1.00	+100.00	16	2	No	0
LC10	3	0.02	Mainstem	0.67	+100.00	44	2	No	0
SC1	1	0.94	Mainstem	1.00	0.00	5	2	No	1
RC1	1	0.00	Mainstem	0.00	-100.00	4	58	No	1
RC2	2	0.00	Multiple Tributaries	0.00	-100.00	3	60	No	0

* Value of “Unknown” assigned due to a lack of data to allow measurement or calculation for existing in a parent node state.

Table A9: Measured and observed redundancy parent node states for each ecological setting in spatial scale 2 for the Rocky Shiner.

Redundancy Unit	Population Isolation (km)	Network Connectivity (%)	Ranging Movements (km)	Extant Populations (Post 1999)	Proportion Extant
WC	Far	High	Short	Few	Low
BCMC	Moderate	High	Short	Many	High
KC	Moderate	Moderate	Short	Moderate	Moderate
LC	Near	Moderate	Short	Many	High
SC	Far	Fragmented	Short	Few	High
RC	Far	High	Short	Few	Low

Table A10: Measured and observed redundancy parent node values for each ecological setting in spatial scale 2 For the Rocky Shiner.

Redundancy Unit	Population Isolation (km)	Network Connectivity (%)	Ranging Movements (km)	Extant Populations (Post 1999)	Proportion Extant
WC	99.19	100.00	< 5	0	0.00
BCMC	32.80	77.78	< 5	8	0.89
KC	15.55	53.57	< 5	5	0.63
LC	14.37	64.44	< 5	10	1.00
SC	> 50.00	< 25.00	< 5	1	1.00
RC	53.50	100.00	< 5	0	0.00

Table A11: Assigned Species Vulnerability parent prior probabilities for the Rocky Shiner spatial scale 1 and 2 under the complete certainty iteration.

Parent Node	State	Prior Probability
Adult Feeding Guild	Piscivore	0.00
	Invertivore	1.00
	Other	0.00
Lotic Dependency	Lotic	1.00
	Lentic	0.00
Benthic Dependency	Non-Benthic	0.00
	Partially Benthic	0.00
	Benthic Syndrome	1.00
Drift Dependency	Drift Dependent	0.00
	Other	1.00
Life History Strategy	Opportunistic	1.00
	Periodic	0.00
	Equilibrium	0.00
Maximum Length	Small	1.00
	Medium	0.00
	Large	0.00

Table A12: Assigned resiliency parent node prior probabilities for each management unit in spatial scale 1 under the informed uncertainty iteration for the Rocky Shiner.

Parent Node	State	Washita	Blue	Clear	Muddy	Kiamichi	Upper Little	Lower Little	Glover	Mountain Fork	Rolling Fork	Cossatot	Saline	Red
Occupied Segments	One	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	Rare	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.50	0.33	0.50
	Many	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	0.50	0.50	0.33	0.50
Occupied Stream Length	Restricted	0.33	0.33	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.33	0.00	0.33	0.33
	Moderate	0.33	0.33	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.33	0.50	0.33	0.33
	Widespread	0.33	0.33	1.00	1.00	1.00	0.33	1.00	0.33	1.00	0.33	0.50	0.33	0.33
Network Complexity	Mainstem	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.50	0.50	0.50	0.00
	Single Tributary	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Multiple Tributaries	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Complex	1.00	1.00	1.00	1.00	1.00	0.50	1.00	0.50	1.00	0.50	0.50	0.50	1.00
Naive Occupancy	Potentially Extirpated	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
	Rare	0.25	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.25
	Uncommon	0.25	0.50	0.00	0.00	0.50	0.33	0.50	0.00	0.33	0.50	0.00	0.00	0.25
	Common	0.25	0.50	1.00	1.00	0.50	0.33	0.50	1.00	0.33	0.50	1.00	1.00	0.25
Naive Occupancy Trend	Relatively Stable	0.33	0.33	1.00	1.00	0.33	0.33	0.33	1.00	0.33	0.33	1.00	1.00	0.33
	Moderate Decline	0.33	0.33	0.00	0.00	0.33	0.33	0.33	0.00	0.33	0.33	0.00	0.00	0.33
	Strong Decline	0.33	0.33	0.00	0.00	0.33	0.33	0.33	0.00	0.33	0.33	0.00	0.00	0.33

Table A12: Continued.

Parent Node	State	Washita	Blue	Clear	Muddy	Kiamichi	Upper Little	Lower Little	Glover	Mountain Fork	Rolling Fork	Cossatot	Saline	Red
Qualitative Abundance	Rare	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.33
	Uncommon	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.33	0.50	0.33	0.33
	Abundant	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.50	0.33	0.50	0.33	0.33
Years Since Last Encounter	Historical	0.33	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.50	1.00	1.00	1.00	0.33
	Moderate	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.33
	Recent	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
Hybridization	Yes	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	No	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nonnative Species Richness	Absent	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	1.00	1.00	0.00	0.00
	Few	0.00	1.00	0.00	1.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	1.00	0.00
	Many	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table A13: Assigned redundancy parent node prior probabilities for each management unit in spatial scale 1 under the informed uncertainty iteration for the Rocky Shiner.

Parent Node	State	WC	BCMC	KC	LC	SC	RC
Population Isolation	Near	0.33	0.33	0.33	0.50	0.33	0.33
	Moderate	0.33	0.33	0.33	0.50	0.33	0.33
	Far	0.33	0.33	0.33	0.00	0.33	0.33
Network Connectivity	Fragmented	0.33	0.00	0.33	0.00	0.33	0.33
	Moderate	0.33	0.00	0.33	0.50	0.33	0.33
	High	0.33	1.00	0.33	0.50	0.33	0.33
Ranging Movements	Short	0.33	0.33	0.33	0.33	0.33	0.33
	Moderate	0.33	0.33	0.33	0.33	0.33	0.33
	Long	0.33	0.33	0.33	0.33	0.33	0.33
Extant Populations	Few	0.33	0.00	0.33	0.00	0.33	0.33
	Moderate	0.33	0.50	0.33	0.00	0.33	0.33
	Many	0.33	0.50	0.33	1.00	0.33	0.33
Proportion Extant	Low	0.33	0.00	0.00	0.00	0.00	0.33
	Moderate	0.33	0.00	0.00	0.00	0.00	0.33
	High	0.33	1.00	1.00	1.00	1.00	0.33

Table A14: Assigned resiliency parent node prior probabilities for each management unit in spatial scale 2 under the informed uncertainty iteration for the Rocky Shiner.

Parent Node	State	W1	W2	BCMC1	BCMC2	BCMC3	BCMC4	BCMC5	BCMC6	BCMC7	BCMC8	BCMC9
Occupied Segments	One	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
	Rare	0.33	0.33	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.33
	Many	0.33	0.33	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.33
Occupied Stream Length	Restricted	0.33	0.33	0.33	0.33	0.00	0.00	0.33	0.00	0.00	0.00	0.33
	Moderate	0.33	0.33	0.33	0.33	0.50	0.00	0.33	0.00	0.50	0.50	0.33
	Widespread	0.33	0.33	0.33	0.33	0.50	1.00	0.33	1.00	0.50	0.50	0.33
Network Complexity	Mainstem	0.50	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.50	0.50
	Single Tributary	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Multiple Tributaries	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Complex	0.50	0.33	1.00	1.00	1.00	1.00	0.50	1.00	0.50	0.50	0.50
Naive Occupancy	Potentially Extirpated	0.25	0.25	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Rare	0.25	0.25	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Uncommon	0.25	0.25	0.50	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Common	0.25	0.25	0.50	0.25	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Naive Occupancy Trend	Relatively Stable	0.33	0.33	0.33	0.33	0.33	1.00	0.33	0.33	1.00	0.50	0.33
	Moderate Decline	0.33	0.33	0.33	0.33	0.33	0.00	0.33	0.33	0.00	0.50	0.33
	Strong Decline	0.33	0.33	0.33	0.33	0.33	0.00	0.33	0.33	0.00	0.00	0.33
Qualitative Abundance	Rare	0.33	0.33	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Uncommon	0.33	0.33	0.00	0.33	0.50	0.00	0.00	0.00	0.00	0.00	0.50
	Abundant	0.33	0.33	1.00	0.33	0.50	1.00	1.00	1.00	1.00	1.00	0.50
Years Since Last Encounter	Historical	0.33	0.33	1.00	0.50	1.00	0.50	0.50	0.50	0.50	0.50	1.00
	Moderate	0.33	0.33	0.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50	0.00
	Recent	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hybridization	Yes	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	No	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nonnative Species Richness	Absent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
	Few	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00
	Many	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A14: Continued

Parent Node	State	KC1	KC2	KC3	KC4	KC5	KC6	KC7	KC8	LC1	LC2	LC3
Occupied Segments	One	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00
	Rare	0.50	0.50	0.50	0.00	0.50	0.33	0.50	0.33	0.00	0.50	0.00
	Many	0.50	0.50	0.50	1.00	0.50	0.33	0.50	0.33	1.00	0.50	1.00
Occupied Stream Length	Restricted	0.33	0.33	0.33	0.00	0.33	0.33	0.33	0.33	0.33	0.33	0.00
	Moderate	0.33	0.33	0.33	0.00	0.33	0.33	0.33	0.33	0.33	0.33	0.00
	Widespread	0.33	0.33	0.33	1.00	0.33	0.33	0.33	0.33	0.33	0.33	1.00
Network Complexity	Mainstem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00
	Single Tributary	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
	Multiple Tributaries	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.00	0.00	0.00
	Complex	1.00	1.00	1.00	1.00	1.00	0.33	0.50	0.50	0.50	1.00	1.00
Naive Occupancy	Potentially Extirpated	0.00	0.00	0.25	0.00	0.00	0.25	0.00	0.25	0.00	0.00	0.00
	Rare	0.00	0.33	0.25	0.00	0.00	0.25	0.00	0.25	0.33	0.00	0.00
	Uncommon	0.50	0.33	0.25	0.50	0.50	0.25	0.50	0.25	0.33	0.50	0.50
	Common	0.50	0.33	0.25	0.50	0.50	0.25	0.50	0.25	0.33	0.50	0.50
Naive Occupancy Trend	Relatively Stable	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	Moderate Decline	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	Strong Decline	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Qualitative Abundance	Rare	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.33	0.33	0.33	0.33
	Uncommon	0.50	0.00	0.50	0.00	0.50	0.33	0.33	0.33	0.33	0.33	0.33
	Abundant	0.50	1.00	0.50	1.00	0.50	0.33	0.33	0.33	0.33	0.33	0.33
Years Since Last Encounter	Historical	0.50	0.50	0.50	1.00	0.50	0.33	0.50	0.33	1.00	0.50	1.00
	Moderate	0.50	0.50	0.50	0.00	0.50	0.33	0.50	0.33	0.00	0.50	0.00
	Recent	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.00	0.00	0.00
Hybridization	Yes	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	No	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nonnative Species Richness	Absent	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
	Few	0.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00
	Many	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A14: Continued

Parent Node	State	LC4	LC5	LC6	LC7	LC8	LC9	LC10	SC1	RC1	RC2
Occupied Segments	One	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33	0.00
	Rare	0.00	0.50	0.50	0.00	0.50	0.50	0.50	0.33	0.33	0.50
	Many	1.00	0.50	0.50	1.00	0.50	0.50	0.50	0.33	0.33	0.50
Occupied Stream Length	Restricted	0.00	0.33	0.33	0.00	0.33	0.00	0.33	0.33	0.33	0.33
	Moderate	0.00	0.33	0.33	0.50	0.33	0.50	0.33	0.33	0.33	0.33
	Widespread	1.00	0.33	0.33	0.50	0.33	0.50	0.33	0.33	0.33	0.33
Network Complexity	Mainstem	0.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.00
	Single Tributary	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Multiple Tributaries	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
	Complex	1.00	0.50	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Naive Occupancy	Potentially Extirpated	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25
	Rare	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.25	0.25
	Uncommon	0.00	0.00	0.33	0.33	0.50	0.00	0.00	0.00	0.25	0.25
	Common	1.00	1.00	0.33	0.33	0.50	1.00	1.00	1.00	0.25	0.25
Naive Occupancy Trend	Relatively Stable	1.00	1.00	0.33	0.33	0.33	1.00	1.00	1.00	0.33	0.33
	Moderate Decline	0.00	0.00	0.33	0.33	0.33	0.00	0.00	0.00	0.33	0.33
	Strong Decline	0.00	0.00	0.33	0.33	0.33	0.00	0.00	0.00	0.33	0.33
Qualitative Abundance	Rare	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	Uncommon	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	Abundant	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Years Since Last Encounter	Historical	1.00	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.33	0.33
	Moderate	0.00	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.33	0.33
	Recent	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.33
Hybridization	Yes	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	No	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Nonnative Species Richness	Absent	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	1.00
	Few	1.00	1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00
	Many	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A15: Assigned redundancy parent node prior probabilities for each management unit in spatial scale 2 under the informed uncertainty iteration for the Rocky Shiner.

Parent Node	State	WC	BCMC	KC	LC	SC	RC
Population Isolation	Near	0.33	0.50	0.50	1.00	0.33	0.33
	Moderate	0.33	0.50	0.50	0.00	0.33	0.33
	Far	0.33	0.00	0.00	0.00	0.33	0.33
Network Connectivity	Fragmented	0.00	0.00	0.00	0.00	0.33	0.00
	Moderate	0.00	0.00	0.50	0.50	0.33	0.00
	High	1.00	1.00	0.50	0.50	0.33	1.00
Ranging Movements	Short	0.33	0.33	0.33	0.33	0.33	0.33
	Moderate	0.33	0.33	0.33	0.33	0.33	0.33
	Long	0.33	0.33	0.33	0.33	0.33	0.33
Extant Populations	Few	0.33	0.33	0.00	0.00	0.00	0.33
	Moderate	0.33	0.33	0.00	0.50	0.00	0.33
	Many	0.33	0.33	1.00	0.50	1.00	0.33
Proportion Extant	Low	0.33	0.00	0.00	0.00	0.00	0.33
	Moderate	0.33	0.00	0.50	0.00	0.00	0.33
	High	0.33	1.00	0.50	1.00	1.00	0.33

Table A16: Assigned Species Vulnerability parent prior probabilities for the Rocky Shiner under the informed uncertainty iteration for spatial scales 1 and 2.

Parent Node	State	Probability
Adult Feeding Guild	Piscivore	0.00
	Invertivore	1.00
	Other	0.00
Lotic Dependency	Lotic	1.00
	Lentic	0.00
Benthic Dependency	Non-Benthic	0.00
	Partially Benthic	0.50
	Benthic Syndrome	0.50
Drift Dependency	Drift Dependent	0.00
	Other	1.00
Life History Strategy	Opportunistic	1.00
	Periodic	0.00
	Equilibrium	0.00
Maximum Length	Small	1.00
	Medium	0.00
	Large	0.00