Articles

Prioritizing Imperiled Native Aquatic Species for Conservation Propagation

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Abstract

Native aquatic species are in decline, and hatcheries can play an important role in stemming these losses until larger ecological issues are addressed. However, as more federal and state agencies face budget uncertainty and the number of imperiled species increases, it is necessary to develop a tool to prioritize species for conservation propagation. Our objective was to create prioritized lists of aquatic species that may benefit from conservation propagation for five states in the United States. Biologists developed an influence diagram and provided information for multiple attributes affecting prevalence of species. The influence diagram and information for each species was used in a Bayesian belief network to generate a score to prioritize propagation of a species and the feasibility of propagation. When all taxa were ranked together within a state, mussels, amphibians, and a crustacean were included among fishes in the top species that may benefit from propagation. We recognize that propagation is one tool for conservation of imperiled species and that additional factors will need to be addressed to ensure species persistence. Nevertheless, we contend our quantitative approach provides a useful framework for prioritizing conservation propagation.

Keywords: conservation propagation; native; imperiled; Bayesian belief network

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Received: July 2022; Accepted: June 2023; Published Online Early: April 2024; Published: December 2023

Citation: Webb MAH, Guy CS, Treanor HB, Wilson KW, Mellon CD, Abate P, Crockett HJ, Hofmeier J, Pasbrig C, Isakson P. 2023. Prioritizing imperiled native aquatic species for conservation propagation. *Journal of Fish and Wildlife Management* 14(2):337–353; e1944-687X. https://doi.org/10.3996/JFWM-22-040

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Freshwater biota are experiencing rapid declines across the globe (Kingsford et al. 2016; Ahmed et al. 2022). For example, 46% of freshwater fishes and 42% of amphibians currently warrant International Union for Conservation of Nature Red List status (Arthington et al. 2016; Kingsford et al. 2016; Petersen et al. 2016). Biologists are observing similar declines of native aquatic organisms in the United States among both cold and warm freshwater species (Jelks et al. 2008; Walsh et al. 2011; Burkhead 2012). Freshwater mussels also have high extinction and imperilment rates (Haag and Williams 2014). Given the unprecedented declines in the abundance and distribution of native aquatic species, natural resource agencies are tasked with determining how best to conserve these taxa.

Conservation propagation is defined as the "production of individuals within a captive environment for the purpose of reintroduction in the wild" (George et al. 2009; page 529) and can be a useful tool for restoring native aquatic species (George et al. 2009; Lorenzen et al. 2010). Herein, we define conservation propagation as the propagation and stocking of a species. A guiding principle in conservation propagation is to avoid harm to existing populations and their habitats (George et al. 2009; McMurray and Roe 2017; Crates et al. 2022). Historically, propagation was used solely to produce sport fishes, but technological and logistical advances over the past 20 y have made propagation for conservation purposes more feasible (Gangloff et al. 2016). Propagation is an important piece of Recovery Plans and State Wildlife Action Plans for many imperiled species (Paragamian and Beamesderfer 2004; George et al. 2009) and can have distinct ecological benefits when correctly implemented and monitored (Overton et al. 2023). Pallid Sturgeon *Scaphirhynchus albus* (Steffensen et al. 2010), White Sturgeon *Acipenser transmontanus* (Crossman et al. 2023), Chinook Salmon *Oncorhynchus tshawytscha* (Fast et al. 2015), and Woundfin *Plagopterus argentissimus* (Maskill et al. 2017) are examples of species with conservation propagation programs that have reduced the threat of extirpation. Conservation propagation programs require careful consideration of multiple factors, including current and historical ecological data on the species in need, maximizing genetic diversity of supplemented progeny, responsible genetic sourcing for augmentation or reintroduction, understanding early rearing environments on phenotype, and the facility best suited to successfully propagate the species (George et al. 2009; McMurray and Roe 2017; Anderson et al. 2022). In addition, the phenotypic costs of captivity and the fitness of propagated and released animals should be monitored to determine the overall success of the program and whether the release of individuals improved the conservation status of the species (Crates et al. 2022).

Federal and state hatcheries are tasked with meeting stocking requests for aquatic species with the greatest conservation need. As of 2022, there were 171 fish species listed under the U.S. Endangered Species Act (ESA 1973, as amended; https://ecos.fws.gov/ecp/report/boxscore), and 70 hatcheries within the U.S. Fish and Wildlife Service's (USFWS) Fisheries and Aquatic Conservation Program that are mandated to conserve and restore aquatic species. The Fisheries and Aquatic Conservation Program 2016–2020 Strategic Plan states that the USFWS will identify and prioritize species with the greatest conservation need for the continuing benefit of the American people (USFWS 2016). However, it is increasingly difficult to achieve Program goals because of growing threats to aquatic resources, increasing costs, and budget uncertainty.

There are many decision support tools for conservation, and the selection of a tool needs to be linked to the conservation question (Bower et al. 2018; Schwartz et al. 2018). Bayesian approaches are popular in decision frameworks because of their probabilistic interdependence and use of prior knowledge (Marcot et al. 2006; Bower er al. 2018). More specifically, Bayesian belief networks use empirical data in combination with expert opinion, uncertainty, and prior knowledge to make probabilistic predictions (see Nyberg et al. 2006). Bayesian belief networks are easy to build, are tractable (using influence diagrams) and flexible, may complement or integrate with other kinds of models, and can handle missing data and uncertainty (Marcot et al. 2006; Chen and Pollino 2012). As with any decision tool or model, caution is needed to avoid creating an unreliable model or one that is not calibrated (see Marcot et al. 2006).

Our objective was to develop and apply a prioritization methodology for conservation propagation of imperiled native aquatic species in five states (Utah, Colorado, Kansas, South Dakota, and North Dakota) within Region 6 of the USFWS. Specifically, we worked with

federal and state biologists using a Bayesian belief network to rank imperiled native aquatic species in each state's Wildlife Action Plan. We created a customized list of species that may benefit from conservation propagation for each state. Though it may be beneficial to prioritize species for conservation propagation across their range, the states involved in this project manage species within their borders. The design of the Bayesian belief network used in this project (i.e., the population attributes including abundance and trend data) means that the prioritized list of species represents those that may benefit from conservation actions in general and not just propagation. Based on other work with this type of decision support tool (e.g., Nyberg et al. 2006), we argue a prioritization process for conservation propagation of native aquatic species will support hatcheries in their efforts to contribute to goals outlined in the Fish and Aquatic Conservation Program 2016–2020 Strategic Plan (USFWS 2016) and individual State Wildlife Action Plans.

Methods

Species selection

Native species selected for each Bayesian belief network were those identified as those of greatest conservation need in each State Wildlife Action Plan (Utah 2015, Colorado 2015, Kansas 2015, South Dakota 2014, and North Dakota 2015). Criteria for inclusion as a species of greatest conservation need varied among states. We determined species identified with the greatest conservation need for the 2015 State Wildlife Action Plan for Utah by evaluating whether it was a valid taxon or listable subdivision of a species, whether it was native to the state, and whether it was vulnerable to extinction, which we assessed using the Nature Serve S and N ranks (Utah Wildlife Action Plan Joint Team 2015). Bonneville Cutthroat Trout *Oncorhynchus clarkii utah* (S4), Weber-Snake Bluehead Sucker *Pantosteus discobolus* (under review as a new species of Bluehead Sucker at the time of this study), and Desert Springsnail *Pyrgulopsis deserta* did not meet these criteria, but we considered them as a species of greatest conservation need because either their rank within the NatureServe did not adequately address the conservation status or ranks had not been developed for the species in Utah. We included 23 fishes, 2 mussels, 12 gastropods, 8 amphibians, and 1 crustacean in the Bayesian belief network analysis for Utah (Table 1).

The 2015 draft State Wildlife Action Plans for Colorado (Colorado Parks and Wildlife 2015) and Kansas (Rohweder 2015) included 1) federal or state candidate, threatened, or endangered species; 2) species of special concern; 3) those that had a portion of their overall native range within the state; 4) those that had urgency of conservation need; 5) those for which there was an ability to implement effective conservation actions; and 6) those with ecological value (e.g., keystone, umbrella, or indicator species). We included 25 fishes and 2 amphibians in the Bayesian belief network analysis for Colorado (Table 2). We included 16 fishes, 13 mussels, 9 amphibians, 3 gastropods, 3 isopods, 1 planarian, 1 turtle, and 1 beetle in the Bayesian belief network analysis for Kansas (Table 3).

The 2014 State Wildlife Action Plan for South Dakota criteria for inclusion of species of greatest conservation need included 1) federal or state candidate, threatened, or endangered species for which the state had a mandate for recovery; 2) those that were regionally or globally imperiled and South Dakota was an important portion of their remaining range; 3) those that were regionally or globally secure and South Dakota represented an important portion of their remaining range; or 4) those that were vulnerable (e.g., species dependent on unique or declining habitat, required large home ranges, had low dispersal ability; South Dakota Game, Fish, and Parks 2014). We included 25 fishes, 9 mussels, 2 turtles, and 4 aquatic insects in the Bayesian belief network analysis (Table 4). Paddlefish *Polyodon spathula*, Lake Sturgeon *Acipenser fulvescens*, and Plains Topminnow *Fundulus sciadicus* were not included in the South Dakota State Wildlife Action Plan as species of greatest conservation need, but we included them in this analysis because of past conservation efforts in South Dakota or petitions for listing under the Endangered Species Act.

The species that we evaluated in the Bayesian belief network for North Dakota were those identified as Level I and II species in the 2015 State Wildlife Action Plan (Dyke et al. 2015). Level I species had a high level of conservation priority because of the declining status in North Dakota or across their range; or Level I species had a high rate of occurrence in North Dakota (i.e., the core of the species breeding range) but were possibly at-risk range wide. Level II species had a moderate level of conservation priority or a high level of conservation priority, but a substantial level of non-State Wildlife Grant funding was available for the species. We included 11 fishes, 6 mussels, 2 amphibians, and 1 reptile in the Bayesian belief network analysis for North Dakota (Table 5).

Bayesian belief network development

Bayesian belief networks represent believed relations among variables, which can be used to determine new beliefs (as probabilities) that assist in making more informed decisions. Influence diagrams, which are used to hypothesize the key factors affecting a species, are the cornerstone of Bayesian belief networks (Marcot et al. 2006). A Bayesian belief network is developed from the influence diagram, and the network is composed of nodes that represent variables of interest that are connected by links to indicate dependencies. The links between nodes contain information about relationships between nodes that are typically represented by conditional probabilities. We used the freely available, user-friendly software Netica (Norsys Software Corporation, Vancouver, BC, Canada; http://www.norsys.com/netica.html) for all Bayesian belief networks. Bayesian belief networks using this program have been used in several instances for decision-making in species conservation (Marcot et al. 2006).

We created an influence diagram that contained key factors in determining the need to propagate a species.

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Table 1. A Bayesian belief network was used to prioritize imperiled native aquatic species in Utah's State Wildlife Action Plan in 2014. The Bayesian belief network prioritized species based on ecological criteria (Tier 1) and logistics of conservation propagation (Tier 2) to develop a list of species that may benefit from conservation propagation. The species list was separated into groups and ranked by the Tier 1 score. Inclusion in the State Wildlife Action Plan was based on the NatureServe state and national ranks (1 = critically imperiled; 2 = imperiled; 3 = vulnerable; 4 = apparently secure; 5 = secure; X = presumed extinct or extirpated; H = possibly extirpated).

Scientific name	Common name	Tier 1 score	Tier 2 score
Fishes			
Gila elegans	Bonytail*	99	80
Plagopterus argentissimus	Woundfin*	98	80
Gila cypha	Humpback Chub*	97	70
Gila robusta	Roundtail Chub	91	85
Ptychocheilus lucius	Colorado Pikeminnow*	85	80
Gila seminuda	Virgin River Chub	82	100
Xyrauchen texanus	Razorback Sucker*	80	80
Pantosteus discobolus	Bluehead Sucker (Weber-Snake River)	78	80
Chasmistes liorus	June Sucker*	78	80
Pantosteus discobolus	Bluehead Sucker	77	85
Lepidomeda copei	Northern Leatherside Chub	70	93
Oncorhynchus clarkii bouvieri	Yellowstone Cutthroat Trout	65	80
Iotichthys phlegethontis	Least Chub*	64	95
Catostomus latipinnis	Flannelmouth Sucker	63	85
Lepidomeda mollispinis	Virgin Spinedace	61	90
Lepidomeda aliciae	Southern Leatherside Chub	57	91
Pantosteuss clarkii	Desert Sucker	46	80
Oncorhynchus clarkii utah	Bonneville Cutthroat Trout*	39	90
Oncorhynchus clarkii pleuriticus	Colorado River Cutthoat Trout*	39	90
Cottus extensus	Bear Lake Sculpin	17	70
Prosopium abyssicola	Bear Lake Whitefish	17	70
Prosopium gemmifer	Bonneville Cisco	17	70
Prosopium spilonotus	Bonneville Whitefish	17	70
Amphibians			
Rana onca	Relict Leopard Frog	88	90
Rana luteiventris	Columbia Spotted Frog	62	80
Anaxyrus cognatus	Great Plains Toad	53	75
Spea multiplicata	Mexican Spadefoot	53	75
Spea bombifrons	Plains Spadefoot	53	75
Rana pipiens	Northern Leopard Frog	51	80
Anaxyrus microscaphus	Arizona Toad	49	75
Anaxyrus boreas	Western Toad*	37	85
Mussels			
Margaritifera falcata	Western Pearlshell	96	70
Anodonta californiensis	California Floater	84	85
Gastropods			
Pyrgulopsis deserta	Desert Springsnail	92	85
Pyrgulopsis pilsbryana	Bear Lake Springsnail	57	85
Pyrgulopsis peculiaris	Bifid Duct Pyrg	55	85
Pyrgulopsis saxatilis	Sub-globose Snake Pyrg	50	85
Stagnicola bonnevillensis	Fat-whorled Pondsnail	50	90
Pyrgulopsis transversa	Southern Bonneville Springsnail	48	85
Pyrgulopsis plicata	Black Canyon Pyrg	32	85
Pyrgulopsis inopinata	Carinate Glenwood Pyrg	32	85
Pyrgulopsis hamlinensis	Hamlin Valley Pyrg	20	85
Oreohelix parawanensis	Brian Head Mountainsnail	20	85
Oxyloma kanabense	Kanab Ambersnail	20	85
Pyrgulopsis anguina	Longitudinal Gland Pyrg	17	85
Crustacean			
Pacifastacus gambelii	Pilose Crayfish	80	85

* Indicates a species propagated and released in Utah in 2016.

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Table 2. A Bayesian belief network was used to prioritize imperiled native aquatic species in Colorado's State Wildlife Action Plan in 2014. The Bayesian belief network prioritized species based on ecological criteria (Tier 1) and logistics of conservation propagation (Tier 2) to develop a list of species that may benefit from conservation propagation. The species were separated into groups and ranked by the Tier 1 score. Criteria for inclusion in the State Wildlife Action Plan were 1) federal or state candidate, threatened, or endangered species; 2) species of special concern; 3) those that had a portion of their overall native range within the state; 4) those that had urgency of conservation need; 5) those for which there was an ability to implement effective conservation actions; and 6) those with ecological value (e.g., keystone, umbrella, or indicator species).

Scientific name	Common name	Tier 1 score	Tier 2 score
Fishes			
Gila elegans	Bonytail*	98	83
Hybognathus placitus	Plains Minnow*	91	66
Pantosteus plebeius	Rio Grande Sucker*	83	59
Oncorhynchus clarkii stomias	Greenback Cutthroat Trout*	82	67
Gila pandora	Rio Grande Chub*	80	76
Ptychocheilus lucius	Colorado Pikeminnow**	79	83
Gila cypha	Humpback Chub	76	78
Oncorhynchus clarkii virginalis	Rio Grande Cutthroat Trout*	75	74
Oncorhynchus clarkii pleuriticus	Colorado River Cutthroat Trout*	70	74
Gila robusta	Roundtail Chub*	57	76
Catostomus latipinnis	Flannelmouth Sucker*****	57	58
Pantosteus discobolus jarrovii	Bluehead Sucker*	56	76
Luxilus cornutus	Common Shiner****	49	76
Phenacobius mirabilis	Suckermouth Minnow*	49	66
Chrosomus eos	Northern Redbelly Dace*	48	58
Fundulus sciadicus	Plains Topminnow	46	53
Noturus flavus	Stonecat***	43	40
Pantosteus platyrhynchus	Mountain Sucker	42	41
Lepomis humilis	Orangespotted Sunfish	42	38
Xyrauchen texanus	Razorback Sucker*	41	76
Hybognathus hankinsoni	Brassy Minnow	40	28
Chrosomus erythrogaster	Southern Redbelly Dace***	38	48
Etheostoma cragini	Arkansas Darter*	35	74
Platygobio gracilis	Flathead Chub	33	28
Etheostoma spectabile	Orangethroat Darter	30	56
Amphibians			
Anaxyrus boreas	Western Toad*	79	56
Lithobates pipiens	Northern Leopard Frog	45	48

* Indicates a species propagated and released in Colorado in 2016.
** Indicates a species propagated but not released in Colorado in 2016.
*** Indicates a species maintained in a conservation propagation facility as a refugia population in 2016.
**** Indicates a species that was propagated and released in Colorado prior to 2016, but these actions were discontinued by 2016 (propagation and release have subsequently resumed).
***** Indicates a species held in captivity in 2016 with propagation efforts underway in anticipation of eventual stocking.

The first influence diagram was established through an expert elicitation process that included participation of 30 state and federal biologists over the course of 6 mo from multiple states within the USFWS Region 6. We acknowledge that federally recognized Native American Tribes were not engaged in the elicitation process. Successful species management will require inclusion of federally recognized Native American Tribes, and they will be included in the assessment of native aquatic species for conservation propagation in future analyses.

From the influence diagram, we developed a Bayesian belief network such that each box in the diagram (node) was converted to a set of discrete states (Marcot et al. 2006). We modified the Bayesian belief network through a series of meetings that involved expert review and testing within each state. Expert review and testing involved the state native species coordinator or nongame coordinator, habitat coordinator, and hatchery supervisor(s), and USFWS Ecological Services project leader(s), hatchery project leader(s), and Fish and Wildlife Conservation Office project leader(s) within each state. We held two webinars in each state. The first webinar familiarized the team with Bayesian belief networks (i.e., how they are created, nodes, conditional probabilities, and final product). The second webinar confirmed the nodes and conditional probabilities for the state. For Utah and Colorado, we held a 2-d, in-person meeting to populate each Bayesian belief network with species data and expert opinion. For the remaining states, we populated the Bayesian belief network with species data and expert opinion by webinar. We populated the network with data from several individual species to test and

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Table 3. A Bayesian belief network was used to prioritize imperiled native aquatic species in Kansas' State Wildlife Action Plan in 2015. The Bayesian belief network prioritized species based on ecological criteria (Tier 1) and logistics of conservation propagation (Tier 2) to develop a list of species that may benefit from conservation propagation. The species were separated into groups and ranked by the Tier 1 score. Criteria for inclusion in the 2015 Kansas Wildlife Action Plan were 1) federal or state candidate, threatened, or endangered species; 2) species of special concern; 3) those that had a portion of their overall native range within the state; 4) those that had urgency of conservation need; 5) those for which there was an ability to implement effective conservation actions; and 6) those with ecological value (e.g., keystone, umbrella, or indicator species).

Scientific name	Common name	Tier 1 score	Tier 2 score
Fishes			
Macrhybopsis tetranema	Peppered Chub**	100	80
Notropis girardi	Arkansas River Shiner**	100	70
Platygobio gracilis	Flathead Chub	100	65
Hybognathus argyritis	Western Silvery Minnow	100	65
Macrhybopsis storeriana	Silver Chub	100	60
Scaphirhynchus albus	Pallid Sturgeon	99	80
Hybognathus placitus	Plains Minnow	98	80
Notropis topeka	Topeka Shiner*	93	100
Nocomis biguttatus	Hornyhead Chub	88	80
Noturus placidus	Neosho Madtom	84	80
Macrhybopsis hyostoma	Shoal Chub	81	75
Macrhybopsis meeki	Sicklefin Chub	81	60
Macrhybopsis gelida	Sturgeon Chub	81	60
Percina maculata	Blackside Darter	63	60
Etheostoma cragini	Arkansas Darter	52	73
Nocomis asper	Redspot Chub	52	60
Amphibians			
Lithobates clamitans	Green Frog	76	66
Notophthalmus viridescens	Eastern Newt	70	70
Gastrophryne carolinensis	Eastern Narrowmouth Toad	69	60
Anaxyrus debilis	Green Toad	64	60
Pseudacris streckeri	Strecker's Chorus Frog	61	60
Eurycea lucifuga	Cave Salamander	51	60
Eurycea spelaea	Grotto Salamander	51	60
Eurycea longicauda	Longtail Salamander	51	60
Pseudacris crucifer	Spring Peeper	35	60
Mussels			
Ligumia recta	Black Sandshell**	100	65
Alasmidonta marginata	Elktoe	100	65
Epioblasma triquetra	Snuffbox	100	65
Venustaconcha ellipsiformis	Ellipse	100	57
Arcidens confragosus	Rock Pocketbook	98	75
Ortmanniana ligamentina	Mucket	98	72
Theliderma cylindrica	Rabbitsfoot***	97	75
Lampsilis rafinesqueana	Neosho Mucket***	93	75
Lasmigona costata	Flutedshell	91	50
Utterbackiana suborbiculata	Flat Floater	86	57
Ptychobranchus occidentalis	Ouachita Kidneyshell	83	73
Cyprogenia aberti	Western Fanshell	83	73
Ellipsaria lineolata	Butterfly	75	60
Gastropods			
Pleurocera acuta	Sharp Hornsnail	87	65
Probythinella emarginata	Delta Hydrobe	58	65
Pomatiopsis lapidaria	Slender Walker Snail	23	60
Isopods			
Caecidotea metcalfi	A Cave Obligate Isopod	71	60
Caecidotea simulator	A Cave Obligate Isopod	71	60
Caecidotea tridentata	An Isopod	71	60

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Table 3. Continued.

Scientific name	Common name	Tier 1 score	Tier 2 score
Planarian			
Sphalloplana kansensis	Kansas Planarian	71	60
Turtle			
Graptemys geographica	Northern Map Turtle	66	60
Beetle			
Optioservus phaeus	Scott Optioservus Riffle Beetle	64	60

* Indicates a species propagated but not released in Kansas in 2016.
** Indicates a species propagated outside of Kansas with individuals from a population outside of Kansas in 2016.
*** Indicates a species propagated outside of Kansas with Kansas individuals in 2016.

calibrate the conditional probabilities and network output prior to acceptance of the model. Once accepted, final population of the network with all individual species data and expert opinion occurred. All data pertained to the species within each individual state and not throughout their national range because management occurs at the state level. Each Bayesian belief network contained a suite of nodes representing attributes of the species, which we assigned to one of two tiers—Tier 1 (ecological criteria) and Tier 2 (logistics of propagation; Figure 1; Table 6). Nodes in Tier 1 were identical among states with one exception: Recreational Fishing Value. Utah and Kansas did not include a node for Recreational Fishing in the Bayesian belief network because the species prioritized were listed within the state as endangered, threatened, species in need of conservation, as endemic, or as extirpated and therefore had no perceived recreational value. Tier 2 included aspects related to propagation of the species (Figure 1). Utah, South Dakota, and North Dakota did not include whether cost of production was known. Kansas added a node to identify whether conservation propagation was a recovery metric for each species (Table 6). We used Tier 1 scores to rank each species within a state; we used Tier 2 scores only to separate species in the case of tied scores in Tier 1.

Within each node was two or more mutually exclusive and exhaustive conditions that could characterize the attribute. The biologists assigned a value (0–100) to each "parent" node reflecting their level of certainty that the attribute was or was not in that condition (Data S1, *Supplemental Material*). If biologists had no information about the status of an attribute, all conditions within the node were given equal scores (Figure 2). We calculated the condition values within each "child" node (the nodes to which arrows point; see Figure 1) using the algorithm within the Bayesian belief network, which in turn generated support for propagation (or not) and an associated score reflecting the strength of that support (a score of 100 indicated the highest recommendation for conservation propagation). We rounded each Bayesian belief network score to a whole number and used it to prioritize species for propagation by a state. If no data were available and expert opinion was lacking for a species, indicating complete uncertainty, the scores allotted to the Bayesian belief network were equivalent among node conditions (Figure 2). We also evaluated skewness for propagation for each state by setting all node conditions to equal probabilities (e.g., Figure 2). The score to propagate with no information about a species was dependent on the conditional probabilities set by each state and therefore differed by state (Table 7). For example, if nothing was known about a species in Colorado, the score to propagate was 51 and not to propagate was 49 (Figure 2; Table 7), indicating the Bayesian belief network was not skewed toward propagation, while Utah (score to propagate = 68 with no species information; Table 7) and Kansas (score to propagate = 65 with no species information; Table 7) were slightly skewed toward propagation. Even though Utah and Kansas were slightly skewed toward propagation, the outcome (prioritized species list) was not affected because species within a state were analyzed with the state-specific Bayesian belief network.

We generated a list of the aquatic species that may benefit from conservation propagation for each state, and each state had a different approach to address the prioritization list. For example, the state of Colorado identified the top 10 aquatic species as highest priority, while the state of Utah identified the top 16 aquatic species as highest priority rather than just the top 10 species. In Utah, 6 of the top 16 species were already being propagated, therefore inclusion of 16 species allowed the state to identify 10 aquatic species that were not being propagated in 2016.

Results

We ranked 100 fishes, 21 amphibians, 30 mussels, 4 insects, 3 turtles, 15 gastropods, 3 isopods, 1 crustacean, 1 beetle, 1 reptile, and 1 planarian from 5 states. When all taxa were ranked together within a state, mussels, amphibians, a gastropod, and a crustacean were included among fishes in the top species that may benefit from conservation propagation. Fishes were at least the top three species in each state (Tables 1–5).

Utah

Four of the top 10 fish species that may benefit from conservation propagation in Utah received scores between 90 and 100 (Table 1). When all aquatic taxa were ranked together, the top 16 species (in order of descending score) were Bonytail *Gila elegans*, Woundfin, Humpback Chub *Gila cypha*, Western Pearlshell *Margaritifera falcata*, Desert Springsnail, Roundtail Chub *Gila*

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Table 4. A Bayesian belief network was used to prioritize imperiled native aquatic species in South Dakota's State Wildlife Action Plan in 2016. The Bayesian belief network prioritized species based on ecological criteria (Tier 1) and logistics of conservation propagation (Tier 2) to develop a list of species that may benefit from conservation propagation. The species were separated into groups and ranked by the Tier 1 score. These species were identified in the 2014 South Dakota Wildlife Action Plan as species of greatest conservation need. Paddlefish, Lake Sturgeon, and Plains Topminnow were not included within the South Dakota Wildlife Action Plan as species of greatest conservation need but were included in this analysis.

Scientific name	Common name	Tier 1 score	Tier 2 score
Fishes			
Scaphirhynchus albus	Pallid Sturgeon*	95	70
Macrhybopsis meeki	Sicklefin Chub	95	68
Polyodon spathula	Paddlefish+*	95	63
Couesius plumbeus	Lake Chub	94	67
Pantosteus platyrhynchus	Mountain Sucker	90	73
Scaphirhynchus platorynchus	Shovelnose Sturgeon	88	63
Macrhybopsis gelida	Sturgeon Chub	87	68
Chrosomus neogaeus	Finescale Dace	85	84
Notropis heterolepis	Blacknose Shiner	85	76
Cycleptus elongatus	Blue Sucker**	84	75
Catostomus catostomus	Longnose Sucker	79	67
Percopsis omiscomaycus	Trout Perch	72	67
Chrosomus eos	Northern Redbelly Dace	71	76
Percina caprodes	Logperch	66	71
Margariscus nachtriebi	Northern Pearl Dace	64	76
Acipenser fulvescens	Lake Sturgeon+	64	63
Fundulus diaphanus	Banded Killifish	62	76
Percina maculata	Blackside Darter	60	76
Notropis percobromus	Carmine Shiner	60	76
Umbra limi	Central Mudminnow	60	67
Nocomis biguttatus	Hornyhead Chub	57	68
Notropis topeka	Topeka Shiner	32	93
Chrosomus erythrogaster	Southern Redbelly Dace	20	76
Chrosomus neogaeus	Finescale Dace Mud Lake	13	84
Fundulus sciadicus	Plains Topminnow+	8	82
Mussels			
Lampsilis higginsii	Higgins Eye++	92	86
Lasmigona compressa	Creek Heelsplitter	92	84
Obovaria olivaria	Hickory Nut	92	84
Lampsilis teres	Yellow Sandshell	92	84
Alasmidonta marginata	Elktoe	92	76
Arcidens confragosus	Rock Pocketbook	92	63
Leptodea leptodon	Scaleshell++	92	63
Quadrula quadrula	Maple Leaf	92	56
Cyclonaias pustulosa	Pimpleback	92	54
Turtles			
Graptemys pseudogeographica	False Map Turtle	36	68
Apalone mutica	Smooth Softshell	36	68
Aquatic insects			
Epitheca petechialis	Dot-winged Baskettail	56	67
Stylurus notatus	Elusive Clubtail	56	67
Analetris eximia	Mayfly	56	67
Perlesta dakota	Stonefly	47	67

+ Indicates propagation requested by South Dakota Game, Fish and Parks or inclusion in this project requested by U.S. Fish and Wildlife Service, but these species are not currently included within the State Wildlife Action Plan as species of greatest conservation need.
++ Possibly extirpated.
* Indicates a species propagated and released in South Dakota in 2016.
** Indicates a species propagated and not released in South Dakota in 2016.

robusta, Relict Leopard Frog *Lithobates onca,* Colorado Pikeminnow *Ptychocheilus lucius*, California Floater *Anodonta californiensis*, Virgin River Chub *Gila seminuda*, Razorback Sucker *Xyrauchen texanus*, Pilose Crayfish *Pacifastacus gambelii*, Bluehead Sucker in the Weber/Snake River, June Sucker *Chasmistes liorus*, Bluehead Sucker *Pantosteus discobolus*, and Northern Leatherside Chub *Lepidomeda copei*. The aquatic taxa list included 11 fishes, 2 mussels, 1 gastropod, 1 amphibian, and 1 crustacean. We focused on these 16 species that may benefit

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Table 5. A Bayesian belief network was used to prioritize imperiled native aquatic species North Dakota's State Wildlife Action Plan in 2016. The Bayesian belief network prioritized species based on ecological criteria (Tier 1) and logistics of conservation propagation (Tier 2) to develop a list of species that may benefit from conservation propagation. The species were separated into groups and ranked by the Tier 1 score. These species were identified in the 2015 North Dakota Wildlife Action Plan as Level I (high level of conservation priority) and Level II (moderate level of conservation priority).

Scientific name	Common name	Tier 1 score	Tier 2 score
Fishes			
Scaphirhynchus albus	Pallid Sturgeon*	71	75
Macrhybopsis meeki	Sicklefin Chub	64	44
Macrhybopsis storeriana	Sturgeon Chub	64	44
Lota lota	Burbot**	56	100
Cycleptus elongatus	Blue Sucker	49	56
Margariscus margarita	Northern Pearl Dace	47	56
Chrosomus eos	Northern Redbelly Dace	47	56
Polyodon spathula	Paddlefish***	47	56
Macrhybopsis storeriana	Silver Chub	47	56
Percopsis omiscomaycus	Trout Perch	47	56
Platygobio gracilis	Flathead Chub	34	31
Amphibians			
Anaxyrus hemiophrys	Canadian toad	49	31
Spea bombifrons	Plains Spadefoot	49	31
Reptiles			
Chelydra serpentina	Snapping Turtle	30	31
Mussels			
Notropis heterolepis	Black Sandshell	43	63
Potamilus alatus	Pink Heelspliter	43	63
Lasmigona compressa	Creek Heelspliter	43	56
Potamilus ohiensis	Pink Papershell	43	56
Potamilus ohiensis	Threeridge	43	56
Fusconaia flava	Wabash Pigtoe	43	56

* Indicates a species propagated in North Dakota and released outside of the state in 2016.
** Indicates a species propagated in North Dakota but not released in 2016.
*** Indicates a species propagated and released in North Dakota in 2016.

from conservation propagation to capture the top 10 species that were not being propagated in 2016 (Western Pearlshell, Desert Springsnail, Roundtail Chub, Relict Leopard Frog, California Floater, Virgin River Chub, Pilose Crayfish, Bluehead Sucker in the Weber/Snake River, Bluehead Sucker, and Northern Leatherside Chub).

Colorado

Two of the top 10 fish species that may benefit from conservation propagation in Colorado received scores between 90 and 100 (Table 2). In 2016, all these species were propagated and released in the state of Colorado, except for Colorado Pikeminnow (propagated but not released) and Humpback Chub (not propagated). When all aquatic taxa were ranked together, the top 10 species were (in order of descending score) Bonytail, Plains Minnow *Hybognathus placitus*, Rio Grande Sucker *Pantosteus plebeius*, Greenback Cutthroat Trout *Oncorhynchus clarkii stomias*, Rio Grande Chub *Gila pandora*, Colorado Pikeminnow, Western Toad *Anaxyrus boreas*, Humpback Chub, Rio Grande Cutthroat Trout *Oncorhynchus clarkii virginalis*, and Colorado River Cutthroat Trout *Oncorhynchus clarkii pleuriticus*. The Western Toad was propagated and released in the state in 2016.

Kansas

Eight of the top 10 fish species that may benefit from conservation propagation in Kansas received scores between 90 and 100 (Table 3). At the time of this study, only the Topeka Shiner *Notropis topeka* was propagated but not released in Kansas. When all aquatic taxa were ranked together, 17 species received scores between 90 and 100, with 9 species receiving scores of 100. In order of highest priority, using Tier 2 as a tie-breaker as needed, the aquatic species that may benefit most from conservation propagation were Peppered Chub *Macrhybopsis tetranema*, Arkansas River Shiner *Notropis girardi*, Flathead Chub *Platygobio gracilis*, Western Silvery Minnow *Hybognathus argyritis*, Snuffbox *Epioblasma triquetra*, Black Sandshell *Ligumia recta*, Elktoe *Alasmidonta marginata*, Silver Chub *Macrhybopsis storeriana*, Ellipse *Venustaconcha ellipsiformis*, Pallid Sturgeon, Plains Minnow, Rock Pocketbook *Arcidens confragosus*, Mucket *Ortmanniana ligamentina*, Rabbitsfoot *Theliderma cylindrica*, Topeka Shiner *Notropis topeka*, Neosho Mucket *Lampsilis rafinesqueana*, and the Flutedshell *Lasmigona costata* (eight fishes and nine mussels). Of these species, the Peppered Chub, Arkansas River Shiner, Flathead Chub, Snuffbox, Black Sandshell, and the Ellipse have not recently been documented in the state, which does complicate propagation efforts in finding a source population.

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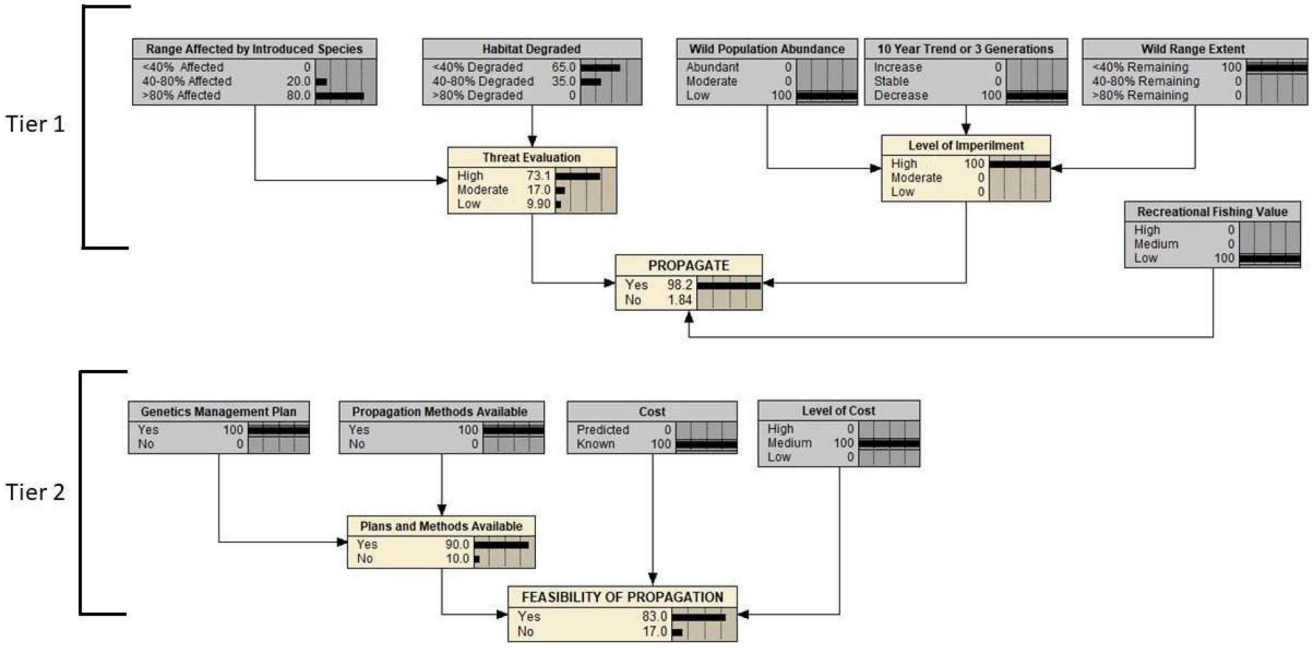


Figure 1. An influence diagram used in the Bayesian belief network for Colorado in 2014 to prioritize imperiled native aquatic species that may benefit from conservation propagation. The Bayesian belief network for each state contained a suite of nodes representing attributes of the species that were assigned to one of two tiers—Tier 1 (upper tier; ecological criteria) and Tier 2 (lower tier; logistics of propagation). Parent nodes (grey boxes) in Tier 1 were identical across states, except for Recreational Fishing Value (not included in Utah or Kansas), and nodes in Tier 2 were identical across states, except for Level of Cost which was included in Colorado and Conservation Propagation as a Recovery Metric which was included in Kansas (node not shown). For descriptions of each node see Table 6. Values shown are for Bonytail in Colorado.

There were no amphibians, gastropods, isopods, planarian, turtles, or beetles in immediate need of conservation propagation (scores all <89).

South Dakota

Five of the top 10 fish species that may benefit from conservation propagation in South Dakota received scores between 90 and 100 (Table 4). Pallid Sturgeon and Paddlefish were propagated and released in South Dakota in 2016, and Blue Sucker *Cycleptus elongatus* were propagated but not released in South Dakota in 2016. When all aquatic taxa were ranked together, the top 13 species that may benefit from conservation propagation that scored between 90 and 100 were (in order of descending score) Pallid Sturgeon, Sicklefin Chub *Macrhybopsis meeki*, Paddlefish, Lake Chub *Couesius plumbeus*, Higgins Eye *Lampsilis higginsii*, Creek Heelsplitter *Lasmigona compressa*, Hickory Nut *Obovaria olivaria*, Yellow Sandshell *Lampsilis teres*, Elktoe, Rock Pocketbook, Scaleshell *Leptodea leptodon*, Maple Leaf *Quadrula quadrula*, and Pimpleback *Cyclonaias pustulosa*. All nine mussels scored equally in terms of those that may benefit from propagation (Tier 1 score = 92). The Tier 2 score was used to separate the mussels with identical scores based on the logistics of propagation, and several of the Tier 2 scores were identical for species.

North Dakota

Within the top 10 fish species that may benefit from conservation propagation in North Dakota, the only species that was propagated and stocked in 2016 in North Dakota was Paddlefish (Table 5). Although not commonly propagated, Paddlefish were propagated and stocked 3 times in the past 20 y in North Dakota. Pallid Sturgeon were propagated in North Dakota but released outside of the state. Burbot were propagated but not released in 2016. The Sicklefin Chub, Sturgeon Chub *Macrhybopsis gelid*, Blue Sucker, Northern Pearl Dace *Margariscus margarita*, Northern Redbelly Dace *Chrosomus eos*, Silver Chub *Macrhybopsis storeriana*, and Trout Perch *Percopsis omiscomaycus* were not propagated and stocked into North Dakota in 2016. When all aquatic taxa were ranked together, the top 10 aquatic species included 8 fishes (Pallid Sturgeon, Sicklefin Chub, Sturgeon Chub, Burbot, Blue Sucker, Northern Pearl Dace, Northern Redbelly Dace, Paddlefish) and 2 amphibians. The two amphibians included in the top 10 species were the Canadian Toad *Anaxyrus hemiophrys* and the Plains Spadefoot *Spea bombifrons*. The Northern Pearl Dace, Northern Redbelly Dace, Paddlefish, Silver Chub, and Trout Perch each had a Tier 1 score of 47 and were alphabetized within the Tier 1 scores because equal scores were generated (Table 5). The Tier 2 score for each of these fish species was 56, suggesting that all these fish species were truly equivalent in terms of the benefit they may receive from conservation propagation. Only the Pallid Sturgeon, Sicklefish Chub, Sturgeon Chub, and Burbot had scores of 56 or higher. No mussels were being propagated and stocked in North Dakota in

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Table 6. The Bayesian belief network nodes, node states, and descriptions used to prioritize imperiled aquatic species that may benefit from conservation propagation in State Wildlife Action Plans in five states within Region 6 of the U.S. Fish and Wildlife Service in 2014–2016. Tier 1 represents ecological criteria, and Tier 2 represents logistics of conservation propagation used in the prioritization process.

Tier 1 Parent node	Node states	Description
Range Affected by Introduced Species	<40%, 40–80%, >80% Degraded	Percentage of the species' historic range in the state that was negatively influenced by introduced species, including the impact of disease(s).
Habitat Degraded	<40%, 40–80%, >80% Degraded	Percentage of habitat degraded (e.g., lost, fragmented, and modified at a level that negatively affects the population [s]) within the species historic range in the state.
Wild Population Abundance	Abundant, Moderate, Low	Abundance of extant wild populations of the species in the state; if hatchery supplementation was already occurring, stocked animals were not included unless the hatchery supplemented population was recruiting. Stocked animals were considered part of the wild population once hatchery-produced individuals recruit to sexual maturity and produce offspring that also recruit.
10 Year Trend or 3 Generations	Increasing, Stable, Decreasing	Percentage of populations where data indicated "Increasing," "Stable," or "Decreasing" population trends in the state; this was data-driven and retrospective, so the past 5 y of data were used to predict the next 5-y trend. If no natural recruitment occurs, the default was "Decrease." These data included translocated animals and progeny of hatchery animals that were naturalized.
Wild Range Extent	<40%, 40–80%, >80% Degraded	Estimated how much of the historic habitat in the state the species currently occupies. All life stages were considered for this node.
Recreational Fishing Value (Colorado, South Dakota, and North Dakota only)	High, Medium, Low	Estimated the value of the fish in terms of recreational fishing. For all nonfish species, the default was "Low."
Tier 2 **Parent node**		
Genetics Management Plan	Yes, No	If a genetics management plan had been developed for the individual species, 100% of value was assigned to "Yes." If a genetics management plan had been initiated but not finalized, 75% was assigned to "Yes" and 25% to "No." If genetic analysis had been conducted but a genetics management plan had not been developed, 50% was assigned to "Yes" and 50% to "No." If no genetics management plan and no prior genetic knowledge exist, 100% was assigned to "No."
Propagation Methods	Yes, No	If propagation methods had been developed for the individual species, 100% of value was assigned to "Yes." If methods had been developed for a surrogate species that can be applied to the species being prioritized, the value was split 50% to "Yes" and 50% to "No." If Propagation Methods had not been developed for the species or a surrogate, 100% was assigned to "No." Addition for Kansas: For mollusks, 70% was assigned to "Yes" and 30% was assigned to "No" if propagation methods for an individual species were close to defined but the lifecycle had not been completed.
Level of Cost	Low, Medium, High	Defined as "Low" for pond culture or extensive culture, "Medium" for streamside spawning, and "High" for intensive culture, such as when broodstock were maintained on station, hormonal injections were needed for spawning induction, or paired crosses were made. If the cost per fish was high but few fish are currently propagated, 100% was assigned to "Medium" cost. Addition for Kansas: For mollusks, 100% was assigned to "High" if the fish host was difficult to culture or maintain; 70% was assigned to "High" and 30% was assigned to "Medium"

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Table 6. Continued.

Tier 2 Parent node		
		when the fish host could be collected from the wild and was easy to maintain; and 50% was assigned to "High" and 50% was assigned to "Medium" if the fish host was easy to culture or maintain.
Cost of Production (Colorado only)	Predicted, Known	Defined whether the cost was "Predicted" or "Known" (known based on the actual species or a surrogate).
Conservation Propagation as Recovery Metric in State (Kansas only)	Yes, No	Identified whether conservation propagation was listed as a recovery metric in Kansas for the species in a federal or state recovery plan. If a recovery plan had been written but had not been finalized and conservation propagation was listed as a recovery metric, 50% was assigned to "Yes" and 50% was assigned to "No."

2016. All six species of mussels scored equally in terms of the benefit they may receive from propagation (Tier 1 score = 43). The Tier 2 score was used to separate the mussels with identical scores based on the logistical aspects of propagation; however, several of the Tier 2 scores were identical for these species as well (Table 5).

Discussion

The Bayesian belief network was a useful tool for identifying and prioritizing native aquatic species that may benefit from conservation propagation in the five states considered. Fish were the predominant taxon, followed by mollusks, amphibians, and crustaceans. No state identified aquatic insects or turtles as being in immediate need of conservation propagation. Future work may consider similar analyses of imperiled species range-wide to assist in distribution of resources across states. For example, the Midwest Landscape Initiative is working to identify Regional Species of Greatest Conservation Need in State Wildlife Action Plans of several Midwestern states. Use of the Bayesian belief network may be a logical step for choosing species in that initiative.

In our analysis, 59 species lacked information for ≥1 node. Lack of information can be problematic because prioritization tools rely on data to assign value. Surrogate species can be used to provide appropriate estimates for factors lacking complete data (Albuquerque and Beier 2016), but this approach is not always applicable. For example, it would be difficult to find surrogate nodes for certain characteristics, such as Habitat Degraded or Wild

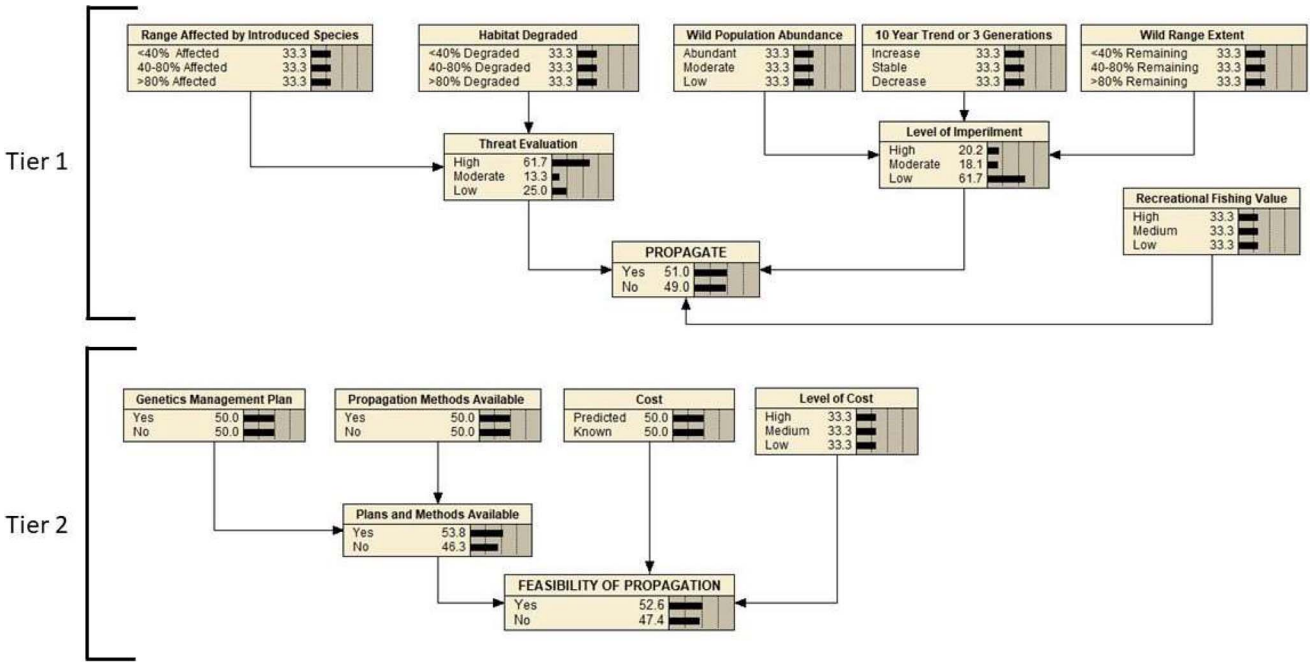


Figure 2. The influence diagram used in the Bayesian belief network used to prioritize imperiled native aquatic species that may benefit from conservation propagation when there was no information for any node (i.e., equivalent scores across node states). For descriptions of each node, see Table 6. Values shown are for the influence diagram for Colorado in 2014.

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Table 7. A Bayesian belief network was used to prioritize imperiled native aquatic species in State Wildlife Action Plans within five states of Region 6 of the U.S. Fish and Wildlife Service in 2014–2016. Score to propagate or not propagate for each state when no data were available for a species and the scores allotted to the Bayesian belief network were equivalent across node conditions. This demonstrated whether the Bayesian belief network was skewed toward propagation or not.

State	Score to propagate	Score to not propagate
Utah	68	32
Colorado	51	49
Kansas	65	35
South Dakota	49	51
North Dakota	56	44

Population Abundance. Instead of defining surrogates or dropping a node from the analysis, we assigned equivalent scores across node conditions (i.e., 33/33/33). This scoring technique allowed us to retain the same nodes in each Bayesian belief network and neutralize the influence of an "unknown" node on the overall propagation score.

The scoring process for lack of information may have indirectly penalized species that might otherwise have been included within the top species lists. Kansas had 18 species and Colorado had 3 species for which ≥1 node lacked information, but only one of these species was in the top list of species that may benefit from conservation propagation in each state. Utah had 10 species lacking information at ≥1 nodes, but only 3 of these species were in their Top 16 list. Additionally, there were species for which the lack of information appeared to weight other nodes more than they ordinarily might. For instance, Topeka Shiner in South Dakota received equivalent scores among node conditions in each of three nodes (Habitat Degraded, Wild Population Abundance, and 10 Year Trend or Three Generations) and scored low in the Recreational Fishing Value node. The Tier 1 score for this species was largely based on complete information for three out of five nodes and was likely more negatively influenced by the Recreational Fishing Value node than it might otherwise have been. Ultimately, the Topeka Shiner ranked at 35 out of 38 aquatic species, which is counterintuitive given its current status as endangered. Other species, such as Sicklefin Chub and Lake Chub, also scored low in the Recreational Fishing Value node, but it is likely that having information for at least four of the five Tier 1 nodes ensured that the Recreational Fishing Value node was weighted appropriately. These species ranked two and four, respectively, in South Dakota.

This analysis did not account for long-term success of propagated species in the wild once released. Although nodes existed that assessed contemporary threats (e.g., Habitat Degradation), a node was not included to project species success in the future once stocked. Probability of success is an important consideration, especially in the face of increasing program costs and budget uncertainty. Joseph et al. (2009) determined that natural resource agencies could finance more conservation projects if they focused on species with low threat status and higher probability of long-term success compared with projects focused on species with high threat status and lower probability of success. Probability of success could function as a "parent node" in future Bayesian belief networks and could be informed by multiple "child nodes" that take into consideration factors such as source of habitat degradation (e.g., climate change, reductions in stream flow), ability to become a self-sustaining population, negative effects on the source population for propagation, and costs associated with maintaining species success in the future. Updating and validating models is part of the adaptive management process that makes Bayesian belief network models more reliable (Marcot et al. 2006; Nyberg et al. 2006).

Despite the absence of a "probability of success" node, these analyses can be used to guide conservation actions outside of propagation of aquatic organisms. The two nodes assessing Threat Condition provided information about anthropogenic factors contributing to species decline. Some species, such as Razorback Sucker or the Flannelmouth Sucker *Catostomus latipinnis* in Colorado, appeared to be negatively affected by nonnative species and habitat degradation consistent with observations elsewhere (e.g., Marsh et al. 2015). Others, such as Hornyhead Chub *Nocomis biguttatus* in Kansas, were affected only by habitat degradation. Natural resource agencies can use these individual node conditions to prioritize and guide development of targeted management and conservation actions. Razorback Sucker and Flannelmouth Sucker conservation in Colorado could be tailored to address both threats, though it is challenging to address the effects of nonnative species when they continue to be stocked for recreational fisheries; whereas Hornyhead Chub in Kansas may likely benefit from management actions that largely address habitat degradation. Analyses presented here clearly identify knowledge gaps in the ecological assessment for individual species, and this information could be used to direct studies to fill these gaps. The Bayesian belief network analyses can inform management efforts for species that did not receive scores high enough to warrant conservation propagation, and with new information, they may warrant conservation propagation in the future. Ideally, propagation should not be used on its own to address population declines (Snyder et al. 1996); however, in many cases the underlying cause of a species' decline may not be addressed in the near future. For example, the lack of recruitment for Pallid Sturgeon in the upper Missouri River is a function of the mainstem dams (Guy et al. 2015), which are likely to be on the landscape for the foreseeable future. Thus, propagation of Pallid Sturgeon is the best tool to prevent extirpation of the species in the upper Missouri River.

Conservation propagation can be an essential tool for species recovery, but in some instances, conservation may be achieved by other means that may be more successful in the long term (George et al. 2009). We argue the prioritized lists for conservation propagation in the five states analyzed accurately reflected the true needs of each species, and the model was "validated" because several species that ranked high are already being

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propagated. The Bayesian belief network incorporated ecological and propagation information to produce a quantitative result, which is less subjective than other approaches to selecting species to propagate, such as one that is easy to propagate. Additionally, a lack of knowledge about a species ecological trait(s) or propagation methods was accounted for in the Bayesian belief network, and the identification of knowledge gaps may direct future research and demonstrates this tool may be used in an adaptive management framework. As new information about a species becomes available, it can be incorporated into the Bayesian belief network to update the propagation score and prioritization list. Sound judgment is always needed when using output from models, including the one presented here. We argue that this tool is useful for developing a prioritization list that may be further adjusted by conversations with natural resource agency staff. For example, the Peppered Chub ranked highest in Kansas and is a good candidate for conservation propagation because its decline was likely due to drought and the species is now confined to a single population, placing it at heightened risk (Pennock et al. 2017). However, propagation of the Plains Minnow was initiated in 2019 because it was the highest prioritized fish with a reliable source population in the state, unlike the Peppered Chub.

A limitation to the Bayesian belief network is that it works best with fewer nodes (Marcot et al. 2006). Node parameters were limited (i.e., we could not include every abiotic and biotic factor); however, the nodes included were considered the most important aspects influencing species persistence, and this was informed from State Wildlife Action Plans. Instead of including another node on ecological traits, we included a node on recreational fishing value because several states thought that if an imperiled species had recreational fishing value, it would highly influence the propagation value. This node was also discussed in the context of increasing the popularity of fishing for native species over nonnative species, and natural resources agencies could promote a species through recreational fishing and a conservation propagation program.

Several states and the USFWS have used the lists of species that may benefit from conservation propagation or conservation action generated in this study. In Kansas, construction was completed for a new state conservation hatchery in 2019. The state began propagation of the Plains Minnow, the highest prioritized fish with a reliable source population in the state and completed the first population augmentation in 2022. In preparation for future propagation and repatriation, the prioritization list is currently being used to draft Safe Harbor Agreements and Candidate Conservation Agreements with Assurances for Peppered Chub, Plains Minnow, Silver Chub, Hornyhead Chub, Topeka Shiner, Neosho Mucket, Flat Floater *Utterbackiana suborbiculata*, Butterfly *Ellipsaria lineolata*, and Flutedshell. These species do not follow the prioritization list exactly, but they were selected to represent a variety of habitat requirements and regions of Kansas, which will simplify drafting and implementation of future conservation agreements because they can be amended to add a species to a previously identified watershed. Kansas is also developing a Recovery Program that will, in part, use this prioritized list of species and conservation agreements to guide recovery of imperiled species. Once the program is established, the prioritized list generated for the state will be vital for assessing propagation opportunities from broodstock within the state or when collaborating with other states to acquire broodstock or propagated individuals. Species from the list will also be used in upcoming studies to evaluate the effectiveness of conservation propagation efforts and post release monitoring and to investigate population genetics of the Neosho Madtom, which will direct potential future propagation of the species. The USFWS cross-programmatic Grassland Ecosystem Conservation Team recently used the lists generated here to identify aquatic species of greatest conservation need in the grassland ecosystem. Lastly, many of the states have used this project to validate prior decisions regarding species to propagate.

At a time when an increasing number of aquatic species are in decline and program costs are increasing, prioritization of conservation actions, such as propagation, is important. This Bayesian belief network analysis identified native aquatic species in five states that may benefit from conservation action. This approach was conservation-centered, data-driven, adaptable to incorporation of new data, and easily applied to species in different geographic locales. The list of species that may benefit from conservation propagation generated by this project can be used by federal and state hatcheries in their efforts to achieve Fisheries and Aquatic Conservation Program strategic plan goals or state strategic goals of conserving native aquatic species. Ultimately, the list provides data-supported guidance to improve conservation program cost-efficiency and performance that is defensible to constituents. We acknowledge that successful management going forward requires collaboration with federally recognized Native American Tribes. In future analyses, the USFWS will ensure that federally recognized Native American Tribes are included in the assessment of native aquatic species for conservation propagation.

Supplemental Material

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Data S1. Full raw data set used to populate the Bayesian belief networks for Utah, Colorado, Kansas, South Dakota, and North Dakota in 2014–2016. The Bayesian belief network was used to generate a score to prioritize conservation propagation of imperiled aquatic species and the feasibility of propagation. Figure 1 and Table 6 show the Bayesian belief network, nodes, and node states. Biologists assigned a value (0–100) to each "parent" node reflecting their level of certainty that the attribute was or was not in that condition. If biologists had no information about the status of an attribute, all conditions within the node were given equal scores (i.e., 33/33/33 if three attributes or 50/50 if two attributes). Definitions for column headers: Intro Species = Range

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Affected by Introduced Species, Habitat Degraded = Habitat Degraded, Wild Pop Abund = Wild Population Abundance, 10 Yr Trend = 10 Year Trend or 3 Generations, Wild Range Extent = Wild Range Extent, Rec Fishing Val = Recreational Fishing Value, Gen Plan = Genetics Management Plan, Prop Methods = Propagation Methods, Level of Cost = Level of Cost, Cost = Cost of Production, Cons Prop Plan = Conservation Propagation as Recovery Metric. Data are shown as three values (e.g., 20/70/10) or two values (e.g., 0/100) for each cell, which reflects the value for each attribute from the top down in the parent node in each column.

Available: https://doi.org/10.3996/JFWM-22-040.S1 (57 KB XLSX)

Reference S1. Colorado Parks and Wildlife. 2015. State action plan: a strategy for conserving wildlife in Colorado. Denver: Colorado Parks and Wildlife.

Available: https://doi.org/10.3996/JFWM-22-040.S2 (31.407 MB PDF) and https://cpw.state.co.us/aboutus/Pages/StateWildlifeActionPlan.aspx

Reference S2. Dyke SR, Johnson SK, Isakson PT. 2015. North Dakota State Wildlife Action Plan. Bismark: North Dakota Game and Fish Department.

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Acknowledgments

We thank Larry Gamble, Doug Fruge, Connie Young-Dubovsky, Mark Fuller, Richard Bottomley, Karl Schnoor, Terry Howick, Maureen Wilson, Larry Crist, Rebecca Lorig, Thomas Czapla, Adam Mendoza, Ed Stege, Dale Ryden, Susan Linner, Pam Sponholtz, Matt Nicholl, Greg Gerlich, Dan Mosier, Kyle Austin, David Bender, Jeff Conley, Jason Luginbill, Ed Miller, Bryan Sowards, Mark Van Scoyoc, Ryan Waters, Laura Mendenhall, Vernon Tabor, John Lott, Jeffrey Powell, Dane Shuman, Matt Schwarz, Carlos Martinez, Rob Holm, Scott Gangl, Steve Krentz, Kevin Shelley, and Paige Maskill for participating in discussions and assistance with populating the Bayesian belief networks. We thank the Associate Editor and three anonymous reviewers for helpful comments and revisions. This project was funded by the U.S. Geological Survey Science Support Partnership. The Montana Cooperative Fishery Research Unit is jointly sponsored by the U.S. Geological Survey, Montana Department of Fish, Wildlife and Parks, Montana State University, and the U.S. Fish and Wildlife Service.

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