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Multi-metric Conservation Assessment for the Imperiled Clinch Dace

Abstract

Planning frameworks allow managers to spatially prioritize actions to promote species conservation. Traditional aquatic conservation planning frameworks are often organized at the ecological community or ecosystem level, which often neglect imperiled taxa occupying species-poor assemblages. In this study, we develop a multi-metric conservation assessment for the 15 geographically distinct candidate conservation areas (CCAs) occupied by the imperiled Clinch Dace (*Chrosomus* sp. cf. *saylori*). Clinch Dace habitat is threatened by anthropogenic landscape alterations, especially for coal mining and timber harvest. Our framework used four metrics to assess the conservation value of each subpopulation of Clinch Dace namely: "*habitat condition*", "*viability*", conservation "*opportunity*" and conservation "*feasibility*". Occupancy models were used to determine the most influential habitat variables to Clinch Dace presence and habitat data collected for each occupied stream were used to score habitat condition in each CCA. Clinch Dace survey data were used to assess demographic population viability to highlight areas where Clinch Dace are most likely to persist. Next, we used the metrics of opportunity and feasibility to identify opportunities for reclamation as well as landownership patterns that may be bridges or barriers to conservation action. Habitat condition and viability varied among our 15 CCAs and highlighted opportunities for specific management actions including habitat conservation in some watersheds and needs for restoration in others. The feasibility metric showed that variation exists in the average lot-parcel size along occupied stream reaches, which may affect the success of some conservation actions. We recommend that managers utilize the data summarized in this study, along with stakeholder input, in a structured-decision making approach to develop specific outreach and management plans targeted to stakeholders in individual watersheds and provide an example of such a framework.

Keywords

Conservation planning, species conservation, imperiled species, aquatic habitat management, stakeholder assessment

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Cover Page Footnote

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INTRODUCTION

The headwater streams of the Central Appalachian ecoregion have historically been overlooked by fish taxonomists and conservation biologists, and often occur on private lands where sampling access is limited. As a result, Clinch Dace (*Chrosomus* sp. cf. *saylori*) remained undiscovered until 1999. Confined to two counties in southwest Virginia, the Clinch Dace has one of the smallest range extents among North American cyprinid species and a distinctive headwater-specialist ecological niche (Jenkins & Burkhead 1994). The Virginia Department of Game and Inland Fisheries (VDGIF) lists the Clinch Dace as a tier 1 species of conservation concern or critically imperiled.

Although the Nature Conservancy and the World Wildlife Fund recognize the upper Clinch River watershed as a high-priority biodiversity hotspot due to the presence of 48 species of rare mussels and fishes (Master et al. 1998; Abell 2000), the small headwater streams where Clinch Dace occur have low fish species richness (usually <10 species). These headwater streams also have little recreational value for fishing or floating. As a result, the catchments in which Clinch Dace occur would be unlikely candidates for conservation prioritization under traditional planning schemes that focus on larger, downstream reaches with higher species richness (Filipe et al. 2004).

Clinch Dace and its congener, the federally threatened Blackside Dace (*Chrosomus cumberlandensis*) occur in highly forested watersheds, with good water quality characterized by low levels of dissolved solids (Griffith et al. 2012; Black et al. 2013; Hitt & Chambers 2014; White & Orth 2014a; Timpano et al. 2015; Hitt et al. 2016; and Moore et al. 2017b). Clinch Dace populations are vulnerable to extirpation resulting from habitat alteration at multiple spatial scales. Persistent threats include watershed modification, riparian forest removal, nutrient enrichment, introduced species, and bait harvest. Catastrophic pollution events in the upper Clinch basin have led to large-scale extirpations of native fish and mussel species. Major chemical spills in 1967, 1970, and 1998 occurred just downstream of known Clinch Dace populations and decimated the aquatic ecosystem for several kilometers (Crossman & Cairns 1974; Lingenfelser et al. 2004).

Habitat condition is one quantitative metric used to assess conservation value of distinct spatial zones in the systematic conservation planning literature (e.g. Boon, Wilkinson, & Martin, 1998; Linke et al. 2007). Maximizing the conservation value of Clinch Dace management decisions could direct limited available conservation resources towards catchments containing quality headwater stream habitats characterized by undisturbed watershed vegetative cover, high water quality, suitable in-channel morphology, and high habitat connectivity.

In addition to prioritizing areas of the greatest conservation value, conservation planners recommend gathering socioeconomic and political data, by means of stakeholder involvement and cost analyses, as one of the first steps of the conservation planning process (Pressey & Bottrill 2008). Planning schemes must consider the costs and practicality of management actions in each catchment. Opportunism sometimes has led to the protection of marginally valuable conservation reserves (Pressey et al. 1993). However, watersheds in southwest Virginia historically have been heavily utilized for coal mining and timber harvest, both of which have degraded instream habitat (Giam et al. 2018). "Informed opportunism," which seeks to balance defensible biological goals with opportunities for success, can increase conservation efficiency (Noss et al. 2002; Knight & Cowling 2007; Pressey & Bottrill 2008).

Since the initial discovery of Clinch Dace populations in 1999, six peer-reviewed publications and additional survey data have better defined Clinch Dace morphology, behavior, life history, distribution, and habitat associations (Skelton 2007; Coyner unpublished data; White & Orth 2013; White & Orth 2014a, White & Orth 2014b, Hatcher et al. 2017; Moore et al. 2017a; Moore et al. 2017b). A study is ongoing at Virginia Polytechnic Institute and State University to better define population genetic structure and barriers to genetically effective dispersal. However, Clinch Dace have not yet benefitted from targeted conservation action. For example, monitoring protocols have not been developed and potential conservation actions — such as habitat protection or restoration at the landscape, riparian, or channel unit scale — have not occurred in watersheds occupied by Clinch Dace. A synthesis of habitat condition, population status, and socioeconomic data of Clinch Dace watersheds will help state and federal agencies make informed conservation actions (Conroy & Peterson 2013).

Here, we present a conservation assessment to: 1) Characterize conservation value of extant Clinch Dace conservation units based on metrics of habitat condition and population viability; 2) Examine the land ownership and land-use patterns pertaining to each population to highlight opportunities or obstacles to recovery actions (i.e., to assess opportunity and feasibility); and 3) Introduce potential restoration actions as well as a structured decision-making framework that can be parameterized with existing data and future stakeholder input.

METHODS

Assessment Units

We hereafter refer to our assessment units as Candidate Conservation Areas (CCAs), which we define as grouped occurrences of Clinch Dace from prior surveys (Skelton 2007; Coyner unpublished data; White & Orth 2013; White & Orth 2014a, White & Orth 2014b, Hatcher et al. 2017; Moore et al. 2017a; Moore et al. 2017b) separated by 1.5 km or more of unoccupied habitat from all other groups. We based the threshold for demarcating CCAs on movement studies of other *Chrosomus* daces that found dispersal events infrequent at greater distances (Detar & Mattingly, 2013; Walker et al. 2013). The 15 CCAs that we considered in this analysis are: Big Lick Creek, Hart Creek, Hess Creek, Hurricane Fork/Grassy Branch, Jackson Fork, Greasy Creek, Indian Creek, Left Fork Coal Creek, Laurel Fork, Lewis Creek, Middle Creek, Mudlick/Zeke Creek, Pine Creek, Town Hill/Little Town Hill Creek, and West Fork Big Creek (Figure 1).

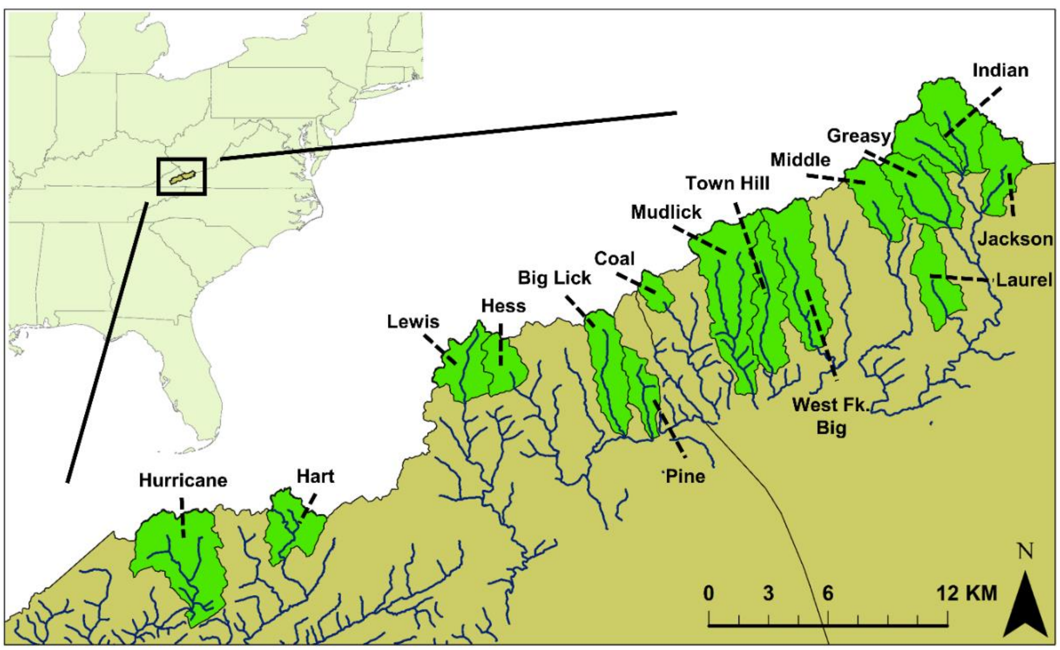

Figure 1. Map of study area containing 15 Candidate Conservation Areas (CCAs) occupied by Clinch Dace based on prior surveys (Skelton 2007; Coyner unpublished data; White and Orth 2013; White and Orth 2014a, White and Orth 2014b, Hatcher et al. 2017; Moore et al. 2017a; Moore et al. 2017b).

Ranking the populations in terms of conservation priority is a subjective process driven by stakeholder values, which are used to parameterize decision models. Lacking stakeholder survey data and agency direction, compiling final conservation priority rankings for the 15 CCAs is outside the scope of our study. Instead, we present a multi-metric characterization of the 15 CCAs as a tool for use by decision makers. A summary of our metrics is outlined below and summarized in Table 1.

Habitat Condition

First, we created a habitat condition metric, which incorporates instream- or catchment-level habitat conditions measured in the field or in a GIS. We based habitat condition on the modeled relationships between select habitat variables and the probability of Clinch Dace presence (Moore et al. 2017b). These multi-scale occupancy models were developed using a dataset of 70 sites sampled with baited minnow traps and backpack electrofishing in Russell and Tazewell counties in Virginia from 2014-2015. To predict occupancy probabilities for each CCA, we selected the top two occupancy models based on minimum *AIC*c using the program Presence v10 (Hines 2010). These models are similar but not identical to the candidate models considered in Moore et al. (2017b). Whereas Moore et al. (2017b) sought to determine the relative influence of different suites of habitat variables on Clinch Dace occupancy, we aimed to build the best model for predicting Clinch Dace occupancy using any combination of occupancy covariates. We combined elements of top models to generate a composite model that had the best fit to the data as measured by lowest *AIC*c. The occupancy covariates in the top two composite models included substrate embeddedness, watershed forest cover, elevation, and conductivity (Table 2). Weighted estimates of occupancy from the top two models were averaged using *AIC* weight.

Next, we compiled average variable measurements from all recorded habitat surveys within each CCA and used the occupancy models to predict occupancy probability for each CCA. Prior to running the models, we scaled covariates by subtracting the mean and dividing by the standard deviation of each variable at the 70 sites used to generate models. We assume that higher predicted occupancy probability suggests more suitable habitat conditions for Clinch Dace presence. Embeddedness was calculated as the number of substrate particles that were >75% embedded during a 100-particle Wolman pebble count at a site, forest cover was the proportion of an occupied watershed covered by any type of forest using the NLCD (National Land Cover Dataset; Homer et al. 2011), elevation was calculated as the average elevation of the upstream and downstream observed extents of Clinch Dace occurrence, and conductivity was an average of all conductivity readings within a CCA in µS/cm. Due to site access restrictions, a few CCAs lacked measurements for one or more variables. We imputed missing values for individual CCAs with the mean value of all CCAs. For more information on habitat variables and occupancy model methods, see Moore et al. (2017b).

Table 1. An outline of the multi-metric conservation prioritization process, including metrics, explanation, and variables and goals (maximize or minimize in parentheses).

Metric	Condition	Viability	Opportunity	Feasibility
Scoring Method	Occupancy model probability of presence to discrete scoring scale	Discrete scoring scale	Opportunity for mining reclamation within the watershed	Description of landownership patterns
Variables and (Ideal State)	% watershed forested (max), conductivity (min), % embeddedness (min).	% of surveys Clinch Dace collected (max), Estimated abundance (max), connectedness of populations (max), length of stream occupied (max).	Area of disturbed current mine land and abandoned mine sites (max opportunities for restoration).	Number of landowners adjacent to occupied stream reaches, average parcel size in acres (subjective).

Table 2. Occupancy models ranked by *AIC*c. Weighted model averages of top two models were used for predicting occupancy at CCA to generate habitat condition.

Model	*AIC*c	Delta *AIC*c	*AIC*c Wgt
psi(75%embed+Forest+elev),theta(.),p(gear)	203.0564516	0.000000000	0.38667522
psi(75%embed+Forest+elev+cond),theta(.),p(gear)	204.7306557	1.674204125	0.167416221
psi(75%embed+Forest),theta(.),p(gear)	204.2333333	1.176881720	0.214679079
psi(75%embed+Forest+Cond),theta(.),p(gear)	205.4564516	2.400000000	0.116464338
psi(Forest+elev+cond),theta(.),p(gear)	207.6064516	4.550000000	0.039749017
psi(75%embed),theta(.),p(gear)	207.2275000	4.171048387	0.048041293
psi(AllForest),theta(.),p(gear)	209.7175000	6.661048387	0.013833054
psi(elevation),theta(.),p(gear)	211.3175000	8.261048387	0.006215592
psi(conductivity),theta(.),p(gear)	212.1675000	9.111048387	0.004063566
psi(.),theta(.),p(gear)	213.3053846	10.24893300	0.002300482
psi(.),theta(.),p(.)	216.1236364	13.06718475	0.000562138

Table 3. Scoring criteria for viability and habitat condition metrics.

		Viability			**Habitat Condition**
Score	% Surveys Clinch Dace Present	Average Abundance	Distance to Nearest Population	Stream Length Occupied	Probability of Clinch Dace Presence
1	0-20	0-10	>8	<1km	<60
2	20-40	10-20	6-8	1-2km	60-70
3	40-60	20-30	4-6	2-3km	70-80
4	60-80	30-40	2-4	3-4km	80-90
5	80-100	>40	<2	>4km	90-100

To aid inter-CCA comparison across multiple metrics, we converted predicted occupancy probabilities into discrete habitat condition scores ranging from 1-5 (Table 3). Final weighting of the value of different levels of habitat condition should be reconsidered with stakeholder and manager input during any future decision-making process.

Viability

Viability in our assessment is an index of population demographic strength and thus the likelihood of population persistence. Most populations of Clinch Dace contain few adult individuals (which based on length frequency analysis are >45 mm; Moore et al. 2017a) and are confined to small lengths of stream, making them vulnerable to extirpation through habitat degradation or natural stochastic processes. We based CCA viability on the following: 1) the percentage of surveys within an occupied stream in which Clinch Dace were detected; 2) the relative abundance of Clinch Dace within each CCA (Moore et al. 2017a); 3) connectedness to other populations as measured by the stream distance to the closest population; and 4) the length of stream from the furthest upstream to the furthest downstream records of occurrence. Presence-absence data came from surveys for Clinch Dace conducted from 1999-2015 (Skelton 2007; White 2012; White & Orth 2014a; Moore et al. 2017a; Coyner unpublished). We used only records of confirmed presence instead of modeling Clinch Dace distribution. Sampling coverage of the study area was thorough, and we placed a premium on avoiding false-positive predictions of species occurrence (Loiselle et al. 2003) that would result in wasting conservation effort on areas that were predicted to, but do not actually contain Clinch Dace (Figure 2). Furthermore, although survey methods were not consistent among all studies, Moore et al. (2017b) found that detection probabilities were high, approaching 90% with as little as 100 m of electrofishing. Relative abundance data came from mark-recapture sampling and transformed count data (Moore et al. 2017a). For more information on methods used to estimate densities and relative abundances of Clinch Dace, see Moore et al. (2017a). We treat upstream and downstream distances the same. Ongoing population genetics studies at Virginia Tech will help better explain connectivity and barriers to connectivity among populations.

We also developed a discrete scoring system for viability, assigning a 1 to 5 score for each viability variable, with 5 being best (Table 3). Scoring ranges encompassed the measured range for each variable among the 15 CCAs. Final viability scores were the unweighted averages of the scores for 4 variables. Again, final weighting of the relative importance of these variables should be considered when using these data in a structured decision-making context.

In order to further elucidate relationships between our habitat condition and viability metrics, we conducted an ordination analysis using non-metric multidimensional scaling (NMDS) with the Bray-Curtis distance measure in the *vegan* package (Oksanen et al. 2018) in Program R. The final solution was reached within 20 iterations. We plotted the NMDS scores for the first and second axes for all 15 CCAs in multivariate habitat space. We used three variables from the condition analysis: embeddedness, conductivity, watershed forest cover, as well as gradient, and % of watershed in active surface mining. We overlaid biplot vectors to illustrate the magnitude and direction of correlation between habitat variables and axes.

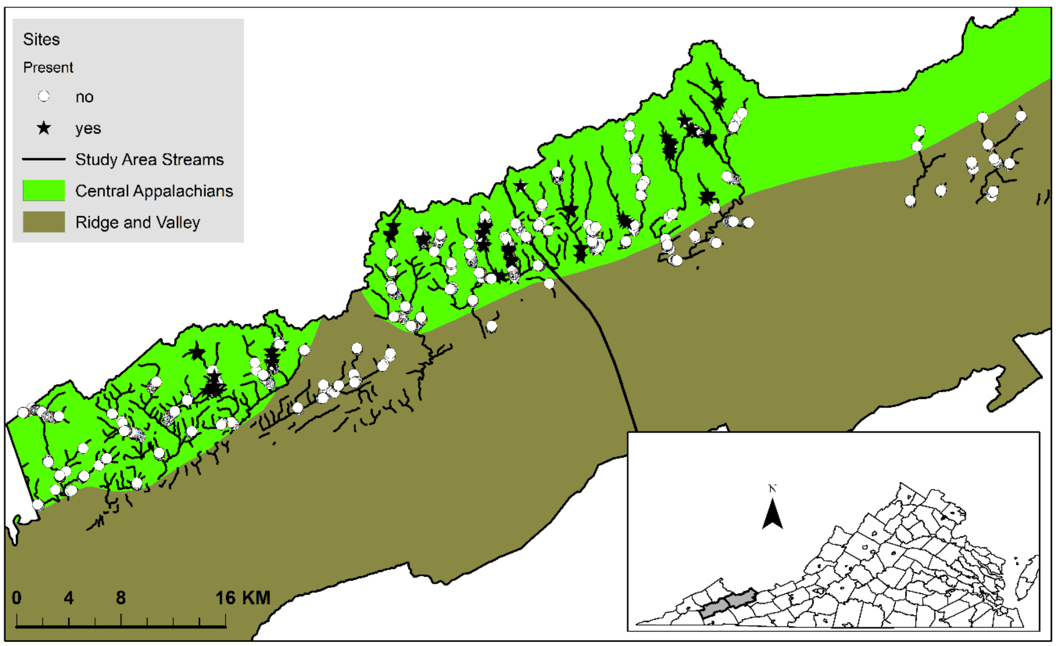

Figure 2. Locations of all of the sampling events within the study area based on prior surveys (Skelton 2007; Coyner unpublished data; White and Orth 2013; White and Orth 2014a, White and Orth 2014b, Hatcher et al. 2017; Moore et al. 2017a; Moore et al. 2017b). Sites where Clinch Dace were absent are indicated by circles. Sites where Clinch Dace were present are indicated by stars. Shading illustrates ecoregion boundary in Russell and Tazewell Counties.

Opportunity

We considered two dimensions of opportunity related to mined land reclamation for the 15 CCAs. The Surface Mining Control and Reclamation Act of 1977 (SMCRA; 30 U.S.C. §§1201-1211, 1231-1251, 1252-1328) mandates restoration of surface mines and promotes the restoration of mines that were abandoned prior to its enactment. Managers may be able to reclaim watersheds with active permits in ways that benefit Clinch Dace. The area of overlap of the CCAs was calculated using two GIS shapefiles obtained from the Virginia Department of Mines, Minerals and Energy (VADMME); reclamation status and designated post-mining land use. We classified each permitted mining site under one of three stages of reclamation: disturbed, regraded, and vegetated. Before mining permits are approved, companies must propose a post-mining land use (PMLU) to which they will attempt to restore the site. Thirteen categories of PMLU exist, including: agriculture-hay land, agriculture-grazing land, agriculture-managed forest, commercial, fish and wildlife habitat-wetlands, fish and wildlife habitat-species management, industrial gas wells or pipelines, industrial utilities, industrial manufacturing, public use-buildings and facilities, public use-public roads, residential, or undeveloped unmanaged lands. We also calculated the proportion of each occupied watershed that overlaps with these PMLU categories in order to envision future land cover.

The Office of Surface Mining Reclamation and Enforcement under the U.S. Department of the Interior handles reclamation on mined lands that were abandoned before 1977. This agency maintains the Abandoned Mine Land Inventory System Database (Office of Surface Mining Reclamation and Enforcement 2016), which contains information on all priority 1 and 2 and some priority 3 abandoned mine sites. Priority 1 and 2 abandoned mine sites threaten human safety, while priority 3 sites threaten the environment. The database also includes information on the specific nature of the problems at each site and the estimated cost of their reclamation.

We selected abandoned mine lands in all three priority levels with problems that were potentially related to aquatic habitat degradation. This includes the following problem types: under priority classes 1 and 2 — clogged streams, clogged stream lands, dangerous impoundments, industrial or residential waste, polluted water: human consumption. Under priority class 3 — hillside benches, industrial or residential waste dumps, processing or transport equipment and facilities, gob piles, exposed high-wall mines, haul roads, pits, spoils, slurry, slumps, water environmental impacts, and other environmental impacts.

Feasibility

We approached our conservation feasibility assessment through an assessment of land ownership patterns and potential numbers of stakeholders. We assembled land ownership records from plat maps at the Russell and Tazewell county government offices. We were not able to identify catchment boundaries on the paper plat maps, and instead we selected acreage of all tracts adjacent to stream reaches with documented Clinch Dace presence.

Potential Actions

Finally, we explored how the data that have been compiled could be used to design an influence diagram and parameterize a structured decision model to weigh management alternatives. We also compiled a list of possible management actions with characteristics of the Clinch watershed landscape and stakeholder base in mind. The list includes mention of existing conservation alliances and other possible approaches for fostering collaboration. We address this in the Discussion section of the paper.

RESULTS

Habitat Condition

Habitat Condition scores among CCAs ranged from a high score of 5 in Greasy Creek to 1 in Big Lick, Hart, Hess, Left Fork Coal, Pine, and Town Hill creeks as well as Hurricane Fork/Grassy Branch. (Figure 3A, Table 3). The condition scores were heavily influenced by the positive relationship between Clinch Dace occupancy and substrate embeddedness. Sites with high predicted occupancy had higher amounts of fine sediments, higher elevations, and larger proportions of forest cover in their watersheds. Conductivity had a smaller negative influence on Clinch Dace occupancy.

Substrate embeddedness was highest in Lewis Creek, Greasy Creek, and Laurel Fork. CCA's with >90% watershed forest cover included Jackson Fork, Indian Creek, Laurel Fork, Mudlick Creek, West Fork Big Creek, and Middle Creek. Forest cover was less than 70% in Hess Creek, and Left Fork Coal Creek. Conductivity was lowest in Big Lick Creek and Mudlick Creek and highest in Hurricane Fork, Greasy Creek, and Hess Creek.

Viability

Composite scores for viability ranged from 4.75 in Pine Creek to 1.0 in Lewis Creek (Figure 3B, Table 3). Within all but one of the CCAs, researchers have detected Clinch Dace at >40% of the site visits. The exception was Lewis Creek, where Clinch Dace were not discovered until 2014 and are believed to be restricted to a few pools within a ~700-m stream reach. In 9 of 15 CCAs, estimated densities of adult Clinch Dace were very low, with < 10 individuals/100 m. Density estimates exceeded 30 individuals/100 m in only 4 CCAs, Hart, Middle, and Pine creeks and Hurricane Fork. Connectedness to other populations was generally low. Exceptions were Pine and Big Lick creeks, which were separated by less than 3.2 km of unoccupied stream habitat, and sites within the upper Indian Creek watershed (Greasy Creek, Indian Creek, and Jackson Fork). Occupied stream length was > 4 km in Hurricane Fork, Mudlick/Zeke creeks, and Pine Creek. Pine Creek and

Hurricane Fork are the only streams in which Clinch Dace occupied a long stream length at relatively high densities. In Mudlick Creek, Clinch Dace occupied a long stream length, but at low densities. Hart and Middle Creeks have high population densities over moderate distances. Big Lick Creek has moderate population densities over moderate distances. Lewis Creek, Laurel Fork, Hess Creek, Left Fork Coal Creek, West Fork Big Creek, and Jackson Fork received the lowest scores for both density and population extent.

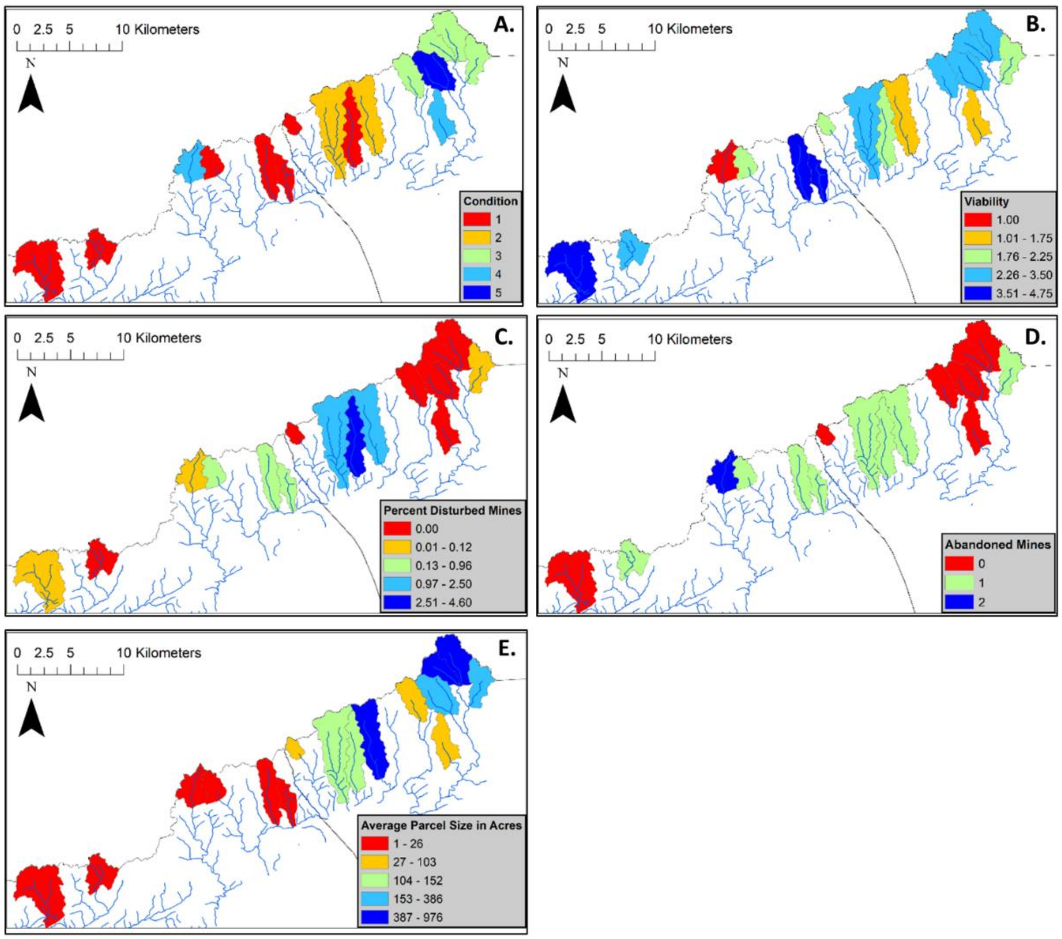

Figure 3. Metric data for each CCA. A. Habitat condition scores as measured by modeled probability of Clinch Dace presence. B. Viability scores for each CCA. C. Percent coverage of disturbed surface mines for each CCA. D. Number of abandoned mine lands in each CCA. E. Average land parcel size in acres adjacent to Clinch Dace streams in each CCA.

Table 3. Data used to assess populations on viability and habitat condition metrics.

CCA	% Surveys Clinch Dace Present	Avg. Abundance/ 100 m	Distance to Nearest Population (km)	Stream Length Occupied (km)	% Forested	Conductivity (µS/cm)	Proportion > 75% Embeddedness	Average Elevation	Probability of Presence**
Big Lick Cr.	80.00	27.54	1.88	2.40	79	143.00	10.00	671.810	0.19
Greasy Cr.	88.89	4.71	5.99	2.93	89	358.00	74.50	721.720	0.89
Hart Creek	100.00	49.37	>8	2.22	72	339.62*	18.80*	575.720	0.08
Hess Creek	83.33	4.15	>8	0.79	61	340.00	19.00	674.915	0.07
Hurricane Fork/ Grassy Br.	84.62	41.33	>8	4.27	83	419.00	25.00	592.265	0.16
Indian Cr.	66.67	N/A	3.03	1.98	91	339.62*	18.80*	729.535	0.56
Jackson Fk.	50.00	0.92	3.03	1.00	93	168.00	7.00	690.600	0.41
Laurel Fk.	40.00	N/A	>8	0.13	91	242.00	55.00	666.920	0.74
Left Coal Cr.	100.00	6.35	>8	0.16	64	170.00	18.80*	712.200	0.14
Lewis Cr.	12.50	N/A	>8	0.73	67	275.00	87.00	713.655	0.72
Middle Cr.	62.50	40.27	>8	1.59	90	189.00	22.00	725.095	0.58
Mudlick Cr.	83.33	8.18	>8	7.00	90	151.00	8.50	648.860	0.28
Pine Cr.	90.00	37.94	1.88	4.42	78	181.00	8.00	661.685	0.14
Town Hill Cr.	72.73	3.02	>8	2.34	87	221.00	12.00	615.685	0.19
W. Fork Big Cr.	60.00	N/A	>8	0.55	90	168.00	18.80*	647.752	0.36

*****Denotes imputed value from CCA averages.
**Generated from models in Table 2.

There was a lack of correlation between habitat condition scores and viability scores (Figure 4); therefore, we present a multivariate analysis of the relationships between specific habitat variables and CCA viability scores. Final stress was 0.047, indicating that the two-dimensional plot represented the data well (Clarke 1993). In the NMDS ordination, sites with high viability scores scored lower on NMDS axis 1 and slightly higher on NMDS axis 2. Highly viable sites correlated with lower conductivity, slightly above-average forest cover, and above-average stream gradient (Figure 5).

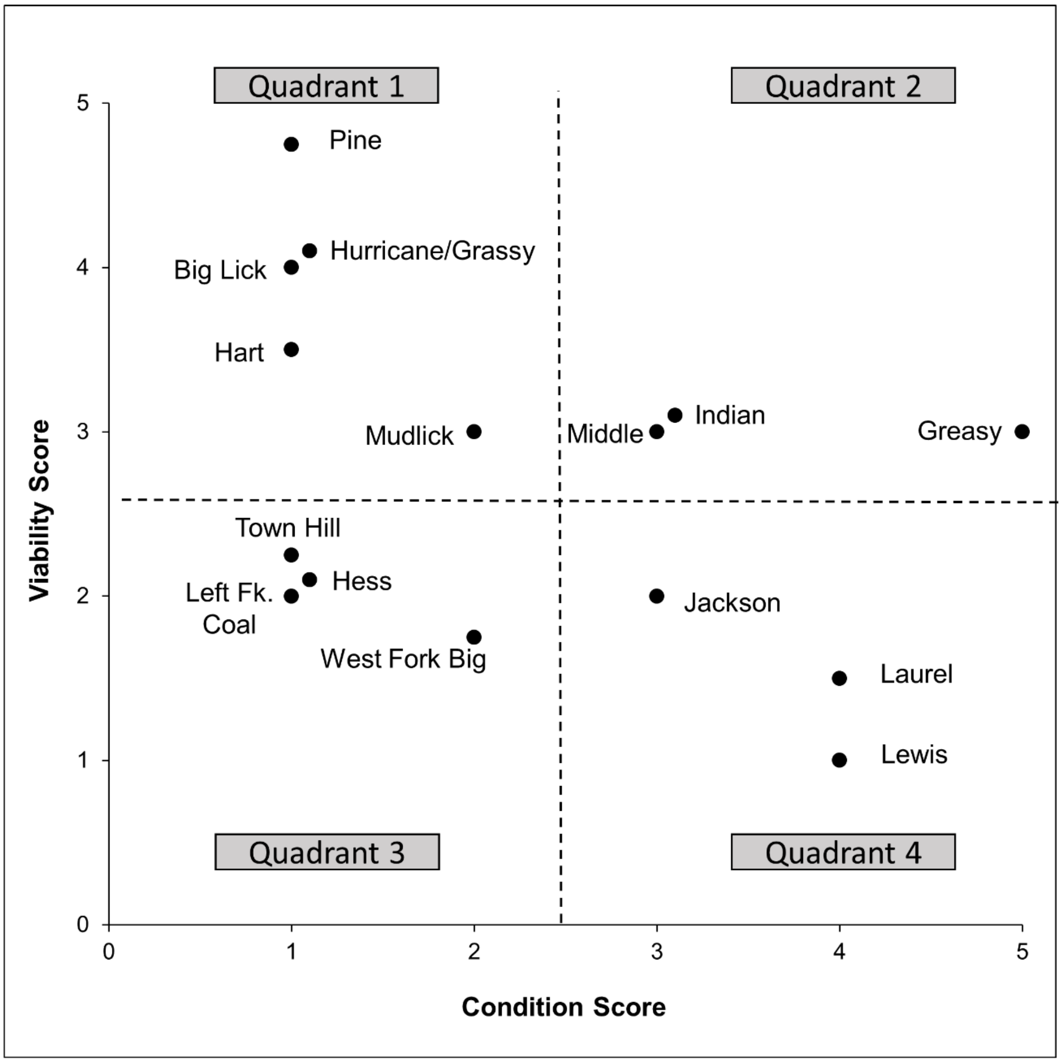

Figure 4. Scatterplot showing the lack of statistical relationship between condition scores (probability of Clinch Dace presence) and viability scores (Pearson's R^2=0.18 P>0.05). Some discrete values were offset to avoid overlap on the plot. The lack of relationship is examined in the discussion and using the NMDS plot (Figure 5). Quadrants imposed to examine site-specific priority management alternatives in the discussion.

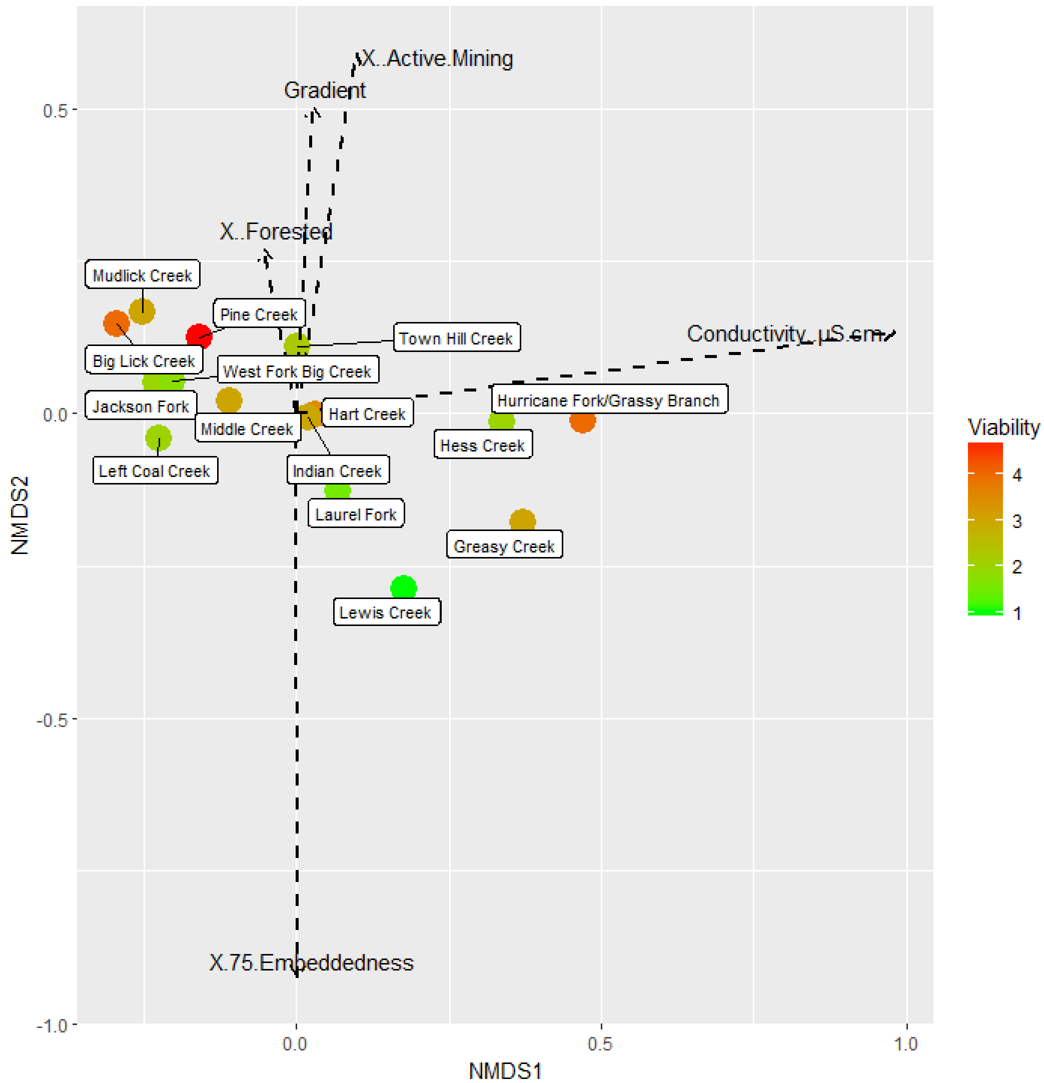

Figure 5. NMDS ordination of viability scores vs. habitat condition variables for all 15 CCAs. The NMDS1 axis is positively correlated with conductivity. NMDS2 is negatively correlated with substrate embeddedness and positively correlated with active mining, gradient, and forest cover.

Opportunity

CCAs with the most land in a "disturbed" reclamation status — areas which could be candidates for restoration opportunities under SMCRA — include Mudlick Creek, Pine Creek, and Town Hill Creek (Figure 3C). The proposed post-mining land uses (PMLUs) across occupied catchments were mostly undeveloped or unmanaged forestry (69.4%). Substantial portions of permitted lands were also designated as agriculture/grazing (17.2%) and industrial gas wells/pipeline (13.2%). A very small proportion of permitted land (<0.2%) was intended to be restored to fish and wildlife habitat following mining.

We identified 47 priority- 1, 2, or 3 mine sites with potential environmental impact in Russell and Tazewell counties, Virginia, with a total of $22,169,818 (Office of Surface Mining Reclamation and Enforcement 2016) in unfunded costs. Ten of these abandoned mine sites occur within Clinch Dace CCAs, with a total of $12,482,999 in unfunded costs. Abandoned mine sites were nearly evenly distributed among candidate conservation areas. Lewis Creek had the most abandoned mine sites, with two. Eight CCAs had one abandoned mine site, and 6 CCAs had no abandoned mine sites (Figure 3D).

Feasibility

Definite patterns in land ownership that would affect restoration efforts emerged among Clinch Dace watersheds (Figure 3E). The CCAs with the largest number of unique property parcels were Town Hill Creek and Pine Creek, with over 50 land-owning stakeholders. In contrast, Indian Creek, West Fork Big Creek, and Hess Creek all had fewer than 10 properties adjacent to reaches occupied by Clinch Dace. CCAs with fewer landowners usually had larger average property sizes. For instance, in West Fork Big Creek, the average parcel size was 813 acres.

CCAs with low human population density and land use likely devoted to resource extraction — such as forestry, mining, or gas drilling — were Greasy Creek, Hurricane Fork, Mudlick Creek, Middle Creek, Jackson Fork, West Fork Big Creek, Indian Creek, and Laurel Fork. Other CCAs have mixed land-use, including Pine Creek, Big Lick Creek, Hess Creek, Lewis Creek, and Town Hill Creek. These CCAs are primarily residential; all have > 5% current land cover in mining as well. Left Fork Coal Creek is primarily residential, but does have degraded condition from a large surface mine not far downstream of the Clinch Dace population. A large portion of the Hurricane Fork watershed is leased from the properties' owners by a forestry management company.

DISCUSSION

This multi-metric conservation prioritization framework provides quantitative conservation direction to benefit a critically imperiled fish by characterizing current habitat conditions and population status, while framing conservation action in light of future opportunity and identifying stakeholder characteristics.

Habitat Condition and Viability

Viability and condition scores should help managers decide which conservation strategies would provide the most benefit to individual CCAs. Results from our occupancy models and NMDS ordination suggest that managers should focus effort on conserving or restoring forest and limiting conductivity in low-gradient, high-elevation streams of southwest Virginia.

The lack of correlation between the habitat condition and viability scores was unexpected but suggests priority management interventions (Figure 4). CCAs that scored high in viability but low in habitat condition — such as: Pine Creek and Big Lick Creek (Figure 4 quadrant 1) — may be good candidates for habitat restoration to improve and further safeguard currently robust populations. However, the high scores may also result from an incomplete understanding of the relationships between some habitat variables and Clinch Dace presence or population size. Forest cover in watersheds has been one of the most consistent predictors of Clinch Dace occupancy (White & Orth 2014a; Moore et al. 2017b). However, substrate embeddedness may be a poor measure of habitat quality. Although substrate embeddedness was a better predictor of Clinch Dace presence in our occupancy modelling analysis than stream channel gradient, it is likely a worse measure of habitat quality. Interactive effects between stream gradient and watershed disturbance likely explain the patterns of embeddedness that we observed. High levels of fine sediments in highly forested watersheds such as Greasy Creek and Laurel Fork may be related to their gradual channel slopes; whereas high levels of fine sediments in low-gradient streams such as Lewis Creek may be amplified by erosion from watershed disturbances such as forest clearing. Furthermore, a recent study in southwest Virginia (Martin et al. 2018) found no relationship between benthic habitat quality (i.e., fine sediment deposition) and mining intensity which leads to large-scale forest clearing. This suggests that high-gradient streams have sufficient power to flush fine sediments downstream (Martin et al. 2018). Substrate embeddedness in our 15 CCAs was negatively correlated with stream gradient measured with a 30-m Digital Elevation Model in GIS in our NMDS ordination, although it is not statistically significant according to a Pearson's correlation test (R^2 = -0.34, P = 0.21).

Clinch Dace also may persist in sandy or silty streams due to nest association with Creek Chubs *Semotilus atromaculatus* and Stonerollers *Campostoma anomalum* (White and Orth 2014b; Hatcher et al. 2017). Thus, Clinch Dace may be able to successfully reproduce in low-gradient streams with abundant fine sediments as long as the nest builders are present. Future research that disentangles the influence of fine sediments and channel gradient on Clinch Dace occupancy would improve managers' ability to more accurately assess benthic habitat condition in Clinch Dace streams.

In contrast, the opposite relationship — where sites with reasonably high condition scores have low viability scores — also occurred (Figure 4 quadrant 4). These sites (Laurel Fork, Jackson Fork, and even Lewis Creek) may be candidates for reintroductions or barrier removal to help augment populations in what is now suitable habitat. An alternate explanation may be that we have insufficient data on Clinch Dace population sizes due to limited sampling access. For example, West Fork Big Creek and Laurel Fork had limited stream access in these upper portions of these watersheds, possibly leading to low population estimates. However, the possibility of penalizing a population for limited access also accurately underscores an obstacle to management and monitoring.

Opportunity and Feasibility

Managers may find opportunity for conservation on mined lands where reclamation is already scheduled. The analysis of surface mines in the "Disturbed" reclamation status category highlights many opportunities for landscape reclamation and revegetation in Clinch Dace CCAs. However, designated post-mining land uses for these watersheds indicate that reclamation standards in these watersheds may be set too low. Clinch Dace populations occurred in watersheds with large proportions of post-mining land uses (PMLUs) in undeveloped/unmanaged forestry, agriculture/grazing, and industrial gas wells/pipeline as post-mining land-uses. These PMLUs may represent a separate conservation planning framework that runs counter to the goals of Clinch Dace conservation, and may prove more of an obstacle than an opportunity for such actions. Lands designated for agriculture and grazing likely will not be returned to forest, which is the natural land cover for the region and is associated with Clinch Dace presence (White & Orth 2014a; Moore et al. 2017b). Undeveloped or unmanaged forestry likely means that little restoration effort will be invested in the land as long as some form of vegetation is restored to meet bond requirements, and top-soils may be too degraded to support native tree species for many years. While the effect of gas drilling on nearby Clinch Dace populations is unstudied, along with drilling come threats posed by road installations, which contribute sediments and whose culverts may create impassable barriers to movement. Wells also might use water withdrawn from creeks or underground sources that feed the same streams. Unless more land is returned to sustainably managed forestry and fish and wildlife habitat, fisheries managers should work with the appropriate agencies and companies to restore mined lands to conditions resembling pre-mining conditions.

Abandoned mine lands are infrequent in Clinch Dace watersheds, but their reclamation could provide water quality and habitat benefits for Clinch Dace populations. Yet, the abandoned mine lands that are listed primarily for their environmental impacts are a lower reclamation priority in the federal reclamation program than those impacting human safety. Reclaiming mined lands inside all Clinch Dace CCAs would cost millions of dollars. The trust fund that pays for abandoned mine land reclamation is administered by the Secretary of the Interior. The merits of the Revitalizing the Economy of Coal Communities by Leveraging Local Activities and Investing More (RECLAIM) Act (H.R. 173) continue to be debated and may fund economic revitalization projects, some of which could enhance connectivity of Clinch Dace habitats. It is unlikely that any of the CCAs are highly suitable for agriculture or urban development. Catchments occupied by Clinch Dace are steep, with mean slopes of 32.5% (95% conf. interval = 30.9-34.2%) and have a rocky surficial geology with a mean of 99% sandstone colluvium (NHDPlus V. 1). Future land-cover conversion is driven by unpredictable coal and timber markets.

Additionally, mining is not the only land use with the potential to impact Clinch Dace populations. On a small-scale conservation opportunity also exists in terms of better riparian management from small-scale agriculture and lawn-care practices by local landowners. Further on-the-ground work with landowners identified through stakeholder analysis can highlight opportunities to amend land use practices and prohibit discharge of household wastes that improve water quality and channel morphology in Clinch Dace streams. At the watershed scale, there are likely opportunities to improve forestry practices that reduce the mobilization of fine sediments from the landscape and protect riparian corridors in headwater streams.

The variation that exists in parcel size among CCA's provides opportunity for strategic decisions. The longstanding debate among conservation biologists over whether a few large or many small reserves best achieves conservation objectives continues today (Diamond 1975; Simberloff and Abele 1982; Davies et al. 2009). However, the existing landownership structure as well as practical financial concerns of management agencies and conservation nongovernmental organizations (NGOs) affects what conservation actions or land purchases are realistic. For instance, costly actions or acquisitions on large land tracts may reduce the operational flexibility of agencies with annual budgets for the rest of the fiscal year (Costello and Polansky 2004; Davies et al. 2009). Parcel size also affects the type of management that can occur. For one of the largest conservation NGOs, the Nature Conservancy, voluntary easements are typically larger than fee simple acquisitions and cost less per unit area (Davies et al. 2009).

Management Alternatives

The use of the data collected for our prioritization framework is only the first step in planning targeted conservation action for Clinch Dace. Through cooperation with stakeholders, managers can improve habitat conditions to benefit Clinch Dace. Stakeholder input and expert knowledge can be used to parameterize structured decision models in a transparent manner that maximizes conservation utility while minimizing cost. Figure 6 presents an influence diagram that could be used to make decisions regarding conservation actions for Clinch Dace. Influence diagrams depict all components of a decision-making problem indicated by the boxes or nodes, with the causal relationships among components indicated by arrows (Conroy and Peterson 2013). Values in square-shaped nodes are known with certainty, while oval nodes contain uncertainty. Blue nodes are decision nodes with mutually exclusive and exhaustive decision alternatives. We deliberately grouped nodes under our conservation metrics (habitat condition, viability, opportunity, and feasibility) to emphasize how the data provided here can be used to aid decision-makers. Different decision combinations in the decision nodes lead to changes in the nodes that comprise our conservation metrics, which results in changes in overall conservation utility. The conservation utility is the final diamond-shaped node. In this framework, conservation utility can be maximized by increasing Clinch Dace habitat condition, population viability, or opportunity and feasibility.

A long-term management plan must navigate regulatory and environmental uncertainty. Structured decision-making and Bayesian belief networks excel at accommodating uncertainty (Conroy and Peterson 2013). For instance, standard errors of presence probabilities from occupancy models can be used to account for uncertainty in habitat condition scores. Models may be updated as more information is gathered on population status, habitat conditions, and the relationship between population status and habitat conditions from long-term monitoring programs. Forthcoming population genetic information would inform management decisions that reflect population structure, such as increasing population connectivity through barrier removal, translocating individuals to supplement demographically depressed populations or start new populations. This design lends itself to an adaptive management approach, in which management becomes experimental by incorporating feedbacks from monitoring data to evaluate project success and periodically adjust actions (Walters 1986; Irwin and Freeman 2002) in the face of such uncertainty. Decisions, such as deciding to sample the population, decrease the uncertainty in node values or the relationships among nodes, thereby adding conservation value.

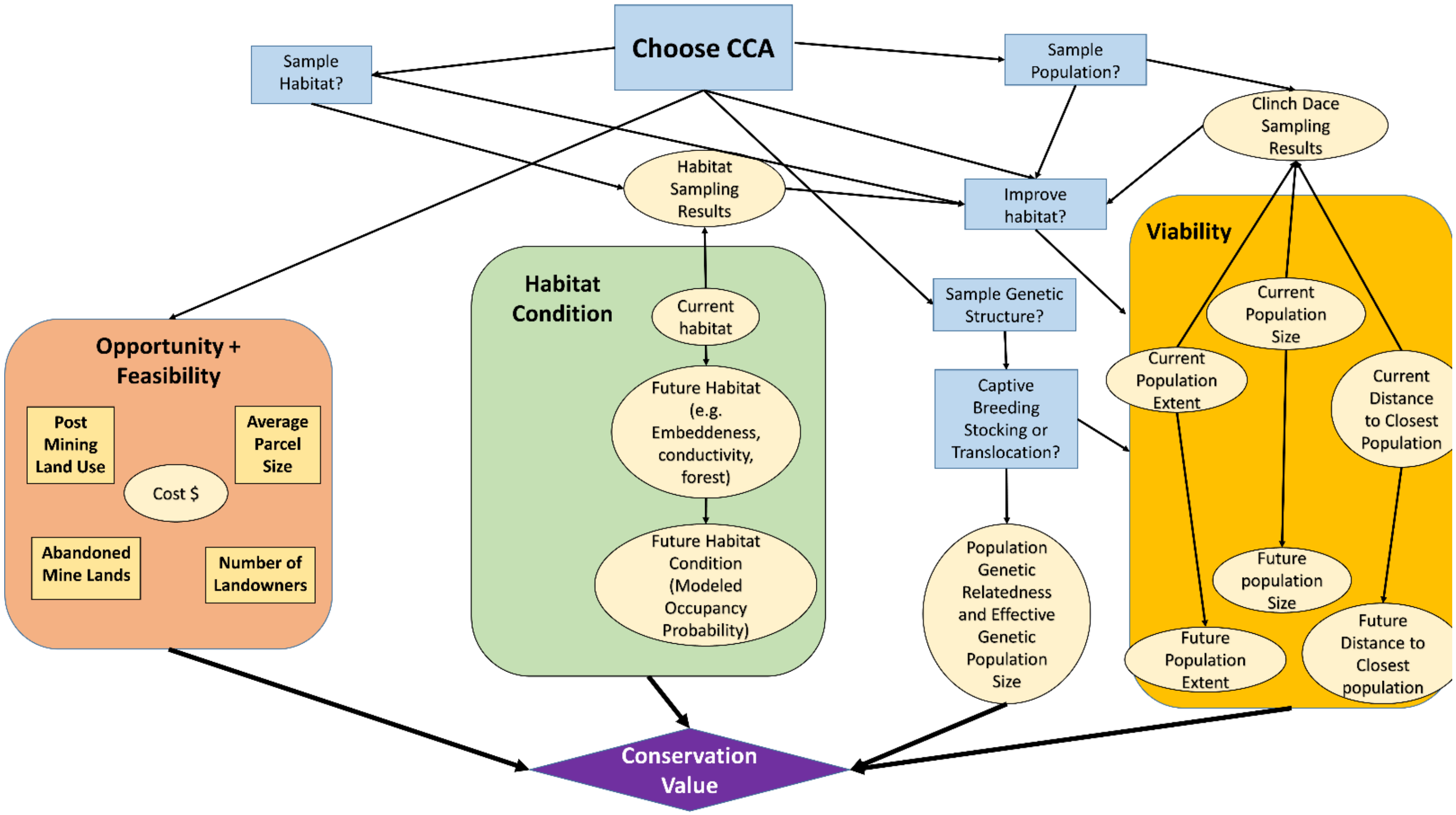

Figure 6. Simulated means objectives diagram showing connections between possible management decision alternatives and how they relate to each of our conservation metrics and the data we provide. Square boxes are nodes can be known with certainty. Oval nodes contain uncertainty. Blue nodes are decision nodes with discrete decision alternatives. Yellow nodes are informed by data or models presented in this study. The conservation utility is the final diamond shaped node. Conservation utility can be increased by increasing Clinch Dace habitat condition, population viability, or opportunity and feasibility. It can also be increased through a reduction in uncertainty.

There are three categories of stakeholders in any decision problem: those that are directly impacted by management plans; those that are indirectly impacted, but have a declared moral or philosophical interest; and those that have little interest one way or another, but can help serve as bridge-builders to resolve conflicts (Hirsch & Dukes 2014). Lists of stakeholders tied to the Clinch Dace are extensive. Direct stakeholders include: coal mining companies, power companies, residents (those employed in mines, farmers, and homeowners), and local business owners. Indirect stakeholders may include: environmental organizations, activists, academic institutions, government agencies such as the Virginia Department of Game and Inland Fisheries, the Environmental Protection Agency, Virginia Department of Environmental Quality, the U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers. Bridge-building stakeholders could include church leaders, community leaders, and educators. Furthermore, local community governments are beginning to embrace the prospect of ecotourism around the aquatic biodiversity in the Clinch River. Many indirect stakeholders may be viewed as outsiders by direct stakeholders, and bridge-builders can help build trust between these two groups.

With such a diverse list of stakeholders, input for Clinch Dace management could be collected at community meetings at churches, schools, or other convenient locations. These meetings can lead to adoption of cooperative actions that involve multiple stakeholder groups including environmental organizations and local governments to achieve economic and conservation objectives (i.e., Clinch River Valley Initiative and Clinch Powell-Clean Rivers Initiative). A regional economy based on outdoor recreation and ecotourism in the Clinch River Valley will increase the river’s value and create opportunities for small local businesses. Proposed actions, such as creating a Clinch River State Park, incentivize protection of the Clinch Basin, its water quality, physical habitat, and native biota. Through this collaborative process, it may be possible for stakeholders to agree upon potential agency management responses in priority conservation areas, such as direct fee acquisition, conservation easements, management agreements, stewardship assistance to landowners, agency designations of special areas (e.g., research natural areas), congressional wilderness designations, and administrative actions such as national monument designations (Noss et al. 2002). Retrofitting road crossings with passable culverts or bridges that preserve the natural streambed should be targeted for high-priority populations in locations where such crossings may restrict Clinch Dace colonization and population connectivity.

Some small-scale habitat restoration projects can proceed on individual properties without total consensus. including maintaining septic systems, planting native riparian grasses, herbs, and trees, installing rain gardens, using pesticides and herbicides less, testing soil to ensure proper application of fertilizers, disposing of trash properly, maintaining forest buffers along streams, fencing cows from streams, and creating conservation easements. Cooperative Extension agents are available to assist landowners in these efforts. Environmental education is correlated with environmentally responsible behaviors (Ostman & Parker 1987), and ongoing education and outreach for local endangered aquatic species at schools and community events (Wetlands Estonoa n.d.) should continue. The strong community and family bonds in rural areas may influence landowners to adopt positive management practices in which they observe their neighbor engaging. These actions would address all of the factors that underlie the Theory of Planned Behavior (Ajzen 1985), namely, that individuals see value in positive conservation actions, feel capable to perform positive conservation actions, and feel social pressures to perform conservation actions.

Other possible management decisions that could benefit Clinch Dace that could be parameterized with additional research or through eliciting expert opinion include protecting refugia (e.g., creation of pools, shaded stream channels, and natural flow regimes), enhancing connectivity between and within populations (removing culverts and predators), and upholding ecosystem processes (large woody debris input, sediment transport reduction, etc.) (Groves et al. 2012). Changes in the enforcement and interpretation of laws regulating coal mining permitting will also affect Clinch Dace populations. Large surface mines — sometimes referred to as mountaintop removal mines — often bury headwater streams with waste materials that overlay coal deposits. Temperature, flow, and ionic composition of the water downstream may be altered downstream of valley fills. A growing body of literature shows impacts to sensitive insectivorous fishes from mining activity in headwater streams (Martin et al. 2018). Elected and appointed officials, especially at environmental agencies, ultimately will interpret key issues related to mining, such as the use of the Nationwide Permit that allows mines to dispose of waste materials in streams and the definition of “fill” as it pertains to valley fills adjacent to surface mines (Hirsch & Dukes 2014).

The conservation assessment for Clinch Dace is a novel adaptation of multispecies conservation planning theory to a critically imperiled aquatic species. This is a first step promoting conservation action for this species. Data synthesized here can be used in future decisions to allocate limited resources for Clinch Dace conservation. Hopefully, place-based identification of conservation hot-spots will help spark recovery for this rare species and Appalachian headwater streams in general.

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