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Rating US reservoirs relative to fish habitat condition

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Abstract

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Fish habitats in many aging US reservoirs have become degraded and require broad-scale assessment to rate their status and facilitate rehabilitation efforts. To help prioritize habitat projects in reservoirs, we assembled a rating system for large reservoirs in the contiguous United States. Using responses to an online questionnaire about fish habitat impairment in 1299 large US reservoirs, we applied multivariate analyses to identify combinations of habitat impairment descriptors that quantified broad impairment types (i.e., a construct). Resulting constructs reflected point source pollution, nonpoint source pollution, excessive nutrients, algae blooms, siltation, limited nutrients, mudflats and shallowness, limited connectivity to adjacent habitats, limited littoral structure, nuisance species, anomalous water regimes, and large water level fluctuations. Scores were summed across constructs to create a composite number that rated overall reservoir habitat impairment. Construct and composite scores differed among geographic ecoregions of the United States. This rating system could provide a starting point for prioritizing reservoirs for habitat rehabilitation and enhancement projects.

Key words: eutrophication, fish, habitat assessment, physical lake features, water quality

Degradation of fish habitat has long been a concern of many reservoir ecologists, but the issue is quickly coming to the forefront as reservoirs age (Miranda and Krogman 2015, Pegg et al. 2015). Most US reservoirs were built in the 20th century, and as of 2014 their median age was 57 years (USACE 2009). Reservoirs are impounded rivers and receive more allochthonous inputs from incoming tributaries than do lakes, thereby experiencing ecological succession at an accelerated rate. Sediments and nutrients entering reservoirs slow and settle, accumulating in the benthic zone and entering the food web through photosynthetic and bacterial uptake (Thornton 1990). Fish habitat issues such as excessive sediments and nutrient loadings, degradation of submerged structure, and erosion of shorelines not adapted to continuous immersion may emerge in an aging reservoir and worsen over time (Agostinho et al. 1999).

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State and federal agencies are expanding habitat activities and calling for implementation of nationwide programs to improve aquatic habitats (AFWA 2012). Many fish management agencies are expanding their reservoir habitat management programs with additional personnel that focus exclusively on habitat enhancement and rehabilitation, although the approaches differ among agencies depending on how local conditions influence aspects of reservoir habitat. These advances have come about because of recognition that aquatic problems in reservoirs are being largely driven by relatively rapid environmental changes and the realization that biotic manipulations and harvest management alone cannot sustain fish communities at desired levels (Miranda 2008).

Assessment systems for lakes and reservoirs generally have focused on in-reservoir water quality parameters indicative of trophic state (e.g., Vollenweider 1968, Schindler 1971, Carlson 1977, Ground and Groeger 1994, Burns et al. 1999). More recently, Kaufmann et al. (2014) outlined a rapid approach for quantifying aquatic habitats (i.e., littoral habitat complexity, fish cover, substrate, aquatic macrophytes, riparian vegetation, and human disturbances) in large-scale assessments, but this methodology was limited to the lakeshore. Habitat monitoring, management, and restoration are hindered by a scarcity of comprehensive quantitative indicators to track habitat condition and provide managerially or scientifically useful information. Quantitative indicators of reservoir fish habitat status, or reservoir ratings, could be used to grade habitat in reservoirs and measure progress toward goals. Managers could use the reservoir ratings to set priorities, evaluate strategies, and possibly provide a systematic, integrated approach to reporting performance of rehabilitation efforts. Moreover, by quantifying concepts about habitat condition, ratings may facilitate research into the causes of habitat impairment.

In view of this need, our objective was to rate US reservoirs relative to fish habitat condition. To score reservoir habitats, we applied a quantitative index similar to that developed by Miranda and Hunt (2010), although we expanded the index to account for additional habitat impairment factors. We used the scores to explore how habitat impairment varies among and within geographic ecoregions of the United States.

Methods

Large reservoirs within the contiguous United States were defined by the Reservoir Fisheries Habitat Partnership (RFHP) as any river impoundment equaling or exceeding 100 ha in surface area (http://www.reservoirpartnership.org). Using this simple definition, our initial sampling frame included > 4300 water bodies ≥ 100 ha documented in the National Inventory of Dams (USACE 2009).

Data collection

We developed an online survey that included 52 questions about habitat impairment, including aspects of habitat availability, water quality, water regime, and degradation processes (Table 1). Questions were expanded from a previous survey (Miranda and Hunt 2010) based on extensive literature review. A 6-point Likert-type scale was used to collect responses with ratings from 0 to 5: 0 = no impairment, 1 = low impairment, 2 = low-to-moderate impairment, 3 = moderate impairment, 4 = moderate-to-high impairment, and 5 = high impairment. Respondents were instructed to rate impairment based on the reservoir's state during the past 5 years and relative to similar reservoirs within their geographic region. The link for the online survey was made available through state natural resource agencies to all biologists responsible for managing fish in reservoirs. After an introduction outlining the survey's purpose, as well as the voluntary and confidential nature of responses, respondents were asked to complete the survey for reservoirs under their jurisdiction. The survey was conducted via the host SurveyMonkey (http://www.surveymonkey.com) between June and December 2010, including a follow-up period when nonrespondents were contacted multiple times to encourage participation.

This survey depended on the perception of professionals, but perceptions may vary geographically depending on exposure. The extent of this effect depends on the extent of the geographic area. To promote equivalence of responses among participants in our study, each question was coupled with an expanded narrative to help focus the respondent. Moreover, respondents were instructed to exclude little-known reservoirs, including privately owned and small reservoirs that were not frequently monitored.

Rating system

All survey responses were examined for completeness and duplication (i.e., one entry per reservoir), and incomplete (i.e., >30 % item nonresponse; Schafer 1997) or duplicated cases were removed from analyses. Remaining missing values were estimated using multiple imputation (MI procedure; SAS 2009).

We hypothesized that the responses to the 52 questions (i.e., observed variables) were intercorrelated and measured multiple facets (i.e., latent constructs) of habitat impairment. To identify the latent constructs, we submitted the 52 observed variables to oblique coordinate analysis (OCA), a clustering procedure similar to principal coordinate analysis but not requiring that axes be orthogonal (Harman 1976). In an ordinary principal coordinate analysis all components are computed with the same set of variables, although in each component each variable is given a different weight, and components are orthogonal (i.e., uncorrelated) relative to each other. In OCA, each cluster component is computed with a different and separate set of variables, and components are oblique (i.e., correlated) relative to each other. We chose an oblique approach because habitat impairments are often interrelated and co-occurring, and therefore statistically dependent. Additionally, OCA typically yields more interpretable scales, an important part of our objective. The OCA was applied with the VARCLUS algorithm (SAS 2009), beginning with all variables in a single cluster component and iteratively splitting components until no additional components with eigenvalue > 0.9 could be defined. The OCA was applied to a distance matrix created using Gower's similarity coefficient (appropriate for ordinal scale data; Gower 1971) on the 52 observed variables, yielding a number of latent impairment constructs. Reliability of latent constructs was assessed using Cronbach's alpha coefficient for internal consistency (Cronbach 1951), and observed variables reducing a constructs' internal consistency were removed.

Table 1. Variables representing diverse sources of fish habitat impairment in large US reservoirs.

Impairment variable	Code	Definition
Excessively shallow reservoir	1	Entire reservoir is excessively shallow, with no or few deep water refuges
Excessive littoral mudflats	2	Seasonally flooded and exposed expansive layers of soft sediments; terrestrial vegetation seldom grows unless the mudflats are exposed for many months
Insufficient adjoining backwaters and wetlands	3	The reservoir or tributaries have no or limited adjoining backwaters or wetlands and therefore lack the benefits of those habitats
Insufficient connectivity to backwaters and wetlands	4	Disconnectivity of a reservoir to adjacent backwater areas and wetlands may prevent fish from accessing these habitats
Insufficient connectivity to tributaries due to sedimentation	5	Sedimentation has resulted in decreased connectivity to tributaries during low-flow periods, acting as a barrier to fish movement
Excessive aquatic macrophytes	6	Overabundance of native or nonnative aquatic plants
Insufficient aquatic macrophytes	7	Lacking or deficient aquatic plants for structural fish habitat
Invasive plant species	8	Presence of nonnative aquatic macrophytes that may negatively impact reservoir systems, reduce public access, or present other problems to reservoir managers
Invasive animal species capable of altering habitat	9	Presence of nonnative fish or other animals that may negatively impact fish habitat
Insufficient structural habitat	10	Lacking or deficient structure such as large woody debris, gravel substrates, and diverse bottom relief
Excessively shallow littoral zone	11	Littoral zone is mostly shallow and therefore heavily influenced by temperature, wind, and other atmospheric changes
Deep or steep littoral zone	12	Littoral zone is missing the habitat benefits of shallower water due to excessive bank slope
Insufficient bank shading	13	Littoral zone receives no or limited shade or cover from terrestrial vegetation or other physical features
Insufficient allochthonous inputs	14	Debris from terrestrial plants (e.g., tree branches, leaves, and other vegetation) rarely falls into or is washed into shore areas
Excessive disturbance of riparian zone	15	Incompatible land management practices (e.g., clearing, mowing, agriculture, bulkheading) and/or development (e.g., housing, industry) extend near the shoreline of the reservoir
Harmful levels of agriculture in the surrounding watershed	16	The watershed surrounding the reservoir, and above the reservoir since the last dam, supports deleterious row-crop agriculture practices.
Harmful levels of livestock production in the surrounding watershed	17	The watershed surrounding the reservoir, and above the reservoir since the last dam, supports deleterious grazing practices and/or feedlot production
Harmful levels of logging in the surrounding watershed	18	The watershed surrounding the reservoir, and above the reservoir since the last dam, supports long-term deleterious logging practices
Harmful levels of mining in the surrounding watershed	19	The watershed surrounding the reservoir, and above the reservoir since the last dam, supports deleterious mining practices
Harmful levels of urbanization in the surrounding watershed	20	The watershed surrounding the reservoir, and above the reservoir since the last dam, supports excessive urban development
Excessive nutrients	21	Excessive chemical nutrients in water, primarily nitrogen or phosphorus, which may result in an increase in primary productivity and lead to excessive plant growth and decay, lack of oxygen, and reductions in water quality
Insufficient nutrients	22	Lack of nutrients, primarily nitrogen and phosphorus, to foster primary production
Excessive suspended sediments or inorganic turbidity	23	Particulate inorganic matter, typically fine sediments, suspended in the water column that may inhibit primary production or affect foraging by fish and other aquatic organisms
Excessive organic turbidity	24	Particulate organic matter, other than algae blooms, suspended in the water column
Extreme seasonal variation in turbidity	25	Marked seasonal changes in suspended sediments
Harmful algae blooms	26	Frequent occurrence of algal blooms that may be toxic to aquatic ecosystems or inhibit public use or enjoyment of the reservoir
Extreme diel variation in dissolved oxygen	27	Potentially harmful daily changes in dissolved oxygen

(*Continued on next page*)

Table 1. Variables representing diverse sources of fish habitat impairment in large US reservoirs. (*Continued*)

Impairment variable	Code	Definition
Oxygen stratification	28	Development of high and low oxygen (i.e., hypoxic or anoxic) layers in the water column, which may reduce the amount of suitable habitat for aquatic organisms
Excessively high temperatures	29	High temperatures regularly exceed the tolerance limitations of fish or other aquatic organisms
Excessively low temperatures	30	Low temperatures regularly exceed the tolerance limitations of fish or other aquatic organisms
Temperature stratification	31	Development of a thermocline separating the warmer epilimnion and the colder hypolimnion
Untimely or frequent turnovers	32	Excessive or untimely destratification events are potentially harmful to aquatic animals or inhibit public use or enjoyment of the reservoir
Thermal pollution	33	Sudden changes in ambient water temperature caused by external processes, such as when water used as a coolant is returned to the natural environment at a higher temperature
Contaminants (heavy metals, biocides)	34	Chemical substances such as heavy metals or other fat-soluble pollutants that disrupt or harm physical processes or ecosystems and may present human health concerns (e.g., mercury in fish tissue); contaminants may be foreign substances or naturally occurring; when naturally occurring, they are considered contaminants when they exceed natural levels
Point source pollution	35	An isolated, or several isolated, source(s) of pollution such as a discharge pipe from a factory or sewage treatment plant
Non-point source pollution	36	Diffuse pollution that does not originate from a single discrete source and is usually found spread throughout a large area
Unfavorable seasonal hydrograph (or rule curve, if one exists)	37	The seasonal hydrograph targeted by the water-controlling authority is inconsistent with the life-history requirements and habitat needs of fish. If no rule curve exists, click NONE
Residual effects of upstream impoundments	38	One or more reservoirs upstream adversely affects water regime in this reservoir
Insufficient retention time	39	Quick flushing of the reservoir maintains high turbidity and precludes development of plankton communities
Insufficient water storage	40	Amount of water stored in the reservoir is not enough to sustain key fish populations, often due to siltation, decreased depth, and long-term drawdowns
Seasonally mistimed water level fluctuations	41	Timing of annual filling and emptying is inconsistent with the life-history requirements and habitat needs of fish
Excessive yearly drawdown	42	Extent of annual water level drop conflicts with the life-history requirements and habitat needs of fish
Excessive long-term drawdowns	43	Water level remains below desired levels most years and only occasionally rises to levels consistent with the life-history requirements and habitat needs of fish
Excessive short-term fluctuations	44	Water level fluctuates frequently, exposing shallow areas on a daily to weekly basis
Rapid water level change	45	The rate of water level increase or decrease is usually too fast and conflicts with the ecology of some fish species
Sedimentation	46	Settling of suspended sediments, which over time may reduce depth and homogenize substrates
Shoreline erosion	47	Removal of soil and associated terrestrial vegetation from the land–water interface due to weathering of banks or adjacent land slopes by water, ice, wind, or other factors
Loss of cove habitat due to depositional filling	48	Sedimentation has produced changes in cove habitat such as surface area reduction, cove isolation, fragmentation, and establishment of terrestrial vegetation in newly deposited land
Shoreline homogenization	49	A reduction of the shoreline's original habitat diversity by erosion or other processes
Homogenization of littoral substrates	50	A reduction of the substrate's original diversity by erosion and sedimentation
Disturbances in upstream watersheds	51	Disturbances in watersheds upstream of the reservoir, as opposed to disturbances in the watershed surrounding the reservoir, affect habitat impairment in the reservoir
Disturbances in adjacent watersheds	52	Disturbances in the watershed surrounding the reservoir, as opposed to disturbances in upstream watersheds, affect habitat impairment in the reservoir

We rated reservoirs with a composite index similar to that described by Miranda and Hunt (2010). Ratings (i.e., 0–5 Likert score) for each observed variable included in each construct were averaged and rounded to the nearest integer, yielding a range of possible construct scores from 0 to 5. Construct scores were then added to compute an overall composite rating score as:

$$\text{rating} = f_m^{'} + f_{m+1}^{'} + \cdots + f_n^{'}$$

$$f_m^{'} = \begin{cases} 0, & f_m < 0.5 \\ 1, & 0.5 \le f_m < 1.5 \\ 2, & 1.5 \le f_m < 2.5 \\ 3, & 2.5 \le f_m < 3.5 \\ 4, & 3.5 \le f_m < 4.5 \\ 5, & f_m \ge 4.5 \end{cases}$$

$$f_m = \frac{v_i + v_{i+1} + \cdots + v_j}{j},$$

where f_m' = score of construct m of the n constructs that make up the composite rating; f_m = average of the j variables that make up the m^{th} construct; and v_{i} = score of variable i of the j variables that make up f_m.

Resulting impairment construct scores (f_m') were summarized nationwide and by reservoir habitat ecoregions (Krogman and Miranda 2015). Ecoregions included Xeric (XER), Western Mountains (WMT), Northern Plains (NPL), Temperate Plains (TPL), Southern Plains (SPL), Upper Midwest (UMW), Coastal Plains (CPL), Southern Appalachian (SAP), and Northern Appalachian (NAP). Ecoregions were originally established by the US Environmental Protection Agency (USEPA) and are an aggregation of Omernik's Level III ecoregions, often but not necessarily contiguous to one another (USEPA 2006). We summarized impairment constructs for each ecoregion by reporting the proportion of reservoirs scoring high (i.e., 4 or 5) on each construct and summarizing composite ratings as regional medians.

Results

We received 1599 responses, including partially completed surveys and duplicate entries; 7 states did not participate and were primarily in the far northern United States where natural lakes predominate. Of the responses received, 1299 matched our study scope (i.e., surface area ≥100 ha and not a natural lake fitted with a water control structure) and were complete enough for analysis. Most surveys had low item nonresponse, with 78% containing no missing items and 99% containing <10% missing items. Considering that the National Inventory of Dams identifies 4300 regulated waterbodies ≥100 ha, our sample represented at least 30% of reservoirs ≥100 ha distributed throughout the contiguous United States. Reservoirs ranged in surface area from 100 to 156,000 ha, in mean depth from 0.3 to 181.2 m, and in age from 10 to 178 years.

Impairment constructs

Oblique component analysis of the 52 observed variables identified 12 constructs that explained 61.4% of the variation in responses (Table 2). Further analysis of each construct with Cronbach's alpha suggested that 3 of the 52 observed variables, including insufficient bank shading, oxygen stratification, and residual effects of upstream impoundments, reduced the reliability of some constructs. These variables were removed not because they are unimportant, but because they showed low correlation with the retained variables. The resulting constructs had alpha coefficients ranging from 0.57 to 0.90, with two-thirds of constructs having an alpha >0.80 (i.e., good internal consistency; Table 2). Only the limited nutrients construct had an alpha coefficient <0.60 (i.e., questionable/poor internal consistency; Cronbach 1951), but the construct was retained because it represented a unique impairment that may have been better measured by variables not included in the original survey. Each construct was assigned a name carefully selected to describe its composing and/or top-loading variables, and then a construct definition was developed to provide the reader with greater context of the construct interpretation.

The siltation construct had the greatest proportion of highly impaired reservoirs (i.e., with construct scores of 4 or 5), followed by excessive nutrients, mudflats/shallowness, and large water fluctuations constructs (Fig. 1). The point source pollution construct had the fewest highly impaired reservoirs, followed by nuisance species and limited nutrients constructs. The proportion of reservoirs scoring high on individual impairment constructs differed by ecoregion (Fig. 2). The large water fluctuations construct had the greatest proportion of highly impaired reservoirs in NAP, NPL, WMT, XER, and SPL. The mudflats/shallowness construct had the greatest number of highly impaired reservoirs in CPL but was a common impairment across the United States. The excessive nutrients construct had the greatest number of highly impaired reservoirs in TPL and UMW, whereas siltation had the greatest number of highly impaired reservoirs in SAP, SPL (tie with large water fluctuations construct), and CPL (tie with mudflats/shallowness construct). The point source pollution construct was influential only in the XER ecoregion. Generally, each ecoregion was defined by a unique set of major impairments (Fig. 2).

Ratings

The ratings ranged from 0 to 46 with a median score of 18 out of a maximum possible score of 60. The distribu-

Table 2. Latent constructs representing major reservoir habitat impairments. Each latent construct comprises several observed variables coded numerically and defined in Table 1. The internal consistency of the construct is reflected by Cronbach's alpha (α) coefficient.

Construct name	Description	α	Observed variables
Point source pollution	Reservoirs with point source environmental problems stemming from watershed activities, thermal inputs, and contaminants	0.73	18, 19, 30, 32, 33, 34, 35
Nonpoint source pollution	Reservoirs with nonpoint source environmental problems stemming from broadly distributed watershed activities	0.82	16, 17, 24, 25
Excessive nutrients	Reservoirs with excessive nutrient inputs originating from a broad area of the watershed	0.82	21, 36, 51
Algae blooms	Reservoirs with water quality problems associated with variable oxygen, high temperature, and algae blooms	0.76	26, 27, 29
Siltation	Reservoirs with high suspended and deposited sediments, and associated loss of habitat	0.87	23, 46, 48
Limited nutrients	Reservoirs that are often deep and oligotrophic, or may be undergoing undesired oligotrophication	0.57	12, 14, 22, 31
Mudflats/ shallowness	Reservoirs that are excessively shallow particularly in the littoral zone, with extensive mudflats	0.90	1, 2, 11
Limited connectivity to adjacent habitats	Reservoirs with a lack or loss of connectivity to adjacent habitats, including backwaters and tributaries	0.86	3, 4, 5
Limited littoral structure	Reservoirs with insufficient physical structure and homogenized littoral habitats	0.82	7, 10, 15, 47, 49, 50
Nuisance species	Reservoirs with aggressively expanding, typically nonnative, plant or animal species	0.64	6, 8, 9, 20, 52
Anomalous water regime	Reservoirs with frequent or poorly timed fluctuations or flushing	0.88	37, 39, 40,41, 44, 45
Large water fluctuations	Reservoirs with large and/or or long-duration water level fluctuations	0.87	42, 43

tion of ratings was approximately normal with 10th and 90th percentiles of 9 and 30, respectively (Fig. 3). Median ratings by ecoregion were 17 in CPL, 17 in NAP, 20.5 in NPL, 17 in SAP, 17 in SPL, 24 in TPL, 17 in UMW, 16 in WMT, and 22 in XER. Nevertheless, there was extensive variability in ratings within regions and nationally, with a wide range of ratings occurring in each ecoregion (Fig. 4). Saylorville Lake, a flood control reservoir in central Iowa, had the highest impairment rating nationwide (i.e., 46), scoring particularly high on the nonpoint source pollution, excessive nutrients, siltation, and anomalous water regime constructs. Four reservoirs shared the lowest possible impairment rating (i.e., 0): Big Lake, Arizona; Marlette Lake, Nevada; Hog Park Reservoir, Wyoming; and Prairie Lake, Illinois.

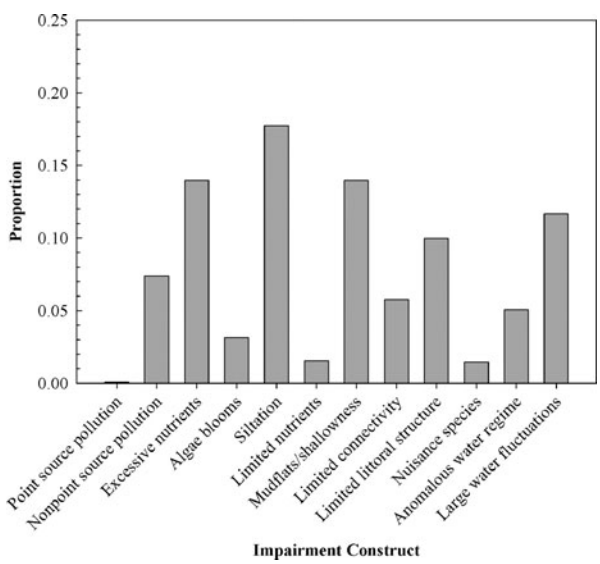

Figure 1. Proportion of 1299 large US reservoirs scoring high (i.e., 4 or 5 on the survey) for each of 12 habitat impairment constructs defined in Table 2.

Discussion

The composite reservoir habitat ratings provide a measure of the overall habitat impairment status of a reservoir and can be used for rapid assessment and for comparing reservoirs. The rating system provides a method to quickly identify high-quality reservoirs for protection and degraded reservoirs for rehabilitation. Distinction between high-quality and degraded reservoirs can be relatively unambiguous; reservoirs with low rating scores generally have low scores on most of the constructs, whereas reservoirs with high rating scores have high scores on many constructs. Conversely, interpretation of ratings in the intermediate range is more ambiguous. Potentially, reservoirs with similar ratings can be impaired by different constructs, requiring scrutiny of construct scores

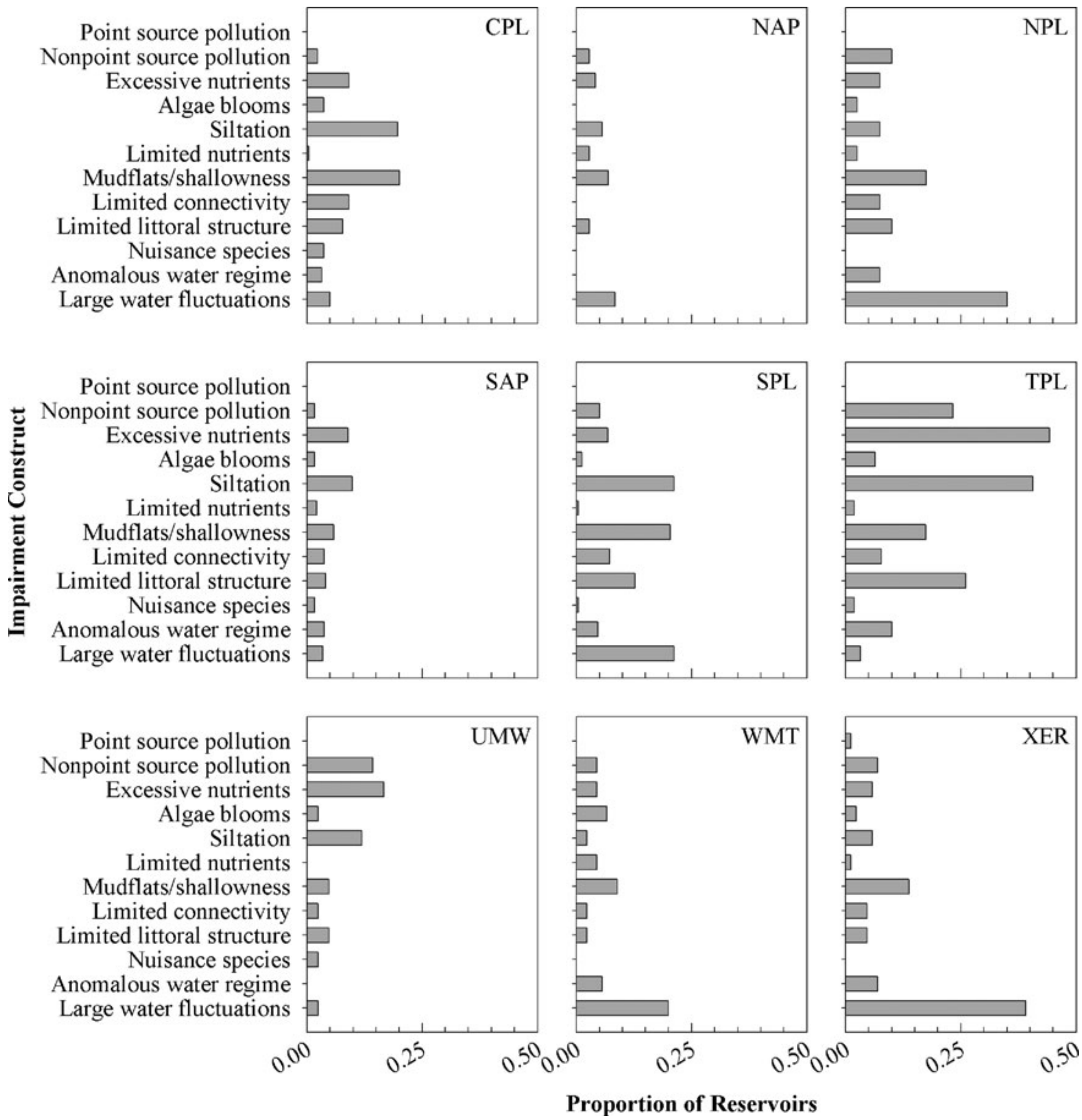

Figure 2. Proportion of large US reservoirs scoring high (i.e., 4 or 5 on the survey) for each of 12 habitat impairment constructs, according to the ecoregions shown in Figure 4.

to sort out the major sources of impairment. Comparison of rating scores among reservoirs may allow prioritization of restoration activities. Reservoirs with high scores may require immediate management attention, whereas those with low scores should have priority for conservation measures. Reservoirs with intermediate scores may require attention on a narrow range of high magnitude impairments or a broad range of low magnitude impairments.

The ratings captured a variety of fish habitat impairments in reservoirs nationwide, with relative importance of specific impairment components changing spatially across wide geographic areas. Ecoregions did not define reservoir condition, however, because the full range of impairment scores appeared in every ecoregion nationwide. Impairments such as sedimentation and nonpoint source pollution were widespread, affecting all or nearly all ecoregions to some degree, and were often associated with inputs from upstream watersheds. Impairments such as point source pollution and limited nutrients were identified by respondents as impairments in relatively few reservoirs.

Our analyses suggested that impairment due to large water level fluctuation was most common in the dryer areas of the contiguous United States, including the West (ecoregions WMT and XER) and Great Plains (SPL and NPL).

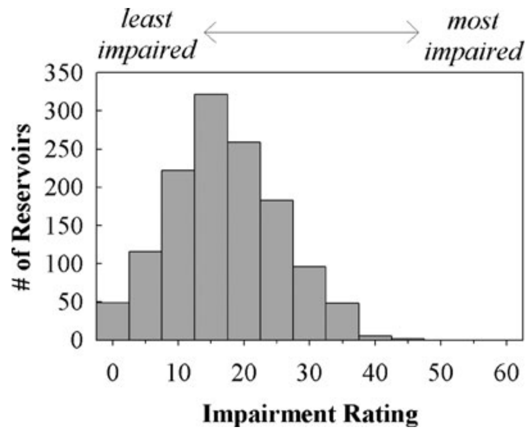

Figure 3. Distribution of habitat impairment ratings for 1299 large US reservoirs. Ratings ranged from 0 to 46, with a possible maximum score of 60.

Water is scarcer in these areas and is typically collected for irrigation (unpublished data from survey); water levels may fluctuate widely as incoming water is stored during the rainy season and released throughout the growing season. The water storage and allocation required to optimize water availability for irrigation can often conflict with the needs of fish in a reservoir by altering environmental cues or seasonal habitat availability (Ploskey 1986, Bunn and Arthington 2002, Dagel and Miranda 2012). Our analyses further indicated that large water level fluctuation was also the most important impairment in the Northeast; however, the extent of this impairment was relatively lower than in other regions.

Unlike the West, most habitat impairments in the Midwest and South emphasized constructs reflective of incoming water quality and land management in the reservoir's watershed rather than water storage. A reservoir's watershed is often the primary source of inputs into the reservoir, including nutrients, sediments, chemicals, and other pollutants (Kimmel and Groeger 1986, Kennedy and Walker 1990, Thornton 1990). Excessive nutrient inputs was the most important impairment in the Midwest, followed by siltation and nonpoint source pollution. Runoff from agricultural land contributes to all of these impairments; farm land covers >74% of Iowa (ISU 2013) and 60% of Illinois (IDNR 2013). In the South, siltation and mudflats/shallowness were the most important impairments, whereas excessive nutrient input was less important. Interestingly, this coincides with less land coverage by traditional agricultural land and greater land coverage by timber land. In the Southeastern states of Florida, Georgia,

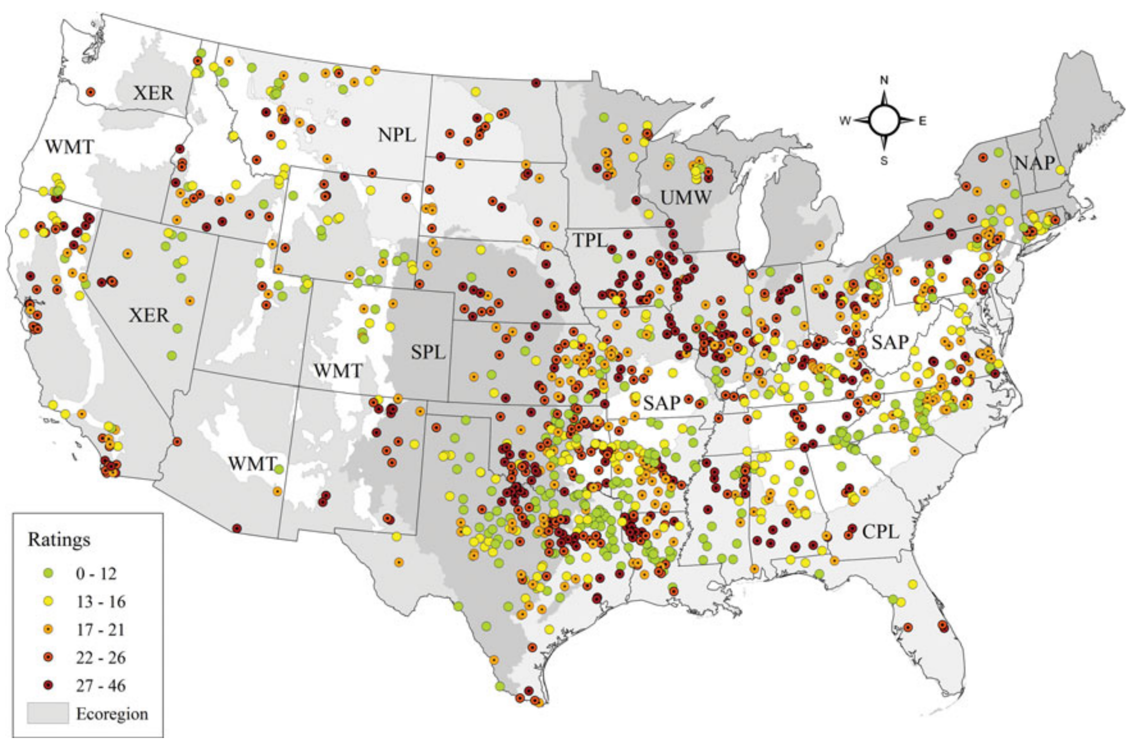

Figure 4. Habitat impairment ratings for 1299 large US reservoirs (0 = low, 46 = high). Ratings are shown by quantile from the rating distribution, with each quantile representing an equal number of reservoirs. Ecoregions included Xeric (XER), Western Mountains (WMT), Northern Plains (NPL), Temperate Plains (TPL), Southern Plains (SPL), Upper Midwest (UMW), Coastal Plains (CPL), Southern Appalachian (SAP), and Northern Appalachian (NAP).

North Carolina, South Carolina and Virginia, 59% of the land was forested in 2007, with 97% of that considered timber land (Smith et al. 2009). In addition, the same region had 12% agricultural land (USDA 2009). In the South Central states of Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas, 33% of the land was forested, with 93% of that considered timber land; the same region had 21% agricultural land (USDA 2009). Commercial forestry practices such as roadbuilding and clear-cutting during harvest could export additional sediment and, to a lesser degree, nutrients to waterways directly (Ensign and Mallin 2001) or indirectly by altering streamflow (Troendle and Olsen 1994). Thus, reservoirs in the Midwest and South show faster rates of sedimentation and eutrophication than in other regions and hence faster functional aging as defined by Miranda and Krogman (2015). The close ties among land use, eutrophication, and functional age were effectively demonstrated for Kansas reservoirs by Carney (2009).

The rating system and its components reflected a wide range of fish habitat issues that transcend those that can be readily measured during onsite quantitative surveys. Many of the habitat descriptors included in our survey measured constructs not typically quantified during onsite surveys, providing new perspective on reservoir fish habitat. Elements such as sediment and nutrient loading, resultant habitat diversity loss, loss of connectivity to adjacent habitats such as backwaters, water storage patterns, algal blooms, and nuisance species may not be captured by most time-limited onsite water quality and quantitative habitat surveys. Our rating system tapped into observational experience accumulated by field biologists. Whereas limitations are associated with relying on this type of knowledge, subjectively scored habitat indexes have been confirmed to show strong correlations among themselves and low-to-moderate correlations with biotic index scores (Hughes et al. 2010). A comparison of the Kaufmann et al. (2014) quantitative survey of nearshore habitats with scores of our siltation, mudflats/shallowness, and limited littoral structure constructs could help clarify the value of these two assessment tools. Further improvement in assessment accuracy may be obtained by upgrading to objective onsite quantitative habitat surveys but at a substantial rise in cost and perhaps without matching increases in evaluation accuracy.

Regional differences in impairment sources contributing to the ratings can inform more effective allocation of funding for habitat renovations. For example, a nonprofit organization like the Reservoir Fisheries Habitat Partnership, which provides funding for reservoir fish habitat improvement in reservoirs across the United States, may use the ratings to identify the least and most impaired reservoirs nationwide and to develop ecoregion-specific priority impairments. The latter may be a more conservative approach if impairment valuation scores differ among regions due to geographical shifts in professional perceptions, as alluded to earlier. A habitat improvement project that addresses priority impairments specific to the ecoregion (e.g., a project in the TPL ecoregion that addresses siltation and excessive nutrients through wetland construction) may be allocated funding over projects that do not address priority impairments (e.g., a project in the TPL ecoregion that installs brush piles and foregoes watershed considerations). The rating system as a whole provides a national snapshot of fish habitat in large reservoirs, enabling objective comparison of a wide variety of reservoirs for decision-making about national, regional, and local habitat management strategies.

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Supplementary Materials

Supplemental data for this article can be accessed on the publisher's website.

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