Perceptions of Fish Habitat Conditions in Oklahoma Tailwater Fisheriess: a Survey of Fisheries Managers

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Abstract: While the downstream effects of dams on fish habitat have long been recognized, broad-scale assessments of tailwater fish habitat have rarely been conducted. In this paper, I report on the status of tailwater fisheries in Oklahoma as determined through a web-based survey of fisheries biologists with the Oklahoma Department of Wildlife Conservation conducted in July 2010. Respondents addressed 38 tailwaters, encompassing all major areas of the state. The majority of fish species comprising these fisheries included blue catfish (*Ictalurus furcatus*), followed by white bass (*Morone chrysops*), channel catfish (*I. punctatus*) and flathead catfish (*Pylodictis olivaris*). Most respondents indicated no or low concerns with fish habitat in tailwaters under their management supervision; only two tailwaters (Tenkiller Ferry and Fort Gibson) had the majority of concerns with fish habitat identified as high to moderately high. Principal components analysis and subsequent correlation analysis showed that tailwaters that scored high for issues related to shoreline erosion, change in water depth, flow fluctuations, and flow timing were associated with dams with large maximum discharge ability. No other factors related to fish habitat condition in tailwaters were found. In Oklahoma, dams with maximum discharge of at least 6,767.5 m^3 sec^{-1} were more likely to have flow-related fish habitat concerns in the tailwater.

Key words: catfish, discharge, National Fish Habitat Action Plan, Reservoir Fisheries Partnership, National Inventory of Dams

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When a dam is constructed on a stream, two altered habitats are created: the reservoir upstream and the river downstream. The downstream portion of the stream whose functions (e.g., hydrology, water temperature, physical habitat) are directly affected by the operations of the dam is commonly referred to as a tailwater. For many fisheries management agencies, especially in the southeastern United States, tailwater fisheries (as a subset of stream fisheries) are not as actively managed as their corresponding reservoirs (Fisher et al. 1998), with the exception of those stocked with trout (Salmonidae) (SARP 2005). While there is a great deal of emphasis on reservoir fisheries management (Hall and Van Den Avyle 1986, Flickinger and Bulow 1993, Hayes et al. 1993, Miranda and DeVries 1996, Allen et al. 2008) or stream fisheries management (Krumholz et al. 1981, Griffith 1993, Rabeni 1993, Sheehan and Rasmussen 1993), there is a lack of emphasis on non-trout tailwater fisheries management specifically, which is distinct from stream fisheries management in general. While downstream effects of dam are known (Collier et al. 1997, Graf 1999) and solutions for many proposed (Ruan et al. 1986, Richter et al. 2006, Olden and Naiman 2010), a broad-scale assessment of tailwater fish habitat conditions has not been conducted, except for tailwater trout fisheries in the southeastern United States (SARP 2005).

In the 1980s, the National Reservoir Research Program conducted some broad-scale studies aimed at quantifying the effects of reservoir releases on tailwater ecosystems, but these studies did not quantify conditions among multiple tailwaters (Walburg et al. 1981a, 1981b, 1983). Rather, these studies aggregated results over many tailwaters and generalized their effects. For example, Walburg et al. (1981b) reviewed the results of several studies and then concluded that water release depth (epilimnion and hypolimnion) along with timing and magnitude of reservoir releases were the main factors affecting tailwater ecology. Summaries such as these illustrate that the literature is replete with studies of individual tailwater systems, but an assessment of conditions of many systems at a single point in time is lacking.

There is currently a high level of interest in assessing conditions of aquatic systems in the United States. The Environmental Protection Agency (EPA) has conducted nationwide assessments of coastal waters (EPA 2001) and wadeable streams (EPA 2006). The U.S. Geological Survey's NAWQA (National Water-Quality Assessment) program has worked to monitor aquatic resources since 1991(available online at http://water.usgs.gov/nawqa/about.html; accessed 16 November 2010). More recently, the National Fish Habitat Action Plan (available online at http://www.fishhabitat.org/; accessed 16 November 2010) works through partnerships to assess and conserve aquatic resources. This study represents an initial effort to focus on the status of tailwaters as unique aquatic resources and is supported by the Reservoir Fish Habitat Partnership.

To begin the development of a broad-scale assessment of fish habitat conditions in tailwater environments, I focused this study on the opinions of fisheries managers who have a good working knowledge of these resources under their purview. Oklahoma was an ideal state to conduct this analysis because it has a lot of dams (fourth among all other states; USACE 2009) across a wide diversity of ecoregion types. The objectives of this study were to 1) identify the main issues perceived to be affecting tailwater fish habitat in Oklahoma and 2) relate those perceptions to existing data on dams in an effort to identify important factors affecting habitat conditions in these fisheries.

Methods

I designed and distributed a questionnaire to fisheries biologists with the Oklahoma Department of Wildlife Conservation (ODWC), the agency responsible for management of fisheries in the state, through a web-based survey developed in concert with the Reservoir Habitat Partnership and Mississippi State University (http://www.reservoirpartnership.org/). The survey assessed both reservoirs and tailwaters, but I report here only on the results from the tailwater portion of the study. A password protected link to the survey site was made available for approximately four weeks in July 2010, and respondents provided their opinions regarding the status of fish habitat in the tailwaters below the dams in the areas they manage. Biologists were encouraged by their administrators to visit the website and complete the survey, but a distinct number of surveys were not sent out. The survey asked if there was a fishery in the reservoir above the dam as well as below the dam in the tailwater, including the primary, secondary, and tertiary fish species targeted by anglers. Respondents were also asked to categorize the extent of the tailwater (km) and their cumulative experience (years) managing the tailwater. The survey then posed a series of 16 questions regarding issues with the tailwater that could affect those fisheries and answers to each were on a modified Likert scale from "not a concern" (0) to "high concern" (5). Because responses to some questions might be inter-correlated (e.g., shore erosion and bed scouring), I conducted a principal components analysis (PCA) on the correlation matrix of the responses to the 16 survey questions using PC-ORD 5 software (McCune and Mefford 2006) to identify the main factors perceived to be affecting fish habitat in the tailwaters. Miranda and Hunt (2011) conducted a similar analysis on reservoirs in the United States by surveying experts and summarizing their responses with ordination, and I followed their general model for tailwaters in Oklahoma.

I obtained data on dams from the National Inventory of Dams (NID; USACE 2009) and paired dam characteristics (e.g., length, width, reservoir surface area, maximum discharge, authorized purposes) with answers from the tailwater fish habitat survey to examine how dam (or reservoir) size might relate to perceived issues in the tailwater. I used Pearson correlation analysis in SAS software version 9.1 (SAS Institute 2004) to identify how the responses to fish habitat conditions in the tailwaters as summarized by the PCA might be related to characteristics of the dams. For NID variables that showed significant correlations with principal component (PC) axes, I separated the NID variables into quartiles (based on the PC axes) and used ANOVA (Proc GLM; SAS software version 9.1; SAS Institute 2004) to test for differences among quartiles and a Tukey post-hoc comparison to reveal where differences occurred.

Results

Surveys were received for 98 tailwaters, but these indicated that only 38 tailwaters had sufficient flow to sustain fish life, representing all areas of the state (Figure 1). One survey did not supply a name for the dam, which precluded its linkage to the NID and was eliminated from further analysis. Respondents indicated they had from 2 to 30 years of experience in managing their tailwater fishery (median = 4), but most (65%) had six or fewer years of experience. Blue catfish (*Ictalurus furcatus*) and white bass (*Morone chrysops*) were the most frequently cited fish species comprising the tailwater fishery, followed by channel catfish (*I. punctatus*) and flathead catfish (*Pylodictis olivaris*). According to the NID, most dams associated with these tailwaters were authorized for more than one purpose, but included (in descending order) water supply (69%), flood control (58%), recreation (39%), other (33%), hydroelectric

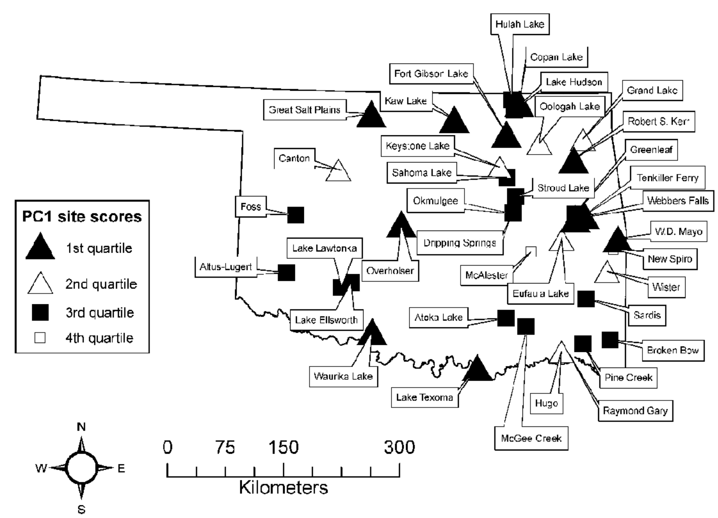

Figure 1. Map of tailwaters in Oklahoma that were assessed for condition of fish habitat. Location symbols are scaled according to PC 1 (principal component 1) site score quartiles; first quartile symbols represent tailwaters that had greater issues with shoreline erosion, change in water depth, flow fluctuations, and flow timing affecting the fish habitat. The loadings from the principal components analysis are found in Table 2.

generation (28%), irrigation (8%), navigation (6%), and fish and wildlife (3%) (Table 1).

The number of concerns with fish habitat in Oklahoma tailwaters was relatively low (Table 1). The average score of the 16 concerns across the 37 tailwaters was 1.76 (low to moderately low). Only two tailwaters had the majority of concerns identified as moderately high (4) to high (5): Tenkiller Ferry and Fort Gibson Lake. Seventeen tailwaters had the majority of concerns identified as none (0) or low (1). Most tailwaters (67%) in Oklahoma were <8 km in length; although four (13%) were stated as being >32 km long. The five most affected tailwaters (i.e., those with the highest mean scores) were authorized for multiple purposes, but commonly included hydroelectric generation ($n = 5$) and flood control ($n = 4$). The tailwaters with the lowest mean scores were all authorized for only one purpose including water supply ($n = 3$), recreation ($n = 1$), and flood control ($n = 1$).

Table 1. Summary of scores of 16 fish habitat concerns in tailwater environments in Oklahoma as related to tailwater extent and identified on a survey to fisheries managers with the Oklahoma Department of Wildlife Conservation in July 2010. Purposes are those functions for which the dam was authorized as listed on the National Inventory of Dams (USACE 2009). Data are sorted descending according to mean score. The fish habitat concerns are found in Table 2. N/A = not answered or not available.

Tailwater	Mean score (none = 0; high = 5)	Number of scores ≥4 (16 total)	Number of scores ≤1 (16 total)	Extent of tailwater (km)	Purposes[a]
Tenkiller Ferry	3.9	11	2	8–16	CH
Fort Gibson Lake	3.2	8	4	1–8	HC
Webbers Falls	2.8	7	6	1–8	HN
Robert S. Kerr	2.8	7	6	1–8	HC
Kaw Lake	2.8	5	3	>32	CSROH
Lake Texoma	2.6	2	1	16–32	CSHO
W.D. Mayo	2.6	7	6	1–8	N
Great Salt Plains	2.6	6	6	N/A	CO
Waurika Lake	2.5	5	5	1–8	CISRO
Copan Lake	2.3	5	6	1–8	CSRO
Overholser	2.3	4	5	1–8	SR
Oologah Lake	2.2	4	7	1–8	CSRO
Keystone Lake	2.0	3	5	16–32	CSHRO
Canton	2.0	3	8	>32	CIS
Wister	2.0	3	5	1–8	CSO
Grand Lake	1.8	1	7	1–8	HC
Eufaula Lake	1.8	2	8	N/A	CSHRO
Broken Bow	1.7	2	8	16–32	CRHSO
Lake Ellsworth	1.6	1	9	<1.6	S
Hugo	1.6	3	8	1–8	CSRO
Altus-Lugert	1.6	4	11	<1.6	ICSR
Atoka Lake	1.5	1	8	>32	S
Okmulgee Lake	1.5	0	9	N/A	SR
Lake Hudson	1.4	1	8	8–16	S
Lake Lawtonka	1.4	0	9	1–8	S
Foss	1.4	1	10	1–8	S
Hulah Lake	1.3	0	10	>32	CSO
Greenleaf	1.1	1	14	<1.6	FRS
Sardis	1.1	0	10	1–8	C
McGee Creek Lake	1.1	0	10	8–16	N/A
Sahoma Lake	1.1	0	12	1–8	SR
Stroud Lake	1.0	0	13	<1.6	C
Pine Creek	0.9	0	10	N/A	C
Dripping Springs Lake	0.9	0	12	N/A	S
Raymond Gary	0.5	0	16	<1.6	R
McAlester	0.0	0	16	N/A	S
New Spiro	0.0	0	16	<1.6	S

a. I = irrigation; H = hydroelectric; C = flood control; N = navigation; S = water supply; R = recreation; F = fish and wildlife pond; O = other

Most of the fish habitat concerns were associated with flow. Principal component 1 explained nearly half (42.85%) of the variation in the answers to the survey questions, with the largest eigenvectors associated with shoreline erosion, change in water depth, flow fluctuations, and flow timing (Table 2). This axis was thus a gradient from those tailwaters with large fluctuations in flow and water depth to areas with stable flows, which tended to have an abundance of aquatic macrophytes (Figure 2). Principal component 2 explained an additional 12.43% of the variation in the responses and was related to bed scouring on one end of the axis to low minimum flows with insufficient dissolved oxygen, warm water temperatures, and high nutrient levels. Principal components 3 and 4 were not as readily interpretable.

I only found significant correlations between NID variables and PC axis 1; all other correlations were not significant ($P > 0.05$; Table 3). The NID variables related to dam size (length and height) and reservoir storage showed moderate relationships to PC axis 1, but maximum discharge showed the greatest relationship ($r = 0.64$, $P < 0.01$). Maximum discharge among PC1 site score quartiles were

Table 2. Eigenvectors from principal components analysis on responses from question, "what is the extent to which the following concerns apply to the tailwater (0 = none; 3 = moderate; 5 = high)?" Eigenvalues and cumulative percent variance (in parentheses) are shown below each principal component (PC) axis. Loadings ≥ 0.30 are shown in bold.

	Eigenvectors			
Variable	PC1 6.86 (42.85%)	PC2 1.99 (55.28%)	PC3 1.72 (66.03%)	PC4 1.34 (74.41%)
Shore erosion	**0.32**	0.21	–0.02	–0.17
Bed scouring	0.29	**0.35**	–0.05	–0.07
Change in depth	**0.31**	0.25	–0.08	–0.21
Minimum flow	0.21	**–0.36**	**0.35**	0.05
Flow fluctuation	**0.33**	0.06	0.28	0.12
Flow timing	**0.31**	0.14	0.24	0.17
Insufficient structural habitat	0.24	0.27	0.28	–0.24
Insufficient dissolved oxygen	0.21	**–0.35**	0.12	–0.28
Temperature out of range	0.17	**–0.33**	0.08	**–0.38**
Excessive dissolved gases	0.27	–0.30	–0.30	–0.10
Other water quality issues	0.29	–0.18	–0.22	0.06
Nutrients out of range	0.24	**–0.30**	**–0.34**	0.01
Harmful algae blooms	0.19	–0.08	–0.27	**0.57**
Abundance of aquatic macrophytes	0.09	0.10	–0.26	0.06
Invasive species	0.23	0.26	–0.26	0.12
Fish passage	0.16	–0.12	**0.41**	**0.51**

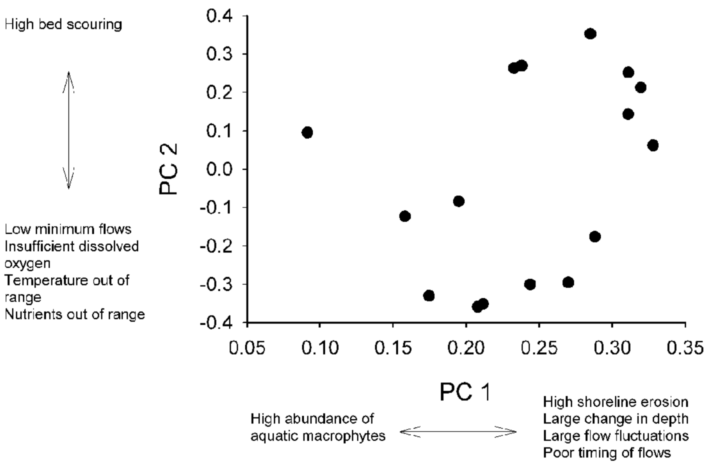

Figure 2. Principal component (PC) analysis plot for the first two PC axes from a survey of fisheries biologist in Oklahoma regarding the factors affecting tailwater fish habitat in the state. The PCA loadings and survey response variables are found in Table 2.

Table 3. Correlation coefficients of dam characteristics from U.S. Army Corps of Engineers (USCOE) National Inventory of Dams (NID) with principal component (PC) axes. An * indicates significance at $P < 0.05$; ** indicates significance at $P < 0.01$.

NID variable	PC1	PC2	PC3	PC4
Dam length (m)	**0.48	−0.18	0.03	0.07
Dam height (m)	**0.48	−0.22	−0.02	−0.08
Structural height (m)	**0.48	−0.23	−0.02	−0.09
Hydraulic height (m)	**0.47	−0.22	−0.10	−0.11
NID height (m)	**0.46	−0.22	0.02	−0.09
Max discharge (m3 s-1)	**0.64	0.17	−0.10	−0.05
Max storage of reservoir (m3)	*0.36	−0.25	−0.13	−0.12
Normal storage of reservoir (m3)	0.27	−0.20	−0.18	−0.13
NID storage of reservoir (m3)	*0.37	−0.25	−0.14	−0.12
Surface area of reservoir (ha)	0.20	−0.05	−0.14	−0.08

significantly different (ANOVA $F_{3,32} = 11.04$, $P < 0.01$). Maximum discharge for the dams in the first quartile (mean = 17,891.4 m^3 sec^{-1}; SD = 11,123.9) was similar to the second quartile (mean = 10,333.2 m^3 sec^{-1}; SD = 7,413.9) and greater than maximum discharge for dams in the third (mean = 3,619.2 m^3 sec^{-1}; SD = 4,270.9) and fourth quartiles (mean = 636.9 m^3 sec^{-1}; SD = 893.3). However, maximum discharge of dams in the second and third quartile was also similar (Tukey $P > 0.05$).

Discussion

Overall, negative factors affecting the condition of fish habitat in Oklahoma tailwaters were relatively few. The major issues perceived to be affecting fish habitat in Oklahoma tailwaters were flow-associated, which was not surprising because tailwaters are lotic systems that are strongly affected by discharge from the upstream dam. The tailwaters with the largest perceived alterations in fish habitat were also associated with the dams that had the greatest ability to alter discharge (i.e., with large maximum discharges), and not related to dam morphology or reservoir storage. Thus, maximum discharge might be used as a surrogate to identify those tailwaters with the most potential for flow-altered fish habitat. In Oklahoma, dams with maximum discharge of at least 6,767.5 m^3 sec^{-1} ([mean] 17,891.4 – [1 SD] 11,123.9) were more likely to have flow-related fish habitat concerns in the tailwater noted by fisheries managers than dams with smaller maximum discharge. Because maximum discharge is a variable contained within the NID (USACE 2009), which is national in scope, the relative number of tailwaters with flow-altered fish habitat might be rapidly obtained. However, surveys of tailwater fish habitat in other parts of the country would need to be conducted to determine if these issues identified in Oklahoma continued across a larger scale.

How the perceived issues identified in this paper relate to actual tailwater conditions remains to be tested. Qualitative data on habitat have been shown to correlate with quantitative biological data (Rankin 1989) and results obtained through expert opinions can be similar to those that are more quantitatively based (Pearce et al. 2001). To improve upon the results of this study and objectively determine the alteration to fish habitat in a tailwater, location-specific data are needed, using a method to assess habitat quality in relation to hydrology, such as Indicators of Hydrologic Alteration (Richter et al. 1996) or Instream Flow Incremental Methodology (Bovee 1982). However, doing so at a state-wide scale would be a massive undertaking, and expert-based opinion surveys such as the one described in this study may be helpful to guide future management efforts until more detailed fish and habitat work can be accomplished.

A survey of expert opinions implicitly relies on their idea of reference or benchmark for the assessment. For natural systems, reference conditions are usually based on "pristine," "unaltered," or "least-altered" examples (Karr 1981, Steyer et al. 2003). It is unclear what a "reference" tailwater would be because it is by definition "altered"; having come into being by the damming of a river and altering the natural flow. Defining a reference condition becomes especially important in the southeastern United States where many tailwaters support non-native, fisheries (e.g., stocked trout; SARP 2005). In stocked trout tailwaters, fisheries managers often regard warming of the water as "thermal pollution," which could alternatively be viewed as returning to "natural" conditions (e.g., Long and Martin 2008). In my survey of state fisheries biologists, the two tailwaters in Oklahoma that support stocked trout fisheries both listed "temperature out of range" as high concern (i.e., 5), suggesting that warming of the tailwater was an issue. Alternative respondents could supply the same answer but refer to the un-natural cold-water that is released from the hypolimnion of the upstream dam that resulted in the loss of many native species and is now "mitigated" as a trout fishery. In this instance, defining "reference" *a priori* would make interpretation of results easier. For altered systems such as tailwaters, research on identifying and quantifying "reference" conditions would be useful for future studies on this topic.

Catfish (Ictaluridae) were the main species comprising the fisheries in Oklahoma tailwaters. Flathead catfish (Jackson 1999) and blue catfish (Graham 1999) are primarily riverine species, and blue catfish are especially known to inhabit tailwaters below dams (Graham 1999, Boschung and Mayden 2004). Catfish are the third most sought-after species by recreational anglers nationwide and Oklahoma anglers pursue catfish proportionally more than the national average, nearly one-half (43%) of the total angling population (USFWS and USBOC 2008). As a result, increased management of fish habitat in Oklahoma tailwaters may increase opportunities and satisfaction for catfish anglers in the state.

A nation-wide survey of catfish biologists and anglers found large rivers were most often thought by both groups to produce trophy catfish (Arterburn et al. 2002), but tailwaters were not specifically identified apart from rivers. In Oklahoma, Kuklinski and Boxrucker (2008) conducted a state-wide survey regarding trophy blue catfish angling at a variety of water bodies, and although they explicitly mention having surveys from reservoirs, tailwaters, small impoundments, and rivers, they did not report results for each water body type. Thus, catfish fisheries in Oklahoma tailwaters especially have the potential to be negatively affected by dam operations (e.g., Richards et al. 1986, Graham and DeiSanti 1999), but further work is needed to determine these relationships. However, angler use of tailwater habitats in Oklahoma appears to be low compared to other water bodies in the state, which might offset any fishery benefits from increased management. For example, only about four percent of anglers targeted fish in these habitats in Oklahoma in 2007 (Summers 2009), which was a slight increase from 2.8% in 2001 (Summers and Crews 2002).

My results can be used by fisheries managers in Oklahoma nominally to identify tailwaters that likely suffer from flow-related impacts where in-situ data are lacking. Non flow-related fish habitat issues in tailwaters, as identified by fisheries biologist opinions, appear to be subject to more local conditions than any characteristics of the dams controlling discharge in their vicinity. Additional research on large-scale factors related to these non flow-related fish habitat issues in tailwaters would be beneficial.

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