Ecological Assessment of Several Central Oklahoma Streams Through Evaluation of Fish Communities and Habitat in a Drought Year

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Assessment of stream ecological health by monitoring chemical water quality alone fails to include important physical habitat and biological integrity parameters that may be critical to a valid assessment of human impact. As part of a larger monitoring effort, we performed rapid ecological assessments, including both habitat and biological community evaluations, for 10 streams in three central Oklahoma counties during the summer of 1998. Habitat assessments and fish collections were conducted on predetermined 400-m stream reaches. The fish community index of biotic integrity (IBI) and a standard habitat scoring procedure were used to estimate overall ecological health of study streams by comparison to reference streams. Habitat scores ranged from 44 to 89 (possible maximum = 180). During the summer 1998 drought, flow-dependent habitat parameters (e.g., pool variability, presence of rocky runs and riffles) significantly affected habitat quality. For individual streams, the total number of fish species and individuals ranged from 1 to 14 and 1 to 292, respectively. The most common species collected was *Lepomis cyanellus*, which was collected in all streams. Fish IBI scores ranged from 10 to 28 for the study streams and integrity classes ranged from very poor to fair, with positive reference streams rated excellent. A comparison of IBI and habitat scores for each stream provided insight into possible water quality concerns. Discrepancies between the actual and expected scores, based on reference streams, are indicative of either habitat degradation or water pollution problems. A combination of habitat and biological community assessment provided a quick and inexpensive tool for evaluating stream ecosystem health.

INTRODUCTION

Determination of human impacts on stream ecosystems has been a topic of concern for many years (*1-4*). Many attempts have been made to quantify the ecological damage to streams caused by pollution and/or habitat degradation (*5-11*). Monitoring of chemical water quality alone fails to include biological water quality parameters that may be critical to a valid assessment of impact. Chemical monitoring often does not account for human-caused habitat perturbation that can impair stream function. Effective monitoring programs include assessments of physical habitat and biotic integrity because the ability to sustain balanced biotic communities is a reliable indicator of stream health (*10,12*).

Ecological assessments of this sort are based on the premise that sites can be compared to nonimpacted or minimally impacted reference sites (*4,12-14*). Reference streams are streams that have been assessed and determined to have satisfactory water quality, habitat quality, or both. Positive reference streams have both high water quality and habitat quality; these streams are often located in areas of minimal anthropogenic influence and have optimal conditions for their ecoregion. Negative reference streams have high water quality but poor habitat quality; these streams demonstrate alteration of stream function by habitat degradation only.

Biological integrity is the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (*8*). The Index of Biotic Integrity (IBI) is a broad-based, quantitative, multi-parameter tool based on the composition of fish or other biological communities (*2*). IBI uses several metrics that vary by ecoregion. These metrics examine both structural and functional characteristics of biological communities. Each metric is qualitatively assigned a quantitative score that is indicative of observed conditions, based on given criteria. Scores from each metric are summed to provide an overall community score. The score is compared to reference streams in the same ecoregion and assigned an integrity class as an indicator of the overall health of the biological community (*15*).

Habitat assessments involve examination of the physical parameters of a stream and the assignment of quantitative values based on observation and given criteria. Scores are summed, creating an overall habitat score for the stream. This score is compared to reference streams that are indicative of what type of communities should be supported under optimal or near-optimal conditions in the same ecoregion.

This study used fish community IBI and habitat assessments to estimate the overall ecological health of several central Oklahoma streams. The study was conducted as part of the Oklahoma City Blue Thumb volunteer monitoring and water quality education program. The purposes of this study were: (1) to demonstrate the combined use of IBI and habitat assessments in monitoring the quality of Oklahoma streams, and (2) to determine the overall ecological health of individual central Oklahoma streams in a drought year.

METHODS

Study Sites: Four reference streams and six study streams were examined in June and July 1998 in the Oklahoma City metropolitan area (Table 1). All streams are located in the Central Lowlands Geomorphic Province and are classified, on an ecoregion basis, as being located in the Cross Timbers and Prairies Section, Prairie Parkland ecological subregion, Prairie Division, Humid Temperate Domain (*16,17*).

West Elm Creek (WEC) and East Elm Creek (EEC) are located in Cleveland County; Coon Creek South (CCS) is located in Logan County; and the remaining seven streams are located in Oklahoma County (Table 1, Fig. 1). WEC and CCS were designated as positive reference streams, and EEC and the unnamed tributary to the North Canadian River 1 (NC1) were designated as negative reference streams for this study (Dan Butler, personal communication, 1998). All other streams were designated as study streams to be compared to reference streams. Each stream was visited once during June and July 1998. Site visits included examination of a predetermined 400-m reach of each stream, completion of a habitat assessment, and collection of fish.

Habitat Assessments: Standard operating procedures (SOP) for abbreviated habitat assessments were followed (*18*). This SOP is currently under revision to include modifications that were implemented after August 1996 (Dan Butler, personal communication, 1998). In general, a predetermined 400 meter length of each stream was assessed for eleven parameters. They were: (1) instream cover, (2) pool bottom substrate, (3) pool variability, (4) canopy cover, (5) presence of rocky runs and riffles, (6) discharge at base elevation, (7) alteration, (8) channel sinuosity, (9) bank stability, (10) bank vegetative stability, and (11) dominant bank vegetation. For each stream, each parameter was scored based on observations and criteria defined in the Oklahoma Conservation Commission (OCC) protocol (*18*), with critical parameters being weighted accordingly. Maximum scores represent optimal habitat conditions.

Habitat scores for study streams were compared to two positive reference streams and percent comparability was determined. A comparability score was then related to an assessment category as described by the United States Environmental Protection Agency (USEPA) (*19*). Categories (excellent, good, fair, and poor) indicate habitat quality of each stream compared to reference sites.

Fish Index of Biotic Integrity: Fish population and community structure are important biological features of streams (*3*), and thus were used in performing the IBI in this study. Macroinvertebrates were not included in this study. The time period (i.e., mid-summer) did not overlap with the time frame established by OCC for optimal macroinvertebrate collection (i.e., late summer, mid-winter), and, to avoid inconsistent results, valid macroinvertebrate data must be collected when populations are most stable (Dan Butler, personal communication 1998).

Fish collection procedures followed the SOP for fish collection in streams (*20*) with the following modifications: the entire 400-m reach (except for dry or prohibitively shallow areas) was seined and electroshocking and chemical water quality monitoring were not performed. All seines were 0.25 inch mesh size and seining was conducted toward the direction of current. The brailes of the net were used to disturb undercut banks and macrophyte beds and the seine was pulled and fish collected at least every ten meters. All fish were either field identified to species or collected and preserved in a 10% formalin solution for later identification by OCC personnel.

IBI scores were calculated for each stream in which sufficient fish-supporting habitat existed. Fish IBI were determined via the method of

TABLE 1: Identifying information for reference and study streams evaluated during summer 1998

Stream name	ID	Date sampled	WBID[1]	Legal description Section	T	R	Latitude Deg	Latitude Min	Latitude Sec	Latitude Hund	Longitude Deg	Longitude Min	Longitude Sec	Longitude Hund
West Elm Creek	WEC	05/15/98	OK520810000140G	SW/SW/SE/SE 25	10N	2W	35	18	18	02	97	21	23	62
Coon Creek south	CCS	07/23/98	OK520710010030Q	SE/SE/NE/NE 27	15N	1W	35	45	00	92	97	16	57	35
Unnamed Tributary to North Canadian River 1	NC1	07/08/97	OK Temp-0472	SW/NW/SW/NE 31	12N	3W	35	28	24	04	97	33	24	06
East Elm Creek	EEC	07/16/98	OK520810000120	NE/NE/SE/SE 26	10N	2W	35	19	35	00	97	21	14	04
Tulakes Fork of Spring Creek	TFS	06/05/98	OK Temp-0466	SE/SW/SW/SE 4	12N	4W	35	32	13	13	97	37	33	14
Unnamed Drainage To Soldier Creek	SCD	06/12/98	OK Temp-0485	NW/NE/NE/NW 11	11N	2W	35	26	58	49	97	22	52	57
Unnamed Tributary to North Canadian River 2	NC2	06/19/98	OK Temp-0474	NW/NE/NW/NE 1	11N	4W	35	37	52	41	97	34	18	21
Unnamed Tributary to Deep Fork River 1	DF1	07/10/98	OK Temp-0520	SW/SW/NW/NW 1	12N	3W	35	32	52	64	97	28	35	69
Unnamed Tributary to Deep Fork River 2	DF2	07/24/98	OK Temp-0529	NW/NE/NE/NW 4	12N	3W	35	33	03	98	97	31	22	76
Unnamed Tributary to Deep Fork River 3	DF3	07/31/98	OK Temp-0535	NE/NE/NW/NE 15	12N	3W	35	31	20	46	97	29	57	95

[1]WBID = water body identification number

TABLE 2. Channel composition for reference and study streams evaluated during summer 1998.

Stream ID	Estimated discharge (m3/s)	Mean thalweg depth (m)	Maximum depth (m)	% depth > 0.5 m	% depth > 1.0 m	Stream width (m)	% of 400 meters Pool	Run	Riffle
WEC	0.0277	0.3	1.2	20.0	30.0	4.0	55.0	35.0	10.0
CCS	0.0102	0.2	0.8	0.0	0.0	1.7	61.5	38.0	0.5
NC1[1]	ND[2]	ND	ND	ND	ND	ND	ND	ND	ND
EEC	0.0736	0.2	0.5	0.0	0.0	2.5	18.0	81.5	0.5
TFS	0.0119	0.3	1.5	12.0	5.0	2.5	84.0	11.0	5.0
SCD[3]	0.0000	0.3	1.0	1.3	1.0	1.5	97.5	2.5	0.0
NC2	0.0037	0.3	1.1	9.0	1.0	2.5	86.0	10.0	4.0
DF1[3]	0.0000	0.4	1.3	10.0	2.0	3.0	100.0	0.0	0.0
DF2	0.0017	0.4	0.8	2.5	0.0	2.0	91.1	5.4	3.5
DF3	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry

[1]Data currently not available
[2]ND, no data
[3]Streams were ~ 100 % pool with no obvious flow, therefore discharge was zero

Plafkin and coworkers. (*19*), with fish species and tolerance levels modified for the central Oklahoma region. Eight metrics were considered: 1) total number of fish species, (2) number of Centrarchidae species, (3) number of sensitive bottom-feeding fish (*Phenacobius mirabilis* and *Campostoma anomalum*), (4) percent tolerant individuals (*Lepomis cyanellus, Gambusia affinis,* and *Cyprinella lutrensis*), (5) percent insectivorous Cyprinids, (6) percent piscivores, (7) total number of individuals, and 8) percent diseased and possessing anomalies (*20*). Scores were assigned based on Karr (*12*). Integrity classes were assigned to each stream based on the total IBI score. Classifications were modified from the USEPA scale (excellent, good, fair, poor, and very poor) of Plafkin and coworkers. (*19*). For purposes of comparison, a classification score of excellent was assigned to positive reference streams.

Microsoft Excel version 6.0 function analysis tools were used to conduct appropriate statistical analyses. Means comparisons were performed via unpaired t-tests, assuming unequal variance.

RESULTS

Stream discharge, depth, width, and percent pool, run, or riffle of the sampled 400 m demonstrated great variability between streams (Table 2). EEC was estimated to have the highest flow (0.0736 m3/s), and several other steams were not flowing during the sampling events. Estimated depths were closely associated with mean stream width. Wider streams had higher maximum and mean depths. For example, WEC was the widest stream (4.0 m) and had one of the greater maximum depths (1.2 m) and mean thalweg depths (0.3 m). Most streams had a much greater percentage of pools than runs or riffles. The mean percent of pool was 75%, with the remaining 25% either runs or riffles.

Habitat scores varied from 44 to 89 (Table 3). The three highest scoring streams were WEC and CCS, both positive reference streams with scores of 84 and 85, respectively, and the study stream Tulakes Fork of Spring Creek (TFS), which scored an 89. Low scoring streams included negative reference stream NC1 and study stream unnamed tributary to Deep Fork River 3 (DF3), with scores of 45 and 44, respectively. Of the parameters most crucial to fish communities (maximum score 20), instream cover had the highest mean score of nine. Of the two mid-scoring parameters (maximum score 15), channel alteration had a much higher mean score of ten. Each of the three low scoring parameters (maximum score 10) had a similar mean of 7. Significant differences were noted for pool variability, rocky runs and riffles, and alteration, when reference streams were compared to study streams ($P < 0.05$). When negative reference streams were compared to study streams, pool bottom substrate, pool variability, canopy cover, bank stability, bank vegetative stability, and dominant vegetation were significantly different ($P < 0.05$). Species names and number of fish collected during seining were recorded for each site (Table 4). For individual streams, the total number of fish ranged from 1 to 292, and the total number of species ranged from 1 to 14. The two positive reference streams, WEC and CCS, were found to have the greatest number of both individuals (246 and 292, respectively) and species (14 and

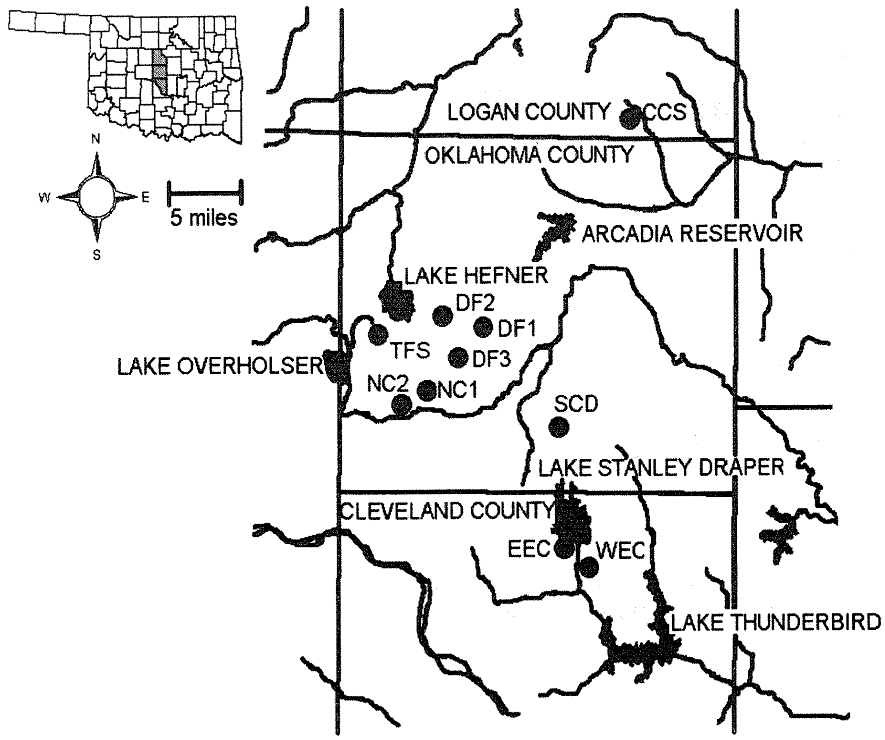

Figure 1. Locations of reference and study streams in central Oklahoma.

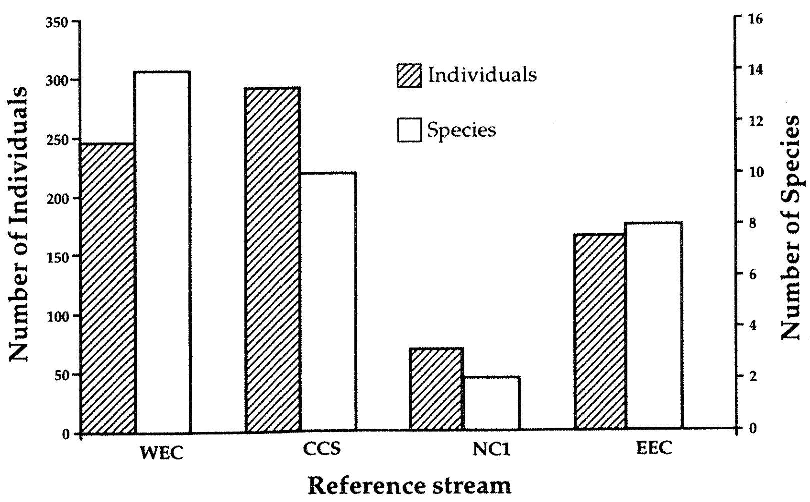

Figure 2. Four reference streams: number of fish species and individuals.

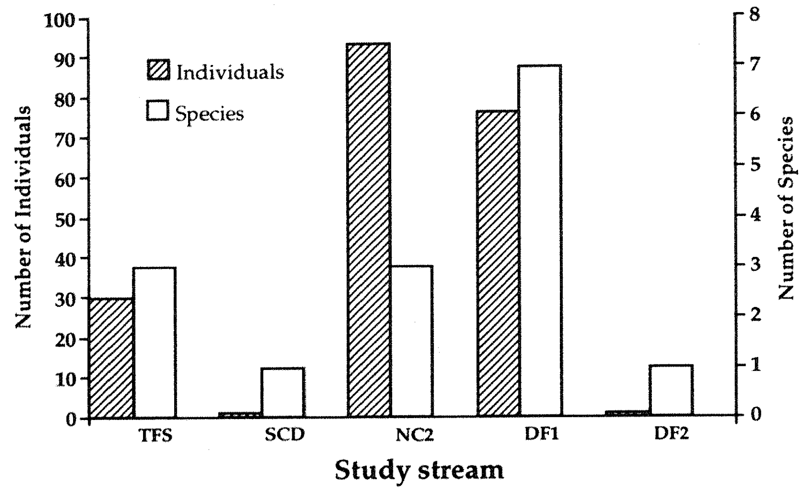

Figure 3. Five reference streams in which fish were collected: number of fish species and individuals. No fish were collected in DF3 because of lack of flow.

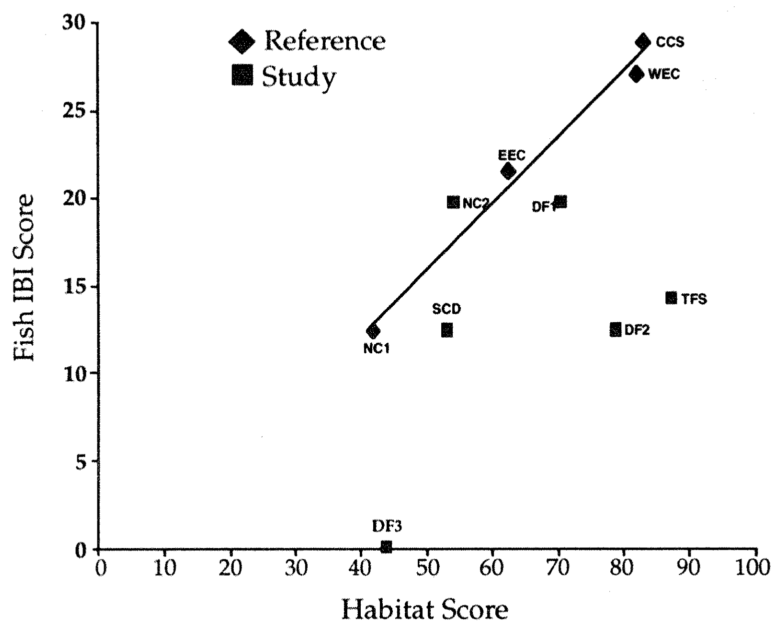

Figure 4. Comparison of habitat scores to fish IBI scores for reference and study streams. The best-fit line for reference streams only is shown ($r^2 = 0.99$). No fish were collected in DF3 because of lack of flow.

TABLE 3: Habitat scores for reference and study streams evaluated during summer 1998.

Stream ID	Instream cover	Pool bottom substrate	Pool variability	Canopy cover	Rocky runs and riffles	Flow at base	Alteration	Sinuosity	Bank stability	Bank vegetative stability	Dominant vegetation	Total
WEC	5	10	10	11	9	6	8	2	8	7	8	84
CCS	8	12	10	16	11	2	6	5	3	3	9	85
NC1	20	0	0	0	0	0	0	0	10	10	5	45
EEC	13	0	1	2	1	11	15	0	9	9	4	65
TFS	13	16	7	17	2	2	9	4	6	4	9	89
SCD	7	5	1	10	0	0	10	0	7	7	9	56
NC2	7	7	5	3	4	1	13	0	6	7	4	57
DF1	6	4	6	16	0	0	15	1	8	8	9	73
DF2	4	17	2	8	7	3	15	4	8	8	7	81
DF3	Dry	Dry	Dry	17	Dry	Dry	Dry	1	8	9	9	44
Maximum Score	20	20	20	20	20	20	15	15	10	10	10	180

TABLE 4: Fish collection data for reference and study streams. Fish were collected by seining a pre-designated 400-m reach of each stream.

Reference streams			Study streams		
Stream ID	Scientific Name	Total Fish[1]	Stream ID	Scientific Name	Total Fish[1]
WEC	*Ictalurus punctatus*	2	TFS	*Lepomis cyanellus*	23
	Lepomis cyanellus	2		*Lepoms megalotis*	4
	Campostoma anomalum	7		*Cyprinella lutrensis*	3
	Phenacobius mirabilis	4		Total	30
	Ictalurus melas	7			
	Pimephales vigilax	47	SCD	*Lepomis cyanellus*	1
	Pomoxis annularis	1		Total	1
	Notemigonus crysoleucas	1			
	Lepomis macrochirus	64	NC2	*Fundulus zebrinus*	84
	Cyprinella lutrensis	64		*Lepomis cyanellus*	4
	Notropis stramineus	40		*Lepomis megalotis*	5
	Aplodinotus grunniens	1		Total	93
	Micropterus salmoides	1			
	Lepomis megalotis	5	DF1	*Lepomis humilis*	32
	Total	246		*Lepomis macrochirus*	5
				Ictalurus melas	12
CCS	*Phenacobius mirabilis*	12		*Lepomis megalotis*	3
	Notropis stramineus	57		*Lepomis cyanellus*	7
	Lepomis megalotis	122		*Notemigonus crysoleucas*	16
	Cyprinella lutrensis	73		*Gambusia affinis*	1
	Lepomis cyanellus	6		Total	76
	Micropterus punctulatus	1			
	Lepomis macrochirus	10	DF2	*Gambusia affinis*	1
	Ictalurus natalis	6		Total	1
	Ictalurus punctatus	2			
	Gambusia affinis	3			
	Total	292			
NC1	*Gambusia affinis*	62			
	Lepomis cyanellus	8			
	Total	70			
EEC	*Gambusia affinis*	85			
	Ictalurus natalis	1			
	Lepomis cyanellus	18			
	Lepomis megalotis	54			
	Micropterus punctulatus	1			
	Ictalurus punctatus	2			
	Cyprinella lutrensis	3			
	Micropterus salmoides	1			
	Total	165			

[1]The number of fish for each species represents all fish that were either identified in the field and returned or preserved for later identification.

10, respectively). Streams with the fewest numbers of species and individuals included the unnamed drainage to Soldier Creek (SCD) and unnamed tributary to Deep Fork River 2 (DF2), each with 1 species and 1 individual. The most common species collected was *Lepomis cyanellus,* which was collected in all streams.

TABLE 5. Comparison of habitat scores for reference and study streams.

Stream ID	Total	% Comparability[1]	Assessment Category (EPA 1989)
WEC	84.00	100.00	—
CCS	85.00	100.00	—
mean	84.50	—	—
NC1	45.00	53.25	Poor
EEC	65.00	76.92	Good
TFS	89.00	105.33	Excellent
SCD	56.00	66.27	Fair
NC2	57.00	67.66	Fair
DF1	73.00	86.39	Good
DF2	81.00	95.86	Excellent
DF3	44.00	52.07	Poor

[1]Percent comparability is calculated as the study site score divided by mean reference score times 100.

DISCUSSION

Habitat Assessment: To assign an assessment category to negative reference streams and study streams, these streams were compared to the positive reference streams (Table 5). TFS and DF2 were placed in the excellent category because these streams were >90% comparable to reference. Because these categories were based solely on habitat scores, one may assume that these streams have the potential to support an acceptable level of biological health that is similar to the reference streams.

EEC and the unnamed tributary to the Deep Fork River 1 (DF1) were considered good because these streams were between 75 and 90%, comparable to references, indicating the overall habitat quality of these streams is high enough to be able to support an acceptable level of biological health, but not high enough to be considered a reference stream. SCD and the unnamed tributary to the North Canadian River 2 (NC2) were considered fair because these streams were between 60 and 75% comparable to references, indicating that some of the habitat parameters have the potential to support an acceptable level of biological health. These streams are not able to support as many fish species as the reference streams.

NC1 and DF3 were considered poor because these streams were > 60% comparable to references. The habitat quality of these streams is so poor that they are not able to support an acceptable level of biological health. It should be noted that DF3 was assessed when the stream was dry, thus resulting in a low habitat score.

Positive reference streams differed significantly ($P < 0.05$) from study streams in pool variability and rocky runs and riffles. These parameters are both dependent on flow. Because these streams were assessed during a drought year, flow-dependent parameters were altered from their normal state. Because of low flows, certain physical attributes of the stream became more apparent (i.e., pool variability, presence of rocky runs and riffles, etc.). Therefore, habitat scores were altered. This comparison also demonstrates that study streams were more altered than the positive reference streams, indicating greater problems with erosion. Negative reference streams differed significantly ($P < 0.05$) from study streams, with respect to pool bottom substrate, pool variability, canopy, and dominant bank vegetation. These results indicate that negative reference streams had poor habitat and that the study streams all had better habitat than the negative reference streams.

Fish Index of Biotic Integrity: Positive reference streams had more individuals and species of fish than negative reference streams (Table 4). A comparison of the number of fish species and total number of individuals for the positive and negative reference streams indicates a distinctive coupling between the two sets of streams (Fig. 2), with the positive reference streams having greater numbers of both individuals and species than the negative reference streams. Inferences can also be made about the study streams using a similar qualitative comparison (Fig. 3). NC2 and DF1 have much greater numbers of species and individuals than the other study streams, thus indicating higher biotic quality. SCD and DF2 indicate poor biotic quality compared to other study streams.

IBI scores were calculated for each of the references and study streams (Table 6) and were used to categorize each stream into integrity classes. The percentage of diseased and anomalies metric was found to be negligible because neither was observed in >three % of the population during any sampling event (Dan Butler, personal communication, 1998). Positive reference streams were assigned an integrity class of excellent because they represent the highest quality streams in terms of both habitat and water

Table 6. Fish Index of Biotic Integrity scores for reference and study streams.[1]

Stream ID	1. Total species	2. Species Centrar-chidae	3. Sensitive bottom-feeding fish	4. Green sunfish, mosquitofish, and red shiner	5. Insecti-vorous Cyprinids	6. Piscivores	7. Total indi-viduals	8. Diseased and anomalies	Total IBI	Integrity Class
Positive reference streams										
WEC										
#	14.0	5.00	11.0	66.0	44.0	1.00	246	ND[3]		
%	N/A[2]	N/A	N/A	26.8	17.9	0.410	N/A	<3.00		
Pts	5	5	5	1	1	1	5	3	26	Excellent
CCS										
#	10.0	4.00	12.0	82.0	69.0	1.00	292	ND		
%	N/A	N/A	N/A	28.1	23.6	0.342	N/A	<3.00		
Pts	5	5	5	1	3	1	5	3	28	Excellent
Mean										
#	12.0	4.50	11.5	74.0	56.5	1.00	269	ND		
%	N/A	N/A	N/A	27.5	20.8	0.375	N/A	<3.00		
Pts	5	5	5	1	3	1	5	3	28	Excellent
Negative reference streams										
NC1										
#	2.00	1.00	0.00	70.0	0.00	0.00	70.0	ND		
%	16.7	22.2	0.00	100	0.00	0.00	26.0	<3.00		
Pts	1	1	1	1	1	1	1	3	10	Very Poor
EEC										
#	8.00	4.00	0.00	106	0.00	2.00	165	ND		
%	66.7	88.9	0.00	64.2	0.00	1.21	61.3	<3.00		
Pts	3	5	1	1	1	3	3	3	20	Fair
Study streams										
TFS										
#	3.00	2.00	0.00	26.0	0.00	0.00	30.0	ND		
%	25.0	44.4	0.00	86.7	0.00	0.00	11.2	<3.00		
Pts	1	3	1	1	1	1	1	3	12	Poor
SCD										
#	1.00	1.00	0.00	1.00	0.00	0.00	1.00	ND		
%	8.33	22.2	0.00	100	0.00	0.00	0.372	<3.00		
Pts	1	1	1	1	1	1	1	3	10	Very Poor
NC2										
#	3.00	2.00	0.00	4.00	0.00	0.00	93.00	ND		
%	25.0	44.4	0.00	4.30	0.00	0.00	34.60	<3.00		
Pts	1	3	1	5	1	1	3	3	18	Fair
DF1										
#	7.00	4.00	0.00	8.00	0.00	0.00	76.0	ND		
%	58.3	88.9	0.00	10.5	0.00	0.00	28.3	<3.00		
Pts	3	5	1	3	1	1	1	3	18	Fair
DF2										
#	1.00	0.00	0.00	1.00	0.00	0.00	1.00	ND		
%	8.33	0.00	0.00	100	0.00	0.00	0.372	<3.00		
Pts	1	1	1	1	1	1	1	3	10	Very Poor

[1]Point values are assigned based on Karr (1981). Metrics 1-3 and 7 are scored relative to the positive reference sites.
[2]Not Applicable - These metrics are scored according to individual stream data.
[3]Not Detectable - Disease and anomalies were not recorded in populations with less than 3% of total fish population.

quality. Negative reference streams, which represent poorer habitat quality, have IBI scores that reflect these findings. NC1 was assigned an integrity class of very poor, and EEC was assigned an integrity class of fair.

Comparison of IBI scores for study streams indicates that none of these streams compare well to positive reference streams. Integrity classes of the study streams ranged from very poor to fair. Considering only IBI scores, all of the study streams compared more closely to negative than to positive reference streams. However, considering IBI scores or habitat scores alone does not provide an accurate assessment of overall stream health. A better understanding of stream health will be gained by considering IBI and habitat scores in combination.

Overall Ecological Assessment: To compare water quality, habitat condition, and comparability to reference streams, IBI and habitat scores for each stream were analyzed together (Fig. 4). A best-fit line for the reference streams demonstrates ideal IBI scores for particular habitat scores.

All of the study streams to the right of the reference line have poorer biotic quality than would be expected for the given habitat score. Undetermined water quality problems may be assumed to cause the lower-than-expected IBI scores. For example, DF2 has a high habitat score that is comparable to the positive reference streams, and is expected to have a much higher IBI score (26 points). Because poor habitat quality is not present, indicated by the habitat score, and a large discrepancy between the actual IBI score and the expected score exists, it may be concluded that this stream has a water quality problem. During the stream assessment, it was noted that an excessive amount of a petroleum-like substance was observed in this stream and its sediments. A similar situation exists for TFS (expected score = 30 points). It was noted that the fish seamed unusually slimy and lifeless, again indicating that a possible water quality problem may exist. Excessive course particulate organic matter was also noted in this stream and, along with very few well-developed rocky runs and riffles, may have contributed to lower dissolved oxygen concentrations. It should also be noted that an IBI score for DF3 was not calculated because the stream was dry. However, the expected IBI score would be >10, which would make this stream comparable to the negative reference stream.

Any streams that fall on the left side of the reference line indicate poorer habitat conditions than would be expected for the calculated IBI score. However, with only four reference streams, accurate confidence intervals could not be calculated. The margin of error was, therefore, estimated to include streams within five points of the expected IBI score and 10 points of the expected habitat score. These streams were considered comparable to the reference with regard to overall quality based on a distinct split between two clusters of study streams. All of the study streams were assumed to have a water quality or habitat condition problem. Streams that fell in between these two points could be assumed to have some problems with both water quality and habitat condition.

Upon comparing the positive reference streams to the four study streams with an IBI of poor or very poor, it was determined that the habitat parameters of pool variability, and rocky runs and riffles were significantly different ($P < 0.05$). Although these streams were determined to have water quality problems, these habitat parameters may also contribute to low IBI scores. Both of the above parameters are dependent on flow, and low flows may allow differences in physical attributes of the stream to be manifested in differences in biological character. NC2 and DF1 were assumed to be of a similar quality to the reference stream EEC. SCD was assumed to be of a similar quality to NC1.

Conclusions: Upon analysis of the above factors, several streams with water quality and/or habitat condition problems were found within the study area. DF2 and TFS have water quality problems and were not comparable to any of the references. The quality of DF3 could not be accurately determined because it was not flowing at the time of assessment. SCD, NC2, and DF1 were somewhat comparable to negative reference streams. An improvement in the quality of habitat in these streams with low habitat scores would most likely raise the IBI scores. There were no streams comparable to the positive reference streams. From this, the two highest quality study streams in this study are NC2 and DF1.

Ecological assessments, including habitat assessment and IBI calculations, are an inexpensive and effective way to determine overall health of stream ecosystems. Although collection and analysis of chemical water quality data are important, especially from a regulatory perspective, investigation of the ecological, health and integrity of streams is imperative to understand the overall effects of human influence. A combination of habitat assessments and biological community assessment provides a quick and inexpensive tool for evaluating stream ecosystem health.

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REFERENCES

1. Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. The river continuum concept. Can J Fish Aquat Sci 1980;37;370-377.
2. Karr JR. Biological integrity: a long-neglected aspect of water resource management. Ecol Appl 1991;1:66-84,
3. Jester DB, Echelle AA, Matthews WJ, Pigg J, Scott CM, Collins KD. The fishes of Oklahoma, their gross habitats, and their tolerance of degradation in water quality and habitat. Proc Okla Acad Sci 1992;72:7-19.
4. Perry J, Vanderklein E. Water quality: management of a natural resource. Cambridge (MA): Blackwell Science, Inc; 1996. 639 p.
5. Hilsenhoff WL. Using a biotic index to evaluate water quality in streams. Technical Bulletin Number 132, Wisconsin Department of Natural Resources; 1982.
6. Hilsenhoff WL. An improved biotic index of organic stream pollution. Gt Lakes Entomol 1987;20:31-39.
7. Hilsenhoff WL. Rapid field assessment of organic pollution with a family-level biotic index. J North Am Bentho Soc 1988;7:65-68.
8. Karr JR, Dudley DR. Ecological perspective on water quality goals. Environ Manag 1981;5:55-68.
9. Lenat DR, Barbour MT. Using benthic macroinvertebrate community structure for rapid, cost-effective, water quality monitoring: rapid bioassessment. In: Loeb SL, Spacie A, editors. Biological monitoring of aquatic systems. Boca Raton (FL): CRC Press; 1994. p 187-215.
10. Loeb SL, Spacie A, editors. Biological monitoring of aquatic systems. Boca Raton (FL): CRC Press; 1994;318 pp.
11. Cummins, KW. Bioassessment and analysis of functional organization of running water ecosytems. In: Loeb SL, Spacie A, editors. Biological monitoring of aquatic systems. Boca Raton (FL): CRC Press; 1994. p 155-169.
12. Karr JR. Assessment of biotic integrity using fish communities. Fisheries 1981;6:21-26.
13. Fausch KD, Karr JR, Yant PR. Regional application of an index of biotic integrity based on fish communities. Trans Am Fish Soc 1984;113:39-55.
14. Karr JR. Biological monitoring and environmental assessment: a conceptual framework. Environ Manag 1987;11:249-256.
15. Lyons J. Using the Index of Biotic Integrity (IBI) to measure environmental quality in warmwater streams of Wisconsin. U.S.D.A: General Technical Report NC-149; 1992.
16. Omernik JM. Ecoregions of the conterminous United States. Ann Assoc Am Geogr 1987;77:118-125.
17. Bailey RG. Ecoregions of the United States [map]. Washington, DC: U.S.D.A.. Forest Service; 1994. Scale 1:7,500,000
18. Oklahoma Conservation Commission. Sampling procedures for fish collection in streams. Standard Operating Procedures 35, 4th revision; 1996.
19. Plafkin JL, Barbour MT, Porter KD, Gross SK, Hughes RM. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. U.S.E.P.A: EPA/440/4-89/001; 1989.
20. Oklahoma Conservation Commission. Procedures for abbreviated habitat assessment. Standard Operating Procedures; 1996.

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