# Health and Condition of Trout in the Norfork Tailwater, Arkansas, Following Hypoxic Periods

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Abstract: Health, feeding, and relative weight of brown *(Salmo trutta)* and brook trout *(Salvelinus fontinalis)* were assessed seasonally at 2 sites on the Norfork tailwater, Arkansas, to evaluate effects of hypoxic water discharges from Norfork Dam. The upper site was immediately below Norfork Dam and subject to low (<6 ppm) dissolved oxygen (DO) in water releases during summer and fall. Dissolved oxygen recovers to ≥6 ppm before reaching the downstream control site. During fall, the health of brook and brown trout was significantly lower at the upstream, low DO, site than at the downstream, normal DO, site, and at both sites during the spring, normal DO period. Feeding rates of brook trout were also found to be reduced during the low DO period at the upper site. Relative weight was significantly higher for brown trout during the normal DO period in spring probably due to food availability during winter. Current efforts to maintain 4 ppm DO in hydropower discharges from Norfork Dam reduce the occurrence and severity of fish kills; however, these efforts are insufficient to provide for trout health or prevent economic losses resulting from a direct loss of fish or reduced angling success.

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The U.S. Army Corps of Engineers (COE) constructed Norfork Dam in 1944 on the North Fork of the White River for flood control and hydropower. Within a few years a trout fishery holding naturalized brown trout *(Salmo trutta)* and rainbow trout *(Orcorhynchus mykiss)* soon developed in the cold tailwater with trout weighing 3.6 to 5.4 kg (Baker 1959). The potential to catch brown trout >13.6 kg together with the put-and-take rainbow trout fishery provides significant benefit to the local economy and attracts anglers from throughout the United States (Rider et al. 1988).

Due to a summer hypolimnetic oxygen deficiency in Norfork Reservoir, from July through November water discharged from Norfork Dam often has low DO concentrations and sometimes has high levels of hydrogen sulfide, manganese, and iron (U.S. Geol. Surv. unpubl, data). In past years, several small-scale trout kills have occurred below Norfork Dam attributed to low DO levels during periods of zero generation. Weithman and Haas (1984) found that angler success, effort, and economic benefit derived from the Lake Taneycomo trout fishery was influenced by DO levels. Likewise, benefits derived from the Norfork tailwater trout fishery are expected to decline during periods when water discharges from Norfork Reservoir are poorly oxygenated.

In response to increasing public concern over fish kills, the COE and Southwestern Power Administration (SWPA) modified flood control and hydropower operations in 1991 to increase DO in hydropower water releases. These efforts proved to be somewhat successful and raised DO levels during generation from as low as 0.2 ppm previously to around 3.5 ppm. Despite improved conditions during power generation, DO in water releases under zero generation remain low and is often near 1 ppm. The COE and SWPA are continuing to investigate alternatives that could increase DO levels in Norfork Tailwater and provide the State standard of 6 ppm DO in all water releases.

Trout behavior changes in response to low DO (Stark and Bowman 1995). Trout are less active, locate themselves in areas with the highest DO content, and feed less (Weithman and Hass 1984). Digestion is slowed, reducing food conversion efficiencies and growth (Mekhanic 1957, Yeager 1987, Young 1987) and continued exposure to stressors like low DO conditions increases susceptibility to disease (Snicsko 1974).

Trout also require significantly higher DO levels during spawning periods (Beamish 1964, Liao 1971). DO concentrations in the Norfork tailwater are generally lowest during the fall brown and brook trout *(Salvelinus fontinalis)* spawning period (Pender 1998) and could reduce spawning success.

The COE attempts to reduce impacts to the fishery by placing loading restrictions on the generators during low DO periods in an effort to increase the efficiency of aeration systems and keep DO levels above 4 ppm. During periods of zero generation the main generators are pulsed to provide some DO above that from the house units. Since the initiation of these practices the number of fish kills has declined; however, sub-lethal effects of low DO have not previously been examined.

The purpose of this study was to compare the health or condition of trout in areas of the Norfork tailwater experiencing low DO concentrations to areas having normal DO levels to determine if trout are negatively impacted. Secondarily, we wanter to determine if assessment of health is sensitive enough to illustrate benefits of further increases in dissolved oxygen concentrations in water releases.

## Methods

Norfork tailwater is located below Norfork Lake in North Central Arkansas. The tailwater is defined as Norfork Dam to the confluence with the White River, a total of 7.7 km. Hypolimnetic releases of 5–14 C water from Norfork Dam range in magnitude from 2.8 to 170 $m^3$/second. Alkalinity ranges from 200 to 400 mg/liter $CaCO_3$. Stream substrates vary from bedrock to boulders, but are mostly gravel and rubble. Channel morphometry is characterized by alternating shoal and pool areas with scattered beds of rooted macrophytes.

Fish health was assessed using methods developed by Goede and Barton (1990) and Goede (1993). This technique assumes that continued exposure to a stressor causes abnormal physiological changes that result in visible changes in appearance of organs. The technique does not diagnose the cause of a condition, but evaluates deviations from appearance of normal healthy organs. The eyes, gills, pseudobranchs, thymus, fins, and opercles were examined followed by the mesenteric fat, spleen, hindgut, kidney, and liver. The color and amount of bile were assessed. Each organ was scored as described in text and photographically by Goede (1993) (Table 1).

A normality index (NI) was generated from the sum of scores from eyes, gills, pseudobranchs, thymus, fins, opercles, spleen, hindgut, kidney, and liver. The NI ranges from 0 to 10 with 10 being completely normal. A feeding index (FI) was generated based on color and volume of bile and ranged from 0 to 1 (1− (bile score) ÷3). A value of 1 indicated that the fish has recently fed. Trout were weighed, measured, and relative weights ($W_r$) calculated based on standard weight equations proposed by Whelan and Taylor (1984) for brook trout and Milewski and Brown (1994) for brown trout:

$$W_r\,(\text{brook trout}) = \frac{100 \times (\text{weight in g})}{10^{-5.085\ +3.043\ \times\ \mathrm{LOG}_{10}(\text{length in mm})}}$$

$$W_r\,(\text{brown trout}) = \frac{100 \times (\text{weight in g})}{10^{-4.867\ +2.96\ \times\ \mathrm{LOG}_{10}(\text{length in mm})}}$$

**Table 1.** Metrics used for calculations of normality (NI) and feeding (FI) indices and attributes of scores (Goede 1993).

| Metric | Score | Attributes |
|---|---|---|
| Eyes | 1 | Normal |
| | 0 | Blind, hemorrhagic, exopthalmic, missing or other abnormalities |
| Fins | 1 | Normal |
| | 0 | Damaged but healed or mild to extensive degradation |
| Opercles | 1 | Normal |
| | 0 | Shortened or missing |
| Gills | 1 | Normal |
| | 0 | Frayed, clubbed, pale, marginate or other |
| Pseudobranchs | 1 | Normal |
| | 0 | Swollen or lithic |
| Thymus | 1 | Normal—No hemorrhage |
| | 0 | Mild to severe hemorrhage |
| Spleen | 1 | Normal—Red, black or granular |
| | 0 | Nodular or enlarged |
| Hind gut | 1 | Normal—No inflation |
| | 0 | Mild to severe inflammation |
| Kidney | 1 | Normal |
| | 0 | Swollen, mottled or granular |
| Liver | 1 | Normal—Red to pale red |
| | 0 | Fatty, with nodules or focal or general discoloration |
| Bile | 0 | Bile straw yellow and gall bladder empty to partially full |
| | 1 | Bile yellow and gall bladder full |
| | 2 | Bile light to grass-green and gall bladder full |
| | 3 | Bile dark green to blue green and gall bladder full |

Two sites were selected for analysis. The uppermost site was directly below Norfork Dam, where DO conditions are at their worst during fall. The control site began 4.7 km downstream and continued to the mouth of the river. Natural aeration within the stream provided at least 6.0 ppm DO throughout the control site.

Fish were collected on 25 September and 2 October 1996 and 24–25 September 1997 from both sample sites to determine if there was a decline in health (NI) in the upper, low DO site. A third set of samples were taken on 3 June 1998 when DO was normal as a control for any variables that may have been present at the upper site that were not related to the low DO period. The spring sample period was selected to maximize the time trout had to recover from the previous low DO period. The U.S. Geological Service (USGS) maintained an automated DO monitor at Norfork Dam that provided hourly DO readings (Fig. 1).

An analysis of variance (ANOVA) was performed for each species on $W_r$ and the ranks of NI and FI to determine differences in the mean indices between the upper and lower sites in both low and normal DO seasons. In order to evaluate responses of trout health to annual changes in DO in water releases, a second set of tests were performed for each species to determine differences in the NI, FI, and $W_r$ between sites during low DO periods in 1996 and 1997.

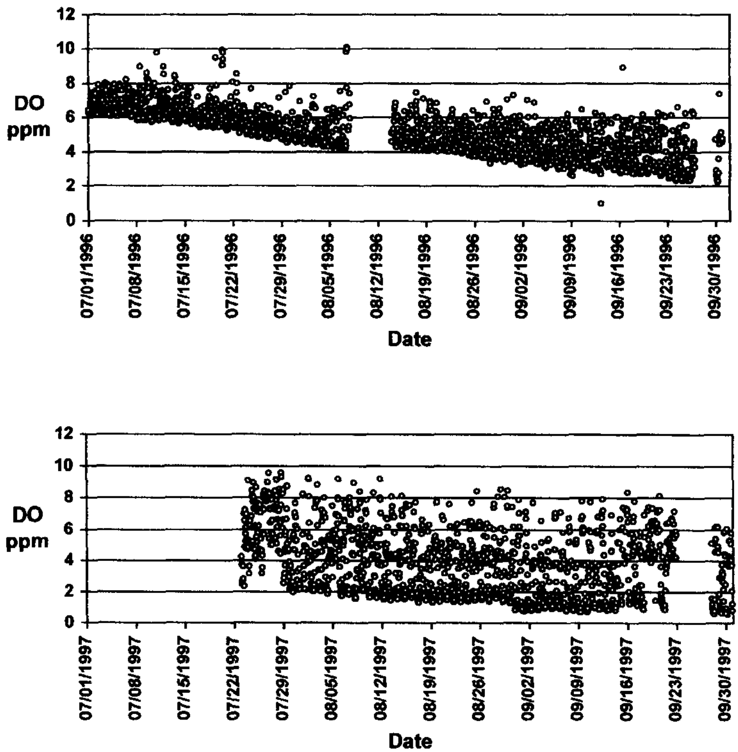


**Figure 1.** Hourly DO measurements in discharge from Norfork Dam from 1 July–1 October 1996 and 1997.

## Results

During both 1996 and 1997 there was a steady decline in DO in water releases from early summer until samples were taken (Fig. 1). Prior to sampling in 1996, DO ranged from just over 2 ppm to over 6 ppm. Daily variation in DO was primarily due to changes in efficiency of aeration systems in Norfork Dam at various discharge rates. In 1997, DO reached levels <1 ppm during periods of zero generation when water discharged through house units or through leakage was not aerated. Prior to the June 1998 sample, DO was falling but remained above the State standard of 6 ppm.

A total of 86 brook trout and 115 brown trout were collected and necropsied. Attempts were made to collect 20 trout of each species per site; however, brook trout were much less abundant at the lower site, and we were unable to collect 20 during a sample. The NI, FI, and $W_r$ were calculated for each fish, and the averages of these

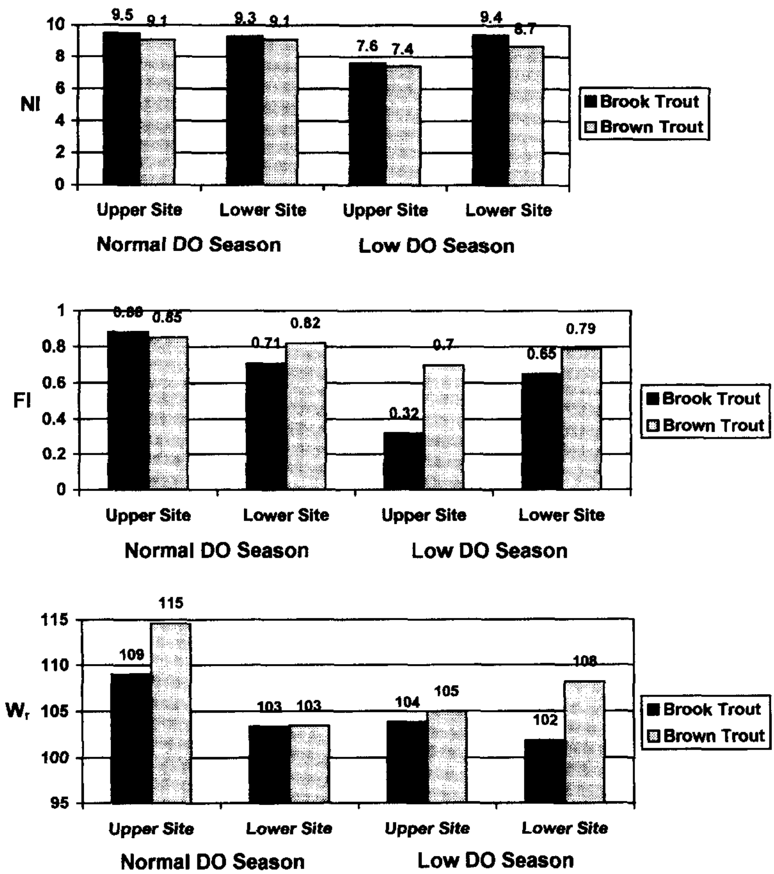


**Figure 2.** Average normality (NI) and feeding (FI) indices and relative weight (Wr) for brook and brown trout for upstream and downstream sites during low and normal DO seasons in the Norfork tailwater.

indices are provided for low and normal DO seasons by site for each species (Fig. 2) and for 1996 and 1997 samples by site for each species (Fig. 3).

Statistical analyses comparing sites between normal and low DO seasons showed significant differences ($P < 0.000$) in the mean NI for both species between normal and low DO sites dependent on season. Brook trout showed a significant difference ($P < 0.000$) in the mean FI between sites dependent on seasons while brown trout showed no difference between samples ($P = 0.383$). Significant differences were detected in the average $W_r$ for brown trout between sites dependent on season ($P = 0.015$), but no differences were found between samples for brook trout ($P = 0.094$).

Similar analyses comparing the 2 fall sample years showed significant differences in the mean NI between sites ($P < 0.000$) but not years for both brown and brook trout (Fig. 3). A significant difference in the average FI was also detected for brook trout between sites ($P < 0.000$) but not years, and no significant difference was found between samples for brown trout ($P = 0.497$). No significant differences were

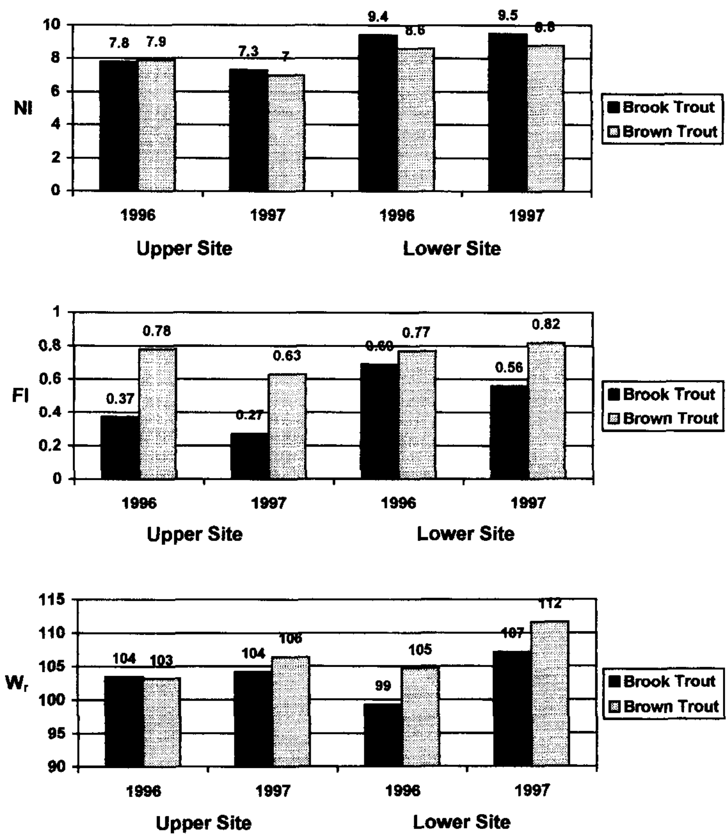


**Figure 3.** Average normality (NI) and feeding (FI) indices and relative weight (Wr) for brook and brown trout for upstream and downstream sites during low DO seasons in 1996 and 1997 in the Norfork tailwater.

detected in the average $W_r$ between samples of either brown ($P = 0.197$) or brook trout ($P < 0.227$).

## Discussion

The average NI for both brown and brook trout was lower at the upper site during the annual low DO period than in areas with normal DO or during normal DO periods at the upper site (Fig. 2). Most variables that are seasonal in nature should influence both upper and lower sites. For example, trout collected during 1996 and 1997 at both upper and lower sample areas would have been in similar reproductive condition. The exceptions are parameters related to water releases from the dam. Food items may be seasonally available near the dam like increased numbers of threadfin shad *(Dorosoma petenense)* discharged during the winter from Norfork Lake. Low DO concentrations (<6.0 ppm) are present between July and December (Fig. 1). High (250–750 µg/liter) manganese levels are sometimes recorded from October through December (USGS unpubl. data).

High manganese levels would not have influenced this study since samples were taken no later than October 2. Furthermore, manganese oxidizes slowly and would have passed through both sample areas before oxidizing (Morgan 1967).

There is the possibility of non-seasonal factors present at the upper site that are different at the lower sample site such as angling pressure or fish density. A creel survey conducted from April 1995 through February 1998 estimated angling pressure at the upper site at 2,343 angler hours per month per km and 1,017 angler hours per month per km at the lower site (Todd et al. 1999). Stress attributable to angling could be partially responsible for the lower average NI at the upper site during fall; however, angling pressure is also seasonal and is typically higher in June than in September or October. If angling-related stress lowered the average NI significantly, then the average NI should have been lower at both sites during the June samples. Any differences in fish densities that could have reduced the average NI at the upper site during the low DO period should have also resulted in a reduced average NI at the upper site during the normal DO period if trout density influenced the NI significantly.

This study found the NI for both species is lowered only at the upper site during periods with low DO (Fig. 2). The June 1998 samples also show that with improved DO levels the occurrence of non-normal trout organs returns to levels equal that of trout in stream reaches not exposed to low DO conditions and suggest that abnormalities observed from samples in fall are due to exposure to stress during the low DO period.

Analyses detected a significantly lower mean FI at the upper site during the low DO period for brook trout only (Fig. 2). The average FI of brown trout was also lower during the same period although not significantly different from other samples.

Temperatures were near 13C during the 1996 and 1997 samples and were within the optimal temperature range reported for brook trout (Mullen 1958, Baldwin 1951) and brown trout feeding (Elliot 1975) and growth (Pentelow 1939, Elliot 1981, and Jensen 1990). It is unlikely that temperature influenced feeding rates during the fall samples since temperature varies little between sites.

Electrofishing catch rates of all trout in the Norfork tailwater were 755 trout per hour (brown trout, 216 trout per hour) (brook trout, 250 trout per hour) in May 1998 at the upper site and 560 trout per hour (brown trout, 219 trout per hour) (brook trout, 9 trout per hour) in July 1998 at the lower site (C.S. Todd unpubl. data). Although the high brook trout density could have reduced the average FI during fall, the spring samples did not show a reduced average FI in brook trout that should have been apparent if trout density were influencing feeding rates. Similarly, analysis of stomach contents of trout in Lake Taneycomo, Missouri, by Weithman and Hass (1980) showed a reduction of feeding during low DO periods.

Average $W_r$ was not lower during low DO periods at the dam. The ANOVA detected a significant difference in the mean $W_r$ in brown trout during the June sample. Both brown and brook trout had a higher average $W_r$ in the upper site during June 1998 (Fig. 2) although the difference was not significant in brook trout. This may be due to feeding on threadfin shad discharged annually from the dam during mid-winter.

Comparisons of the 1996 and 1997 samples showed significant differences in the mean NI between sites for both species and in the mean FI between sites for brook trout (Fig. 3). Although there were measurable differences in DO in water releases, the average NI, FI, or $W_r$ was not significantly different in the brown or brook trout populations between years. Although not significant, both species showed a decline in average NI and FI at the upper site in 1997 as would be expected due to the lower daily minimum DO the tailwater experienced that year.

This study strongly suggests that lowered NIs at the upper site during low DO periods are primarily due to low DO conditions in the Norfork tailwater. The trout health assessment used in this study is sensitive enough to show the effects of low DO levels in the Norfork tailwater under current conditions. The NI was the most useful of the 3 indices in showing effects of low DO. Over short periods $W_r$ did not seem to be affected by low DO conditions; however, long term effects may still exist.

Techniques used in this study were unable to detect changes in the health of trout in response to changes in DO regimes during 1996 and 1997; however, the study establishes baseline data for comparisons following future improvements to dam aeration systems. With sufficient improvements in DO we should be able to detect improvements in health of trout.

The study demonstrates that additional improvements to aeration systems for Norfork Dam can potentially reduce detrimental effects to trout health due to low DO in discharges from the dam. Although modified operations of Norfork Dam have reduced the number and severity of fish kills, generator load restrictions designed to maintain at least 4.0 ppm DO in main generator discharge are insufficient to prevent reductions in trout health (NI) and to prevent economic losses resulting from direct loss of fish or from reduced angling success through a significant portion of the year.

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