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Field observations on the production of rainbow trout (*Oncorhynchus mykiss*) under high concentrations of water-borne iron

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ABSTRACT

Effluents from brown coal mines are frequently rich in iron, the water being red-brown in colour and turbid. For several years a fish farm in the Lusatia (Brandenburg, Germany) has used such mine effluents for rearing rainbow trout. The total iron content of this water varies between 5 and 10 mg/l with pH ranging from 6.7 to 7.4. Water turbidity is high with a transparency of 10 to 40 cm at the most due to the substantial ferric hydroxide concentrations. Until 1989 trout have been reared in net cages within concrete settling basins destined for settling the ferric hydroxide mud. The cages were stocked with fingerlings in autumn, reaching portion size in the spring of the following year. Specific growth rate was 0.98% per day, comparable to that of trout in another farm unpolluted by iron but stocked at higher densities. The results show that fingerling rainbow trout may live in water containing more than 5 mg/l total iron but in the absence of Fe^{2+}. These concentrations of water-borne iron seem to have only a limited detrimental effect on fish growth and feed conversion and do not prevent trout culture in principle.

Introduction

Iron occurs as a variable component of numerous natural waters. Especially in acid environments it is dissolved in water as ferrous hydrogen carbonate. In the presence of oxygen it is very rapidly transformed to Fe^{3+} at higher pH and is then sedimented as ferric hydroxide, which causes the red-brown colouring of water and mud. Trout farms are often supplied with water containing high iron concentrations, but the levels which can be tolerated by fish have not yet been determined unequivocally. This paper reports results which were obtained during trout culture in water with extremely high total iron levels.

Local situation and water chemistry

The water originates from surface mining and initially contains Fe^{2+} in dissolved form, but as it flows along a delivery channel oxidation of the iron takes place. In order to utilize this water for cooling in Jänschwalde power station (Brandenburg, Germany) it is directed through settling basins, where large amounts of iron sediment out and may be removed.

The settling basins are 7 m deep and comprise a volume of about 37000 m^3. The water inflow amounts to a maximum of 5000 m^3/h, so there is a water residence time of 7–8 hours. In these settling basins rainbow trout have been reared within net cages having a depth of 3 m and a volume of about 30 m^3 until 1989, after which they were set free in the basins. The cages are stocked with fingerlings averaging 30–50 g in autumn, but in some years there was an additional stocking with bigger fish (100–110 g) in spring.

The physico-chemical parameters of the water supply are given in Table 1. The total iron content varies between 5 and 10 mg/l in the inlet of the settling basins. Because of sedimentation, ferric hydroxide levels were lower at the outlet (4–6 mg/l). Fe^{2+} could no longer be detected in the inlet water (the limit of detection being 0,1 mg/l).

Results of trout culture

In 1983 the first experiments were conducted concerning the possibilities of using the iron-rich water of the settling basins in Jänschwalde power station for trout culture. They were successful, so since 1984 portion-sized trout have been produced commercially (Riedel, 1990).

During harvest the trout had a weight of 220–300 g. In the years 1984 to 1989 the total annual yield amounted to 39–62 t (Table 2). The fish were supplied with dry feeds. Losses were lowest and feeding efficiency was best in the first year. Since physico-chemical conditions did not change during the experimental period, it is assumed that the higher mortalities in the years 1985–1989 were caused less by the high total iron level than by other factors related to management (oxygen deficiency in the cages).

Much better results were obtained in 1990 and 1991, when the fish were reared in the settling basins without cages and mortality was reduced to 10%. Considering the lower feed conversion ratio, it must be noted that diets of higher quality were fed to the trout.

Table 1. Physical and chemical parameters of the water supply used for rainbow trout production in the settling basins

Water temperature:	6–16°C
Transparency (Secchi depth)	10–40 cm
Dissolved oxygen:	8.0–10.5 mg/l
pH:	6.7–7.4
Total hardness:	287 mg/l $CaCO_3$
Alkalinity:	111 mg/l $CaCO_3$
Filtrable substances:	17–19 mg/l
NH_4^+:	0.6–2.4 mg/l
NO_2^-:	0.03–0.19 mg/l
NO_3^-:	0.02–0.3 mg/l
COD:	10.1–19.4 mg/l
Fe_{total}:	5–10 mg/l

Table 2. Results of rainbow trout culture in the iron-rich water of the settling basins in Jänschwalde power station

Year	1984	1985	1986	1987	1988	1989	1990	1991
Yield (t)	39	51	62	62	49	54	90	102
Feed conversion ratio (kg feed/kg gain)	2.12	2.77	3.59	2.64	3.07	2.40	1.81	1.45
Mortality (%)	6	33	38	33	39	25	10	10

During 1989/1990 (October to April) the specific growth rate of trout was 0.98 % per day. Trout of similar size in another commercial fish farm attained a growth rate of 0.97 %, but the water temperature in this farm was less favourable and the densities of fish were higher. It can be stated, however, that similar growth results were obtained under similar conditions in water not polluted with iron. In an experiment at the Institute of Inland Fisheries in Berlin-Friedrichshagen the specific growth rate of rainbow trout at a constant water temperature of 11° C was 1.34 % per day (Fredrich and Steffens, 1983) which is considerably better, but cannot be regarded optimum (Figure 1).

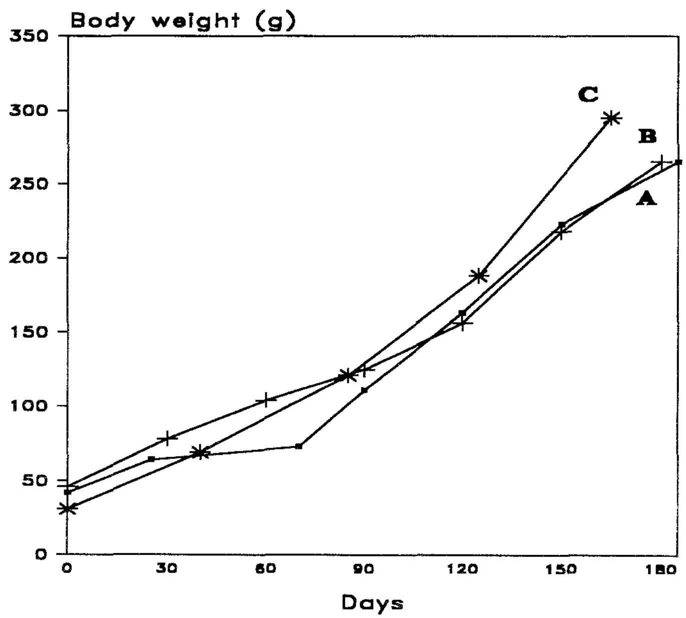

Figure 1. Trout growth in iron-rich water of Jänschwalde power station (A), in another Brandenburg trout farm with low water-borne iron concentration (B), and in experimental tanks of the Institute of Inland Fisheries Berlin-Friedrichshagen (C)

Discussion

The toxicity of iron to freshwater fish is inadequately defined because ferrous iron is not stable in water and quickly oxidizes to ferric iron, especially in well aerated, alkaline or neutral waters. In order to maintain very high levels of soluble iron in the water, extreme pH-values must be employed, which further complicates the toxicity of dissolved bivalent or trivalent iron (Mattheis 1988). Surface waters characterized by the above physico-chemical parameters are scarce and depend on geochemical conditions and human activities. They most commonly originate from coal and ore mining operations.

Dahl (1963) reported that over the last 25 years an increasing number of fish kills have been observed in Denmark, caused by iron and sulphur derivatives of the natural or artificial transformation of the organogenic pyrite (FeS_2) content of Danish soils. The problem arose because of intensive strip mining of lignite and large scale land reclamation and drainage work.

Evaluating the actual situation Dahl (1963) stated that the steady decrease of the population of sea trout (*Salmo trutta*), at least in west Jutland, is mainly caused by destruction of spawning grounds by land reclamation, followed by ochre precipitation derived from iron-rich discharges from lignite mines. Nearly all lignite mines now neutralize their discharge water with calcium hydroxide. But it is very difficult to neutralize the acid water drained off fields and meadows.

In 1969 and 1976 von Lukowicz reported on acid stress and gills covered by ochre in rainbow trout and carp (*Cyprinus carpio*) while testing their sensitivity to ferrous iron and during the overwintering period. He observed this situation in wintering ponds in northeast Bavaria, when two-summer-old carp suffered from a combined stress caused by inflow of drainage water containing low dissolved oxygen (1 mg/l), low pH (5.3) and a ferrous iron concentration of 1 mg/l. Their primary lamellae were covered by a grey-brown slime containing ferric hydroxide. Generally the gills were pale and especially their marginal zones were brightened. Carp stock exhibited mortalities of 3%. Repeated applications of quicklime and an additional inflow of water of neutral pH free of iron stopped the fish losses. In a similar situation this author observed current mortalities in rainbow trout suffering from low pH (6.0–6.5) and ferrous iron concentrations between 5.0 and 25.0 mg/l.

Schäperclaus (1990) stated that slightly acid water with low oxygen content often contains high concentrations of dissolved ferrous iron. If fish are present in such a water, their alkaline gills will be covered with a brown slime composed of ferric hydroxide. The alkaline surface of fish eggs might also be covered with an inert coat of ferric hydroxide.

Decker and Menendez (1974) conducted a series of flow-through tests simulating acid mine pollution of rivers and streams in West Virginia, U.S.A. 96-hr-LC50-values of ferrous iron for brook trout (*Salvelinus fontinalis*) were 1.75 mg/l at pH 7.0, 0.48 mg/l at pH 6.0, and 0.41 mg/l at pH 5.5.

Amelung (1981) exposed fertilized eggs and freshly hatched yolk-sack fry of rainbow trout to four concentrations of soluble bivalent iron in a combined diluter and flow-through apparatus. During incubation eggs had distinctly increased mortalities only in the highest ferrous iron concentration of 5.7 mg/l. In three concentrations between 1.2 and 4.2 mg/l mortalities ranged slightly above the control value. All freshly hatched larvae exposed to 2.3 and 3.7 mg/l died within 24 hr. The mortality of larvae in 1.2 mg/l reached 80% within 24 hr, after 3 d 100%. An acute toxicity value as 24-hr-LC50 derived graphically from this data may be about 0.47 mg/l.

Von Lukowicz (1976) exposed rainbow trout of three size classes (5–6, 10–12, 20–25 cm) in flow-through tests to well water containing a constant ferrous iron concentration of 5.0 mg/l. The actual pH was 6.5, the dissolved oxygen value 5.5 mg/l. Within 2.5 hr the first fishes of the largest size class died with all the signs of ochre suffocation. No fish survived of this class. The medium-sized rainbow trout had mortalities of 90% within 24 hr. Fish of the smallest size class had no mortalities. Repeated tests using ferrous iron concentrations up to 25 mg/l exhibited identical results: the younger the rainbow trout, the more tolerance they showed. Under identical test conditions carp up to 15 months old produced neither symptoms worth mentioning nor mortalities.

In a series of flow-through experiments Sykora et al. (1972, 1975), and Smith and Sykora (1976) studied the long-term effects of lime-neutralized suspended iron on several salmonid species. Their experimental flow-through apparatus consisted of a modified proportional diluter equipped with a neutralization device and additional oxygenation and detention tanks. Ferric hydroxide was obtained by continuously mixing of stoichiometric stock solution of ferrous sulfate and calcium hydroxide. The resultant ferrous hydroxide was then diluted with well water to 4 or 5 concentrations and oxidized to ferric hydroxide in aerated tanks. Exposing 3 months old brook trout to 4 concentrations of suspended iron (total iron) Sykora et al. (1972) revealed a definite trend towards smaller growth of fish with increasing concentrations (6, 12, 25, and 50 mg/l) of total iron, with the largest trout in 6 mg/l and in the control. Based on data of egg hatching time and hatchability, alevin survival, and growth Sykora et al. (1975) calculated a 90-d MATC (Maximum Acceptable Toxicant Concentration) of suspended iron (total iron) for brook trout of 10.5 mg/l. Sykora et al. (1975), from another 22-months bioassay with juvenile and yearling brook trout, concluded that the MATC of suspended iron for brook trout may lie between 7.5 and 12.5 mg/l.

In view of the growth reduction of coho salmon (*Oncorhynchus kisutch*) alevins at 90 d post-hatch in one 1.5 mg Fe/l replicate and in both replicates of 3 and 6 mg/l, and the sharply reduced survival in 12 mg/l Smith and Sykora (1976) stated, that the 90-d MATC of suspended iron for coho salmon may lie between 0.75 and 1.5 mg/l (0.97–1.27 mg/l).

Our field observations on rainbow trout culture and toxicity data from the literature show that trout culture is possible in water comprising a total iron content between 5 and 10 mg/l. Two important provisions have to be strictly adhered to: (1) pH should be circumneutral or slighthly alkaline and (2) the dissolved oxygen content must be always higher than 5 mg/l. This ensures that any ferrous iron species occurs only in concentrations non-toxic to rainbow trout. Acid water destined for supplying trout farms and containing considerable amounts of ferrous iron should first be aerated and neutralized by application of slaked lime ($Ca(OH)_2$) or quicklime (CaO).

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