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Short-term Effects of a Partial Drawdown on Fish Condition in a Eutrophic Reservoir

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Abstract Prescribed or natural drawdowns occur frequently in reservoirs but their effects on fish populations have been barely studied. As a consequence of a severe drought and the need to optimize water quality, a partial drawdown was prescribed in autumn 2005 to a eutrophic reservoir that provides water supply to a large metropolitan area (Barcelona, Spain). In order to avoid a potential massive fish kill given the reduced oxygen availability and high fish abundance, preventive purse seine fisheries were performed to reduce the fish stock. The fisheries had little effect on the fish assemblage because final population size structure and species composition did not change significantly. The species composition of the purse seine catches varied significantly during the drawdown with higher proportion of bleak (*Alburnus alburnus*) in pelagic water during the days of worst water quality, confirming that bleak is more tolerant than roach (*Rutilus rutilus*) to poor water quality and a potential good indicator of water pollution. The weight–length relationship (i.e. condition) of roach and bleak also varied significantly during the drawdown following the same tendency in both species, losing and recovering their weight (4.99% in roach and 5.96% in bleak) in only 16 days. The close relationship found between water quality and fish condition demonstrates that fish condition can be a good metric of the well being of fish, even for extreme short-term changes.

Keywords Water quality · Ecological indicators · Iberian Peninsula · Roach *Rutilus rutilus* · Bleak *Alburnus alburnus*

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1 Introduction

Humans have profoundly altered river ecosystems through impoundments and diversions. There are over 45,000 dams above 15 m high worldwide that hold about 15% of the total annual river runoff (Nilsson et al. 2005). The purpose of damming includes irrigation, hydroelectric power generation, flood control, and public water supply (Han et al. 2000; Poff and Hart 2002; Nilsson et al. 2005). The construction of artificial reservoirs destroys terrestrial ecosystems, alters the downstream flux of water and sediment causing extensive modification of aquatic communities, and obstructs the dispersal and migration of organisms (Poff and Hart 2002; Nilsson et al. 2005; Villanueva et al. 2006). The efficient management of reservoirs is thus essential. Due to natural causes (i.e. drought) or to management, reservoirs are often subjected to drawdown (Gaboury and Patalas 1984;

Paredes and Lund 2006; Yamamoto et al. 2006). The studies of the effects of natural or deliberate drawdown on fish have mainly focused on reproductive aspects. For instance, the lowering of water level exposes and reduces areas being used for spawning and kills eggs and fry (Jackson 1966), reducing reproductive success (Il'ina and Gordeyev 1970; Kuznetsov 1971) and in some cases even inhibiting spawning (Yakovleva 1971; Yamamoto et al. 2006). These effects are not only dependent upon the degree of depth variation, but also on time, area, and duration of flooding or lowering (Wood and Pfitzer 1960). On the other hand, if water level in reservoirs is maintained or slightly increased during the spawning, fish reproduction will be favoured (Fraser 1972). Although the effects of drawdown on fish recruitment have been well investigated, very little is known on its effects on fish condition.

Reservoir's drawdown causes strong changes in the water column: transparency generally decreases and the concentrations of nutrients and chlorophyll-*a* increase mostly as a result of sediment resuspension (Heman et al. 1969; Lin and Caramaschi 2005). It is widely known that long-term exposure to environmental stressors such as pollution or low oxygen causes detrimental effects on important fish features such as metabolism, growth, resistance to diseases, reproductive potential, and, ultimately, the health, condition, and survival of fish (Barton et al. 2002). Condition or health is a particularly important attribute of fish because it has a strong influence on growth, reproduction and survival (Lambert and Dutil 1997; Adams 1999; Marshall and Frank 1999). The condition of a fish is a measure of the physical and biological circumstances during some previous period and is affected by interactions among food availability, physical factors, parasitic infestations and environmental conditions (Lloret and Rätz 2000; Vila-Gispert et al. 2000; Oliva-Paterna et al. 2003). Fish condition can be assessed by a variety of criteria ranging from morphometric (weight–length) and physiological (liver and gonad weights) measures to biochemical measures such as lipid or protein content (Barton et al. 2002; Lloret et al. 2002). Biochemical measures reflect more rapidly environmental stressors, whereas morphometric measures are less sensitive to acute stressors but less costly and reflect responses at the whole-organism level that may affect fish performance (Barton et al. 2002).

Sau reservoir (Ter River basin, Spain) is the first of a cascade of three reservoirs supplying (a maximum of 8 m^3/s) drinking water to the region of Barcelona (Armengol et al. 1986, 2003). This water source represents ca. 60% of the water annually consumed in the Barcelona area (460 Hm^3), inhabited by 4 million people. In 2005, the region of Barcelona (Catalonia) was affected by a severe drought and the water level in reservoirs was very low (Fig. 1). The Catalan Water Agency (ACA, Agència Catalana de l'Aigua) decided to partially empty Sau reservoir, in order to improve

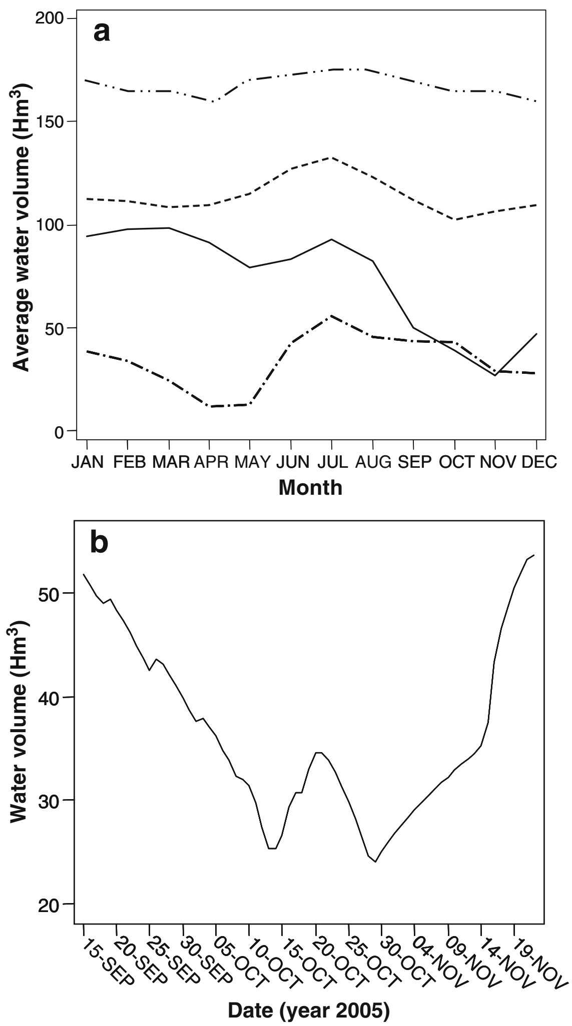

Fig. 1 **a** Maximum (—··—), mean (- - - -), and minimum (—·—) monthly averages of water volume in Sau reservoir during 39 years (between January 1966 and December 2004) and the mean for 2005 (———) (year of the partial drawdown, which started in September). **b** Variation of the water volume in Sau reservoir during the drawdown

water quality in the subsequent reservoirs by selecting water extraction from the best layers and so optimising water supply to the Barcelona region. The fish populations were studied during the drawdown. The objectives of this study are: (1) to evaluate the effects of the drawdown on the fish assemblage; and (2) to report short-term variation (in 10 days) on habitat use and condition of roach (*Rutilus rutilus*) and bleak (*Alburnus alburnus*) during the drawdown due to water quality deterioration. Roach and bleak are among the most frequent and abundant fish in many European reservoirs and lakes (Irz et al. 2002; Carol et al. 2006) and hence important species for reservoir assessment and monitoring. Roach and bleak are cyprinid fish typical of eutrophic ecosystems (Persson 1991) and bleak has been shown to be particularly tolerant to pollution (Dray et al. 2003).

2 Methods

2.1 Study Area and Drawdown Process

Sau reservoir is a canyon-type reservoir, 18.2 km long and with a maximum width of 1.3 km in the vicinity of the dam. It is located (41° 58′ N, 2° 23′ E) in the middle reaches of the River Ter (Catalonia, NE Spain). Because of its importance as a source of water to Barcelona, Sau reservoir has been monitored since it was first filled in 1963 (Armengol et al. 1986) and its limnology has been extensively studied (see e.g. Han et al. 2000; Gasol et al. 2002; Armengol et al. 2003). It is a monomictic reservoir with thermal stratification in summer and vertical mixing in winter (Armengol et al. 1986, 2003). Selected physical and limnological features are: capacity, 168.5 Hm^3; surface area, 570 ha; maximum depth, 75 m; mean depth, 29 m; altitude, 426 m a.s.l.; conductivity, 592 μS/cm; total P, 3.51 μM and integrated chlorophyll 0–8 m, 82.93 $\mu g/m^2$ (Carol et al. 2006). Since its filling, the reservoir has suffered a eutrophication process, especially noteworthy in the phosphorus and the nitrogen concentration (Armengol et al. 1986, 2003). Nowadays its concentrations of chlorophyll *a* are typical of eutrophic systems. The fish assemblage of Sau consists of eight species, all introduced to the river basin, although roach and bleak dominate the pelagic zone representing more than 76% of the individuals captured. Sau was the reservoir with most abundance of pelagic fish (total catch per unit effort of with multimesh gillnets) among 14 Catalan reservoirs sampled in 2003 (Carol et al. 2006).

During the drawdown, the water level decreased 11.6 m in 40 days and the water volume from 51.76 Hm^3 (15 September 2005) to 24.07 Hm^3 (29 October), besides a deterioration of water quality with less oxygen and more ammonium. On 14 October rain started throughout the river basin and much water entered in the reservoir, oxygenating the water column; for this reason, the Catalan Water Agency decided to close the sluice gates and to stop the drawdown on 4 November.

2.2 Field and Laboratory Methods

During 2005, a physical multi-probe profile was taken monthly from the surface to the bottom in a point near the dam. In the field, we measured temperature, conductivity, pH, redox potential, oxygen saturation and concentration, light energy in the photosynthetic radiation spectrum and nephelometric turbidity at 0 m of depth and we took a water sample for chemical analysis. We also measured Secchi disc depth. During the partial drawdown we determined this physical profile every 2 days. At the laboratory, the surface water sample was analysed for suspended solids, nutrient concentrations and chlorophyll *a* content. Nutrient concentrations were measured by conventional spectrophotometric or chromatographic techniques (see Carol et al. 2006 for further details on water analytic methods). During the drawdown (October 2005) professional fishermen worked in the reservoir with a purse seine (130 m long, 18 m deep and 8 mm of stretched mesh size) in the pelagic zone to reduce the fish stock in order to avoid a potential massive fish kill, given the reduced oxygen availability. We took six subsamples of the fish catches (11, 14, 18, 21, 25 and 27 October 2005) by randomly taking about 100–400 fish (ca. 1–4 kg) from the 500–2,000 kg of the catches. These subsampled fish were identified and fork length and total weight were measured to the nearest 1 mm and 0.01 g, respectively. Fish data of a sampling in 2003 (Carol et al. 2006) were also used for comparison.

2.3 Statistical Analyses

The species composition in the samples throughout the days of the drawdown was compared with a *G*-test of independence (Sokal and Rohlf 1995). The variation in fish structure (averages of fork length and total weight) during the drawdown was analyzed with Spearman's correlation coefficient (r_S). Analysis of covariance (ANCOVA) was used to compare the condition (weight–length relationship) among days of the drawdown taking into account fish size (covariate). ANCOVA has several advantages over condition factors and similar indices (García-Berthou and Moreno-Amich 1993; García-Berthou 2001). All data analyses were performed with SPSS 13 (SPSS Inc., Chicago, USA).

3 Results

3.1 Water Quality

At the beginning of 2005 the vertical mixing of the water column produced re-oxygenation of Sau reservoir and a low concentration of ammonium (Fig. 2). From March, the photic layer was supersaturated of oxygen because of phytoplankton production, while at 10 m depth the oxygen concentration decreased until anoxia conditions prevailed due to the effect of the breath and mineralization of organic matter. On 15 September, the sluice gates of the reservoir were opened to start the drawdown and from this day the concentration of dissolved oxygen decreased and ammonium increased in the whole water column (Fig. 2 and 3). 14 October was the day with the lowest oxygen concentration in the water column. On the same day, it started to rain throughout the river basin and much water entered the reservoir oxygenating the water column (Fig. 3). On 4 November it was decided to close the sluice gates, thus increasing the oxygenation and the vertical mixing of the water column.

3.2 Drawdown Effects on the Fish Assemblage

During 4 weeks, fishermen caught 14.7 tons of roach, 962 kg of bleak and 820 kg of European catfish (*Silurus glanis*). A few individuals of carp (*Cyprinus carpio*) and barbel (*Barbus graellsii*) were also captured. In total 16 tons were captured, but this was a very small proportion of the reservoir's fish stocks, since the volume sampled was very small (in total 58 purse seines were laid sampling a total of 1.40 Hm^3, mostly in the same area of the reservoir) compared to the water volume of the reservoir (average water volume was 29.59 Hm^3 during the fishery). Total catch per unit effort of purse seine did not vary significantly during the drawdown (Spearman's r_S= −0.01, n=16, P=0.97) or with water volume (r_S= −0.17, n=16, P=0.52). Moreover the fishery did not significantly change the average fork length of bleak (r_S=0.43, n=6, P=0.40) and roach (r_S=−0.31, n=6, P=0.54) during the drawdown, indicating that there was no important effect of the fishery on the fish assemblage.

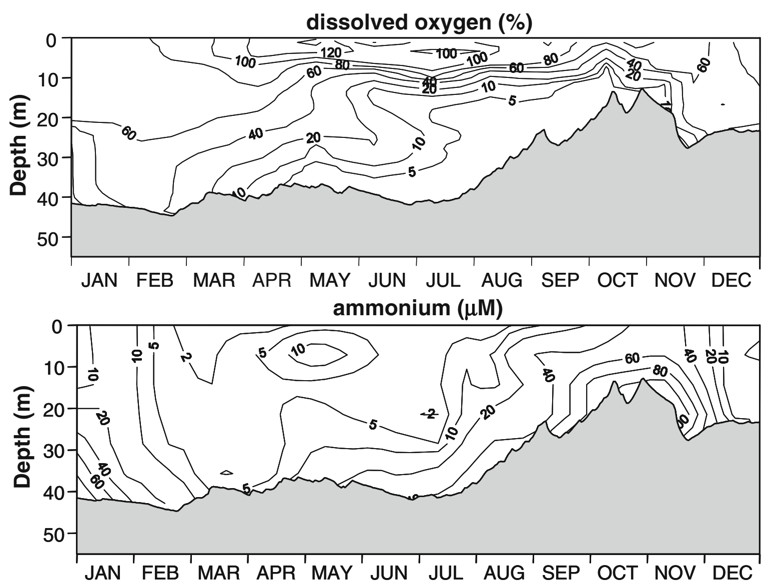

Fig. 2 The variation of the dissolved oxygen (*top*) and ammonium concentration (*bottom*) along 2005 in Sau reservoir. The *shaded area* represents the bottom of the reservoir

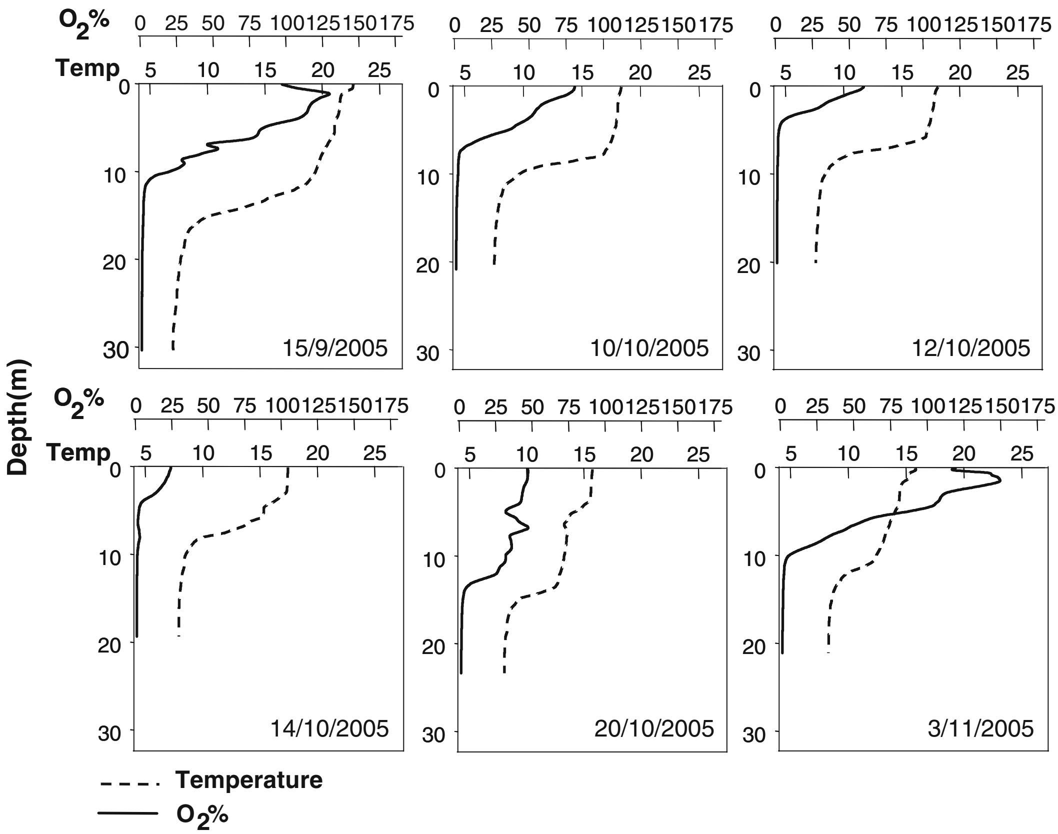

Fig. 3 Depth variation of temperature and dissolved oxygen during the drawdown

The species composition of the purse seine catches varied significantly during the drawdown (G=42.7, df=10, P<0.0005). A higher proportion of bleak was found on 21 October (Fig. 4), when the lowest oxygen concentration occurred in the water column (Fig. 3). Echosounding showed that in those days with least oxygen concentration most fish were closer to the shore in contrast to a few days before or after.

The weight–length relationship of roach and bleak significantly varied during the drawdown (Figs. 5 and 6). After accounting for fish size (covariate in ANCOVA), significant differences were found in the condition of roach (ANCOVA: $F_{5,\ 1526}$=29.4; P< 0.0005) and bleak ($F_{5,\ 88}$=2.7; P<0.024) during the days of the drawdown. Differences were stronger if data of 2003 were included (roach: $F_{6,\ 1581}$=70.3; P< 0.0005; bleak: $F_{6,\ 183}$=9.8; P<0.0005), because bleak and particularly roach had a much better condition in 2003 (Fig. 5). The adjusted mean of total weight (controlling for length with ANCOVA) indicated that individuals of roach at the beginning of the drawdown (11 October, adjusted mean of weight (log-transformed)=1.001) were 4.99% heavier (i.e. in better condition) than a few days after the worst water quality (21 October, adjusted mean=0.951) (Fig. 5). Similarly, bleak on 11 October (adjusted mean=1.308) were 5.96% heavier than on 21 October (adjusted mean=1.230). On average, a bleak individual of 110 mm of fork length weighed 14.74 g on 11 October and 13.96 g on 21 October, losing 0.78 g in only 10 days (Fig. 6). During the drawdown, the loss and recovery of weight in bleak and roach varied following the same tendency (correlation of adjusted means: r_S=0.79, n=7, P=0.033).

4 Discussion

4.1 Fish Catches and Species Composition during the Drawdown

The aim of the work by professional fishermen in the reservoir was to reduce the fish stock in order to avoid a potential massive fish kill given the reduced oxygen

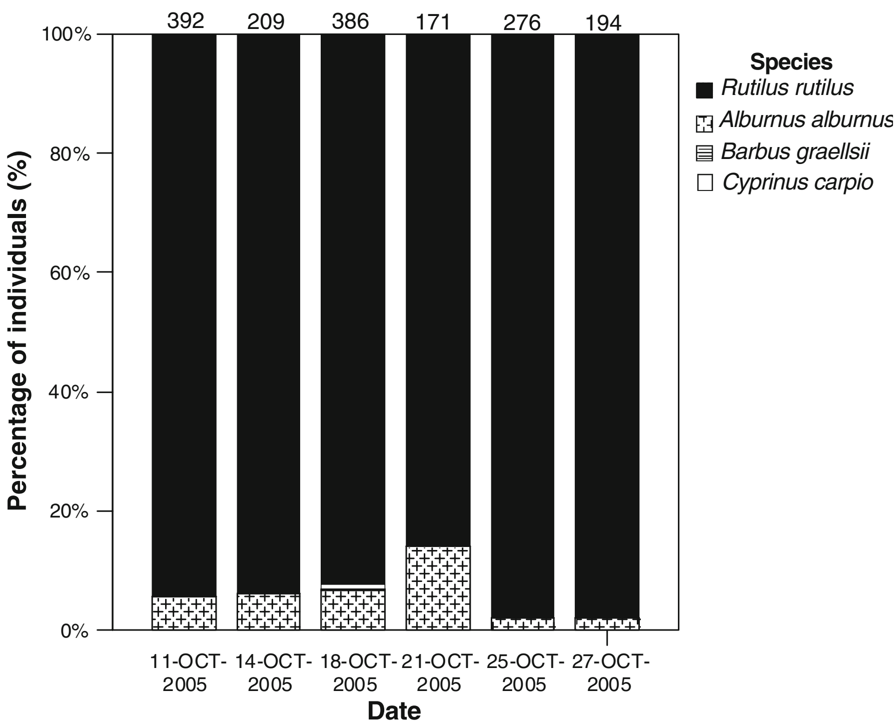

Fig. 4 Fish species composition in the purse seine catches during the drawdown. The figures above the bars are the total number of individuals in the subsamples

availability. However, the fisheries had no significant effects on the fish assemblage (species composition and size structure) because a very small proportion of the reservoir's fish stocks were captured. The proportion of bleak in the (pelagic) fishery catches was maximum on the days of worst water quality (Fig. 4), when most fish moved to the shore (echosounding data), and this proportion returned to the initial values after water quality recovery. This indicates that roach refuged to the shore more than bleak. The littoral zone of lakes and reservoirs often has better water quality than the pelagic zone due to wind action and convection (Singh 1983; Petersen et al. 2001) and bleak, has been previously shown to be more tolerant than

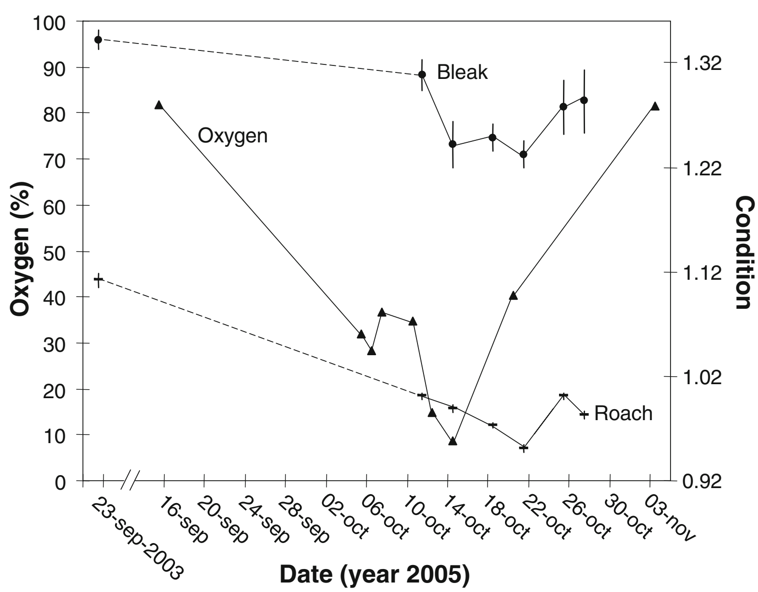

Fig. 5 Changes in oxygen concentration (average of the top 10 m of the water column) and condition (ANCOVA adjusted means of weight, with length as covariate; *error bars* are standard errors) of roach (*Rutilus rutilus*) and bleak (*Alburnus alburnus*) during the drawdown

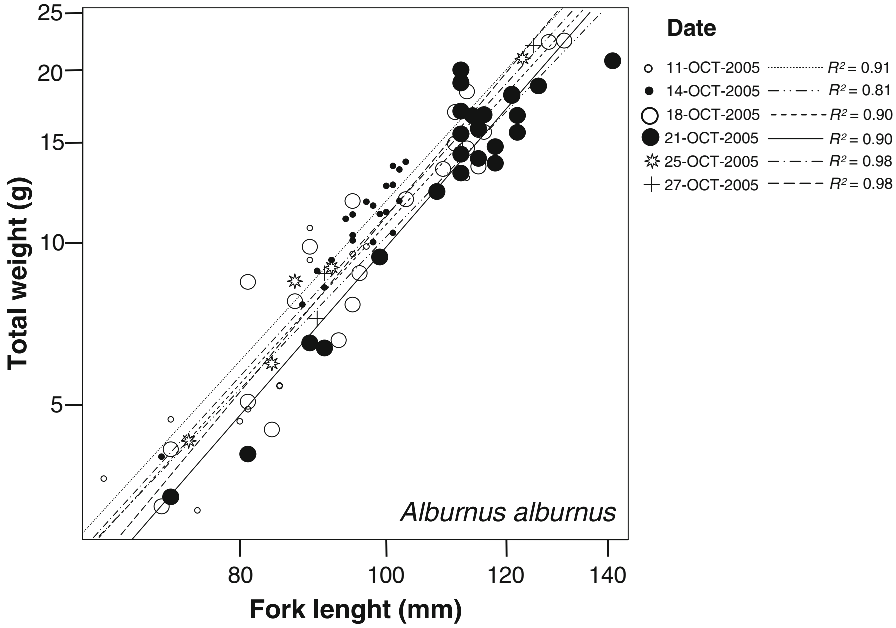

Fig. 6 Weight–length relationship (log-scales) of bleak during the drawdown. The linear regressions and coefficients of determination are shown for each date

roach to poor water quality. Irz et al. (2002) point out that the final stage of eutrophication in reservoirs is characterized by the dominance of cyprinids, particularly bleak, and pikeperch (*Sander lucioperca*), which are more tolerant to poor water quality. Similarly, Dray et al. (2003) related 11 environmental variables and the distribution of 21 fish species in the Doubs River (France) and found that bleak was more tolerant to pollution (low oxygen, high ammonium,....) than most other species, including roach. Moreover, Horppila and Kairesalo (1992) found in an enclosure experiment in eutrophic lake that with unusually high pH, roach but not bleak were schooling near the bottom trying to escape unfavourable conditions and Stott and Cross (1973) found with laboratory channels that falling concentrations of dissolved oxygen caused roach to move downstream to better oxygenated water and that when an aerated water flow was restored the fish quickly reoccupied their original position. Therefore, our results and previous literature suggest that bleak is particularly resistant to poor water quality and could be used as an indicator of water pollution.

4.2 Short-term Variation of Fish Condition

The changes in fish condition were significant and similar for both species, and clearly coincided with the variation in water quality. Within 10 days (from 11 to 21 October) roach lost ca. 4.99% of its condition and bleak 5.96%. When the water quality improved, they recovered almost their initial condition within only 6 days (from 21 to 27 October) (Fig. 5). A wide range of physiological effects has been associated with low dissolved oxygen concentrations and poor water quality, including circulatory changes, altered heart rate, reduced blood oxygen saturation, change in respiratory quotient and change on spleen, liver and kidney weights (Seager et al. 2000). Poor condition (i.e. lower available energy reserves) may also lower the chances of survival of fish, leading to an increase of natural mortality (Adams 1999). Drawdown-induced water changes resulted in a sublethal response of the fishes, as indicated by the significant loss of condition (Fig. 5). It seems plausible that there would have been a massive fish kill had the drawdown lasted a few more days, but because rain started the water column oxygenated and the fish recovered its condition.

Environmental conditions, physical factors and the habitat features influence fish condition (Lloret and Rätz 2000; Vila-Gispert et al. 2000; Lloret et al. 2002). Although other factors such as season, geographical variation or life history stages can also influence fish condition, fish condition is regarded as a good, simple metric of the well being of the fish (Barton et al. 2002). Although seasonal variation in condition is routinely studied (e.g. Jamet 1995; Hartman and Margraf 2006), there are few examples of such short-term variation in fish condition. Jachner and Janecki (1999) experimentally demonstrated in the laboratory short-term changes (8 days) in the condition of roach in response to alarm substances (released from injured skin of conspecifics and interpreted as predation risk). Although morphometric condition appears to be relatively insensitive to environmental stressors compared with most specific measurements of blood chemistry, lipid or protein content (Lloret et al. 2002; Barton et al. 2002), we found that the fish condition changed in just 10 days following water quality impairment. Therefore, our study demonstrates that fish condition is not only interesting for understanding long-term (seasonal or interannual) variation of fish populations exposed to chronic environmental stressors (Barton et al. 2002), but also as a good, cost-effective metric for extreme short-term changes.

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