Abiotic control of brown trout (*Salmo trutta* L.) population dynamics by highly variable stream flow regimes in a central Iberian mountain basin.

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ABSTRACT: The main objective of this study is to find out effects of natural variability of stream flow regimes on the principal parameters of a brown trout (*Salmo trutta* L.) population. Following the work hypothesis from which highly variable hydrological conditions can lead to a clearer response of the population, works were conducted in a high mountain basin in Central Iberian Peninsula, characterized by a continental climate and variable natural flow regimes. Both population dynamics parameters and hydrological regimes were estimated annually in fourteen sampling stations spread in the whole basin during a period of five years, between 1998 and 2002. Correlations between hydrological and population variables were analysed and statistical significance tests were conducted. Four strong linear relationships were detected: two of them describing a link between young-of-the-year recruitment and flow variables; and other two relating mean fork length of age classes 0+ and 1+ to hydrological variables. Meaning of the observed relations is discussed and implications for river related resources management, as well as for further research, are proposed.

1 INTRODUCTION

"Changes in salmonid population densities are largely due to negative density-dependent factors in favourable habitats with high densities, and to density-independent factors in unfavourable habitats with low density" (Elliott 1994). Following the above-mentioned reference, the effects of stream flow regimes on the limitation of some population dynamics parameters are expected to be more pronounced in a high mountain watershed with such an intraannual variability of hydrological regimes like upper river Tormes basin. This little predictable flow regime suggests that there might be a kind of abiotic population control based on the influence of flow on survival and growth of individuals integrating each cohort (Baeza Sanz & García de Jalón 1997).

Stream flow regime, through its mean values (affecting the carrying capacity and suitable habitat) as well as its extreme values (floods and droughts), is known to act as an important abiotic factor in the environmental limitation of brown trout populations. The limitation and control of population parameters produced by catastrophic events of the stream flow regime has been profusely studied by several authors. Extreme minimum values of flow regimes reflect the intensity of droughts, and can affect individual growth (Weatherley et al. 1991), density (Elliott et al. 1997; Bell et al. 2000) and shelter availability by brown trout (Elliott 2000). In a similar way, extreme maximum flows appear to have an important role in riverine fish population control. Thus, floods during snowmelt periods govern survival (Jensen & Johnsen 1999) and recruitment of salmonids (Latterell et al. 1998). It appears to be clear that every study on the effect of stream flow natural variability has to be focussed in each stage of first year of life of the individuals of the population (Cattanéo et al. 2002). In this context, annual flow regime data were studied in the present work after establishing three periods: (1) spawning till emergence of fry, (2) emergence till first summer of life, and (3) the whole year before till the date when sampling campaigns took place.

This work has been planned on the basis of taking into account the response of a whole brown trout population inhabiting a basin, supposing that the whole population might reflect more accurately the variability of flow regimes through time than isolated studies of a single reach.

In summary the main objective of the present work is to find out effects of natural variability of stream flow regimes on the principal parameters of the dynamics of a brown trout population, following the work hypothesis from which highly variable hydrological conditions can lead to a clearer response from the population.

2 STUDY AREAS

The study area (mean altitude 1200 m; area ca. 900 km^2) involves the basin of the upper river Tormes, in the Northern slope of Sierra de Gredos Mountains, in central Spain (40º20'N; 5º42'W). The situation of the basin and its altitude put it under a highly variable continental climate. Mean air temperatures range intra-annually between –1 and 18 ºC, and annual rainfall regime (mean value ca. 850 mm) has a marked minimum in summer (ca. 20 mm) and local maxima in autumn-winter. Geologically, the study basin is located in a great batholith with a relative uniform mineralogical granite composition. The vegetal structure of the basin is made of a series of extended grazing lands with Scotch pine (*Pinus sylvestris*) forests and meadows when nearing the lowest points of the slopes.

The river Tormes (tributary of river Duero) flows through a v-shaped basin for ca. 40 km until it reaches the limit of the study area.

The study watershed maintains a medium-sized population (mean biomass 5.4 $g.m^{-2}$) of brown trout (*Salmo trutta* L.), and cohabiting cyprinid species (2.4 $g.m^{-2}$). Water is mainly acidic or neutral ($6.6<pH<7.5$) with a good biotic integrity of the invertebrate community (Alba-Tercedor & Sánchez-Ortega 1988). The mean annual flow varies from 1.8 $m^3.s^{-1}$ in the upper reaches of the river Tormes to 55.8 $m^3.s^{-1}$ in its lower reach in the study basin.

3 METHODS

3.1 *Population parameters*

Fourteen sampling stations were selected in the study ranging 1010 to 1470 m in altitude, seven in river Tormes and seven in tributaries maximizing representativeness of the watershed. Five annual survey campaigns were carried out in July during the five-year period (1998–2002).

During each survey campaign three pass removal electrofishing were conducted in each net-closed sampling station. Fork length (L) to the nearest 1 mm and wet weight (W) to the nearest 0.1 g were measured in every captured fish. Scales were extracted to a sample of 25% of captured trouts.

Densities (D) were estimated by the Maximum Weighted Likelihood method (Carle & Strub 1978). Age was determined for each age class by means of a combination of scale reading and length frequency analysis (Bhattacharya 1967 modified by Pauly & Caddy 1985). Emergence period of each cohort was estimated by modelling the growth of the captured 0+ class individuals between their emergence and the date of capture by taking into account the stream temperature regime during this period (Baglinière & Maisse 1990; Alonso-González, in prep.). Spawning season was determined: (1) by subtracting 440 ºC.day to the emergence date and (2) by the observation of spawners during each season.

Loss rate (Z) of each cohort was determined as the reduction % of each cohort between two consecutive annual sampling campaigns. Growth rate (G) was estimated by the difference of the natural logarithm of mean fork lengths observed in the same cohort in two consecutive years. Fulton condition factor (K) was determined for each individual.

Population variables were $\ln(x+1)$ transformed in order to normalise their distribution.

3.2 *Stream flow regime*

Two series of data each from a gauging station (Duero Basin Water Authority – C. H. Duero) have been employed in this work: (1) mean daily flow data (to the nearest 0.001 $m^3.s^{-1}$) from station nº 02006 in river Tormes headwaters (altitude 1377 m; catchment area 88 km^2), and (2) mean monthly flow data (to the nearest hm3) from a 54 year historical series (1931-1990) in gauging stations nº 02006 (see above characteristics) and nº 020135 in river Tormes lower reach, 4.2 km downstream the exit of the study basin (altitude 976 m; catchment area 900 km^2).

Annual stream flow regimes in the fourteen sampling reaches were estimated by flow standardised data from both gauging stations, adjusted in a linear model ($R^2=0.93$) that relates flow regimes to catchment area and mean catchment altitude. Transferability of flow data from both gauging stations was checked by: (1) the similarity ($R^2=0.74$) of downpour peak distributions recorded in two meteorological stations INM adjacent to both gauging stations; and (2) the homogeneous geology of the basin, indicative of a similar hydrologic response to rainfall regimes in separated points.

Five variables were determined for every period in which years were divided according to the abovementioned 1st year of life stages (see *3.1. Population parameters*): maximum (Q_{max}), mean (Q_{med}) and minimum (Q_{min}) daily flow, the number of days in which maximum flow was higher than the value of percentile 75 of the data series (Q_{perc75}) and lower than the percentile 25 of the data series (Q_{perc25}). Thus, annual flow, intensity of floods and droughts, and frequency of both events, were considered.

Hydrological variables were also $\ln(x+1)$ transformed so as to normalise their distribution.

3.3 *Statistical analysis*

One of the work hypothesis followed in the present study is based in the supposition that the samples captured in all the sampling stations belong to a single brown trout population as it exits the possibility of free movement of individuals in the whole studied basin. According to this, it can be expected that the population parameters of the whole population will vary in a relatively homogeneous manner. For this reason, electrofishing survey data from all stations were synthesised so as to quantify yearly variations of the whole population. Prior to statistical analyses, two verifications were made: (1) Shapiro-Wilks normality tests; and (2) the existence of statistically significant differences between the means, medians and distributions of the fourteen values of each annual campaign.

Linear relationship between every combination of population-hydrological variables was analysed by a correlation matrix. Relations were selected when matching the three following criteria: (1) r-Pearson correlation coefficient absolute value higher than 0.9, (2) number of pairs of data values used to compute each coefficient ≥ 4, and (3) p-values below 0.05, which indicate statistically significant non-zero correlations at the 95% confidence level.

4 RESULTS

A summary of the values observed for each population variable is presented in Table 1.

Table 1. Mean values (Mean) and standard deviations (SD) of the population variables determined in the 14 sampling stations of river Tormes brown trout population. Where: B is trout biomass ($g.m^{-2}$); and Di+ density ($individual.m^{-2}$); Zi+ loss rate ($year^{-1}$); Li+ mean fork length (mm); Gi+ growth rate ($year^{-1}$); Wi+ mean wet weight (g); and Ki+ condition factor ($10^5.g.mm^{-3}$) of age class i+.

	B	D0+	D1+	D2+	D3+	Z0+
Mean	5.42	0.16	0.08	0.02	0.00	-0.76
SD	0.57	0.09	0.03	0.01	0.00	1.14
	Z1+	L0+	L1+	L2+	G0+	G1+
Mean	0.73	61.44	152.76	209.02	0.88	0.36
SD	0.09	2.69	5.72	9.67	0.03	0.05
	W0+	W1+	W2+	K0+	K1+	K2+
Mean	2.65	45.66	123.64	1.11	1.18	1.21
SD	0.33	5.37	16.28	0.03	0.04	0.02

Table 2. Mean values (Mean) and standard deviations (SD) of the hydrological variables estimated in the 14 sampling stations of river Tormes. Where: Q_{max} is maximum; Q_{med} mean; and Q_{min} minimum daily flow ($m^3.s^{-1}$); and Q_{perc75} and Q_{perc25} are the number of days in which flow is higher, or lower, the percentile 75 and 25 of the temporal series, respectively. Every variable is determined for each period: Incubation ($_{Inc}$); emergence to 1st summer ($_{EJul}$); and the year immediately before sampling campaign ($_{year}$).

	Q_{maxInc}	Q_{medInc}	Q_{minInc}	$Q_{perc75Inc}$	$Q_{perc25Inc}$
Mean	28.42	5.28	1.69	56.75	10.57
SD	20.84	3.21	1.00	13.72	6.81
	$Q_{maxEJul}$	$Q_{medEJul}$	$Q_{minEJul}$	$Q_{perc75EJul}$	$Q_{perc25EJul}$
Mean	14.03	3.26	0.36	43.00	25.71
SD	10.29	1.49	0.31	14.23	2.92
	$Q_{maxyear}$	$Q_{medyear}$	$Q_{minyear}$	$Q_{perc75year}$	$Q_{perc25year}$
Mean	35.44	3.09	0.03	90.66	108.50
SD	29.84	1.50	0.04	14.23	26.81

In a similar manner, Table 2 show the summary of the values observed in the hydrological variables.

Four correlations presented in Table 3 were selected attending to the explained criteria (see *3.3 Statistical analysis*).

Table 3. Population and hydrological variables between which a strong linear relationship was detected, correlation coefficients (r-Pearson) and statistical significance (p-value).

Population var.	Hydrological var.	r-Pearson	p-value
D0+	$Q_{perc75Inc}$	-0.9425	0.0164
D0+	$Q_{medyear}$	-0.9568	0.0432
L0+	$Q_{perc25Inc}$	-0.9078	0.0332
L1+	$Q_{perc25EJul}$	-0.9649	0.0078

5 DISCUSSION

Four relations were found between both types (hydrological and population) of variables.

A strong negative linear relationship appeared to link the frequency of floods during the incubation period to the recruitment of fry during the first summer of life. This relation suggests that the more frequent floods between spawning and emergence are, the lower recruitment of young-of-the-year is. Many authors have found a negative relationship between the discharge intensity and recruitment of fry, Jensen & Johnsen (1999) linked intensity of discharge during the emergence of a cohort with a reduction on the cohort strength, so does Spina (2001) who detects a negative correlation between flood peaks during incubation and the cohort strength. Cattanéo et al. (2002) found that 0+ trout density was strongly and negatively related to the discharge rate during the emergence period, and reports that other authors found similar effects in salmonids. The high number of works showing the similar conclusions suggests that intensity of floods during the incubation and emergence are very important factors determining of trout recruitment. Nonetheless, it is not so frequent to find references on the effect of frequency of discharges on annual recruitment. This effect can be due to the damage occasioned in the redds when occurring repeated flooding episodes during incubation. As no relationship between intensity and recruitment has been detected, moderated but repeated floods could be able to affect to the annual recruitment at least so markedly as big isolated spates. Moreover, this observed effect could become a useful basis from which to explain the absence of effects on the recruitment of a severe spate in a brown trout population in the North of Spain, reported by Lobón-Cerviá (1996). Thus, a big isolated spate could not be significantly effective in reducing recruitment but frequent repeated moderated floods would. The application of this conclusion to populations inhabiting rivers affected by regulated flows and hydropeaking episodes can justify further research in this direction.

Other effect found on the influence of natural flow regimes on the recruitment of young-of-the-year is the one that relates mean annual flow to the density of 0+ trouts in summer. This relationship is harder to explain, as many effects can be masked into the variable “mean annual flow” such as the absence of droughts of floods that scour the redds, or smoother regimes that permit an easier migration of spawners. More detailed analyses have to be done in this direction in order to find out what does “mean annual flow” really mean, and which variables are responsible of the variability in values of this parameter.

A reliable negative relationship between mean length of fry and the frequency of occurrence of low flow episodes during incubation was also found. This interesting correlation can suggest an effect of low temperatures on eggs laid in a redd when it is affected by a reduction in the water column depth. A lower flow leads to a shallower water column over the redds and thus a higher influence of wintery air temperature regimes on the water temperature in the redd and, consequently, around the eggs or larvae. A repeated occurrence of these circumstances can lead eggs or larvae to a slower development and a less efficient use of energy reserves in the yolk. Further research has to be conducted in order to contrast this explanation, water temperatures in redds should be measured and modelled so as to find the relation between water temperature, air temperature and flow in redds.

A harder to explain correlation was also found, which links negatively mean fork length of 1+ age class trouts to the frequency of days with low flow in late spring and early summer (between emergence period of fry and late July). A similar effect was also observed by Weatherley et al. (1991), who found that autumn weights of 1+ trouts were 30-40% of predicted (maximum growth) when droughts occurred. A general explanation would possibly be deduced when improving studies on the invertebrate emergence in river Tormes, which usually takes place during the mentioned period, and the effects produced on it by the low flow episodes. If some relation could be detected in this direction, it would be very likely that growth in 1+ trouts could be affected indirectly by flow regimes in spring through its influence on prey availability. This is another direction in which further research has to be conducted.

As a summary, it can be concluded that natural variability of flow regimes can act as a major factor influencing, and possibly controlling, the dynamics of a brown trout population through affecting annual recruitment and early development and growth. This control might be not only driven by the intensity of discharge and drought episodes but also by the frequency at which these events occur.

6 AKNOWLEDGEMENTS

This study has been supported by Castilla y León Environmental Authority (Consejería de Medio Ambiente), and technical and managerial support is due to Emilio Roy Berroya and Félix López Moyano.

7 REFERENCES

Alba-Tercedor, J. & Sánchez-Ortega, A. 1988. Un método rápido y simple para evaluar la calidad biológica de las aguas corrientes basado en el de Hellawell (1978). *Limnetica*, 4: 51-56.

Alonso-González, C. (in prep.). Caracterización de la dinámica de poblaciones de trucha común (Salmo trutta L.) en la cuenca alta del río Tormes y de los principales factores que influyen en ella. Tesis Doctoral, 2003. ETSI de Montes, Universidad Politécnica de Madrid, Madrid.

Baeza Sanz, D. & García de Jalón. 1997. Caracterización del régimen de caudales en ríos de la cuenca del Tajo atendiendo a criterios biológicos. *Limnetica*, 13(1): 69-78.

Baglinière, J.L. & Maisse, G. 1990. La croissance de la truite commune (*Salmo trutta* L.) sur le bassin du Scorff. *Bulletin Français de la Pêche et de la Pisciculture*, 318: 89-101.

Bell,V.A., Elliott, J.M. & Moore, R.J. 2000. Modelling the effects of drought on the population of brown trout in Black Brows Beck. *Ecological Modelling*, 127(2-3): 141-159.

Carle, F.L. & Strub, M.R. 1978. A new method for estimating population size from removal data. *Biometrics*, 34: 621-630.

Cattanéo, F., Lamouroux, N., Breil, P. & Capra, H. 2002. The influence of hydrological and biotic processes on brown trout (*Salmo trutta*) population dynamics. *Canadian Journal of Fisheries and Aquatic Sciences*, 59(1): 12-22.

Elliott, J.M. 1994. Quantitative ecology and the brown trout. Oxford University press, Oxford: 286 pp.

Elliott, J.M. 2000. Pools as refugia for brown trout during two summer droughts: Trout responses to thermal and oxygen stress. *Journal of Fish Biology*, 56(4): 938-948.

Elliott, J.M., Hurley, M.A. & Elliott, J.A. 1997. Variable effects of droughts on the density of a sea-trout *Salmo trutta* population over 30 years. *Journal of Applied Ecology*, 34 (5): 1229-1238.

Jensen, A.J. & Johnsen, B.O. 1999. The functional relationship between peak spring floods and survival and growth of juvenile Atlantic Salmon (*Salmo salar*) and brown trout (*Salmo trutta*). *Functional Ecology*, 13: 778-785.

Latterell, J.J., Fausch, K.D., Gowan, C. & Riley, S.C. 1998. Relationship of trout recruitment to snowmelt runoff flows and adult trout abundance in six Colorado mountain streams. *Rivers*, 6(4): 240-250.

Lobón-Cerviá, J. 1996. Response of a stream fish assemblage to a severe spate in northern Spain. *Transactions of the American Fisheries Society*, 125: 913-919.

Pauly, D. & Caddy, J.F. 1985. A modification of Bhattacharya's method for the analysis of mixtures of normal distributions. *FAO Fisheries Circular*, 781: 16 pp.

Spina, A.P. 2001. Incubation discharge and aspects of brown trout population dynamics. *Transactions of the American Fisheries Society*, 130: 322-327.

Weatherley, N.S., Campbell-Lendrum, E.W. & Ormerod, S.J. 1991. The growth of brown trout (*Salmo trutta*) in mild winters and summer droughts in upland Wales: model validation and preliminary predictions. *Freshwater Biology*, 26(1): 121-131.