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Angling impact on conservation of Spanish stream-dwelling brown trout *Salmo trutta*

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Abstract Spanish brown trout, *Salmo trutta* L., populations are currently overexploited as a result of unsuitable management activities, and their genetic uniqueness is threatened by introgression of foreign genes because of stocking. In this study, the status and management of trout fisheries were reviewed and the effects of fishery management on abundance, production and life history of trout in Spain assessed. Angling exploitation has reduced the mean age, the age diversity and number of trout exceeding the minimum size in exploited sections. Likewise, exploited areas show a general decrease in overall abundance parameters and production, as well as a depletion of the breeding stock and population fecundity. Current minimum size limit control reduces the spawning chances in fast-growing populations because of higher susceptibility to angling harvest. The effects of fishery management on population dynamics, production and life-history characteristics exhibit different patterns among Spanish rivers, and seem to depend on the environmental and biological characteristics of the populations. The current declining trend of brown trout could be reduced by river-specific management and alternative fishing regulations.

KEYWORDS: conservation, life history, management, population dynamics, *Salmo trutta*, Spain.

Introduction

Brown trout, *Salmo trutta* L., populations show a high genetic (Machordom, Suárez, Almodóvar & Bautista 2000; Sanz, García-Marín & Pla 2000; Suárez, Bautista, Almodóvar & Machordom 2001) and ecological (e.g. Almodóvar 1999; Nicola 1999; Nicola & Almodóvar 2002) differentiation between Spanish drainage systems, and have high conservation value because of genetic uniqueness caused by their geographical isolation. The Iberian Peninsula display five major evolutionary lines for brown trout within the southern limits of the species original distribution, i.e. North Atlantic, Douro (an endemism restricted to the Douro basin), South Atlantic, Adriatic-Andalusian and Mediterranean. As a result of its geographical position, this area has played a major role in the present Palaearctic distribution of the species, as illustrated by its haplotype diversity (Machordom *et al*. 2000; Suárez *et al*. 2001). However, brown trout is an important angling species in Spain, and consequently has high socio-economic status. This impedes efficient conservation of the species because of a complex legislative situation and unsuitable management (Almodóvar & Nicola 1998; Almodóvar, Nicola & Suárez 2002).

The number of fishing licences has gradually increased from 27 000 in 1950 to 850 000 presently, increasing public demand for more fish. This led to an overexploitation of trout stocks in some rivers (Almodóvar & Nicola 1998; Almodóvar *et al*. 2002). Additionally, the genetic uniqueness of wild stocks is currently threatened by introgression of foreign genes because of stocking (e.g. García-Marín, Jorde, Ryman, Utter & Pla 1991; Machordom, García-Marín, Sanz, Almodóvar & Pla 1999; Almodóvar, Suárez, Nicola & Nuevo 2001). The cumulative effect of habitat destruction, water pollution and the introduction of exotic species is also responsible for the current decline of

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brown trout (Almodóvar & Nicola 1999; Elvira & Almodóvar 2001).

Consequently, there is an urgent need for a survey of the current status of wild brown trout in Spanish rivers. In this study the current status and management of trout fisheries in Spain are reviewed. The aim was to examine whether the abundance and life-history traits of stream-dwelling brown trout are influenced by fishery management. Specifically, the effects of angling exploitation on the abundance, production, age structure, growth and reproduction of wild stocks were evaluated. Finally, some management guidelines that could improve the conservation of brown trout are proposed.

Materials and methods

Investigations to evaluate the effects of fishery management on trout populations, as well as the current management practices, throughout Spain were reviewed. Unfortunately, it was difficult to find quantitative information about brown trout stocks. Furthermore, reports from regional governments and historical catch records were scarce and unreliable and there was a lack of scientific studies focused on the ecological basis for management of brown trout.

The authors' own 6-year data set (1992–1998) from 10 rivers of central Spain, covers a wide range of ecological conditions and management regulations. Seven rivers are tributaries of the River Tagus (Hoz Seca, Cabrillas, Gallo, Dulce, Jarama, Guadiela and Bornova) and three of the River Douro (Cega, Eresma and Aguisejo) were also used. These studies were on non-polluted streams with important recreational fisheries for brown trout. The rivers Cega, Eresma, Jarama and Bornova have soft, infertile waters arising from granite and gneiss catchments at elevations between 1000 and 1300 m above sea level. The rest of the rivers flow through limestone catchments at elevations from 850 to 1400 m above sea level (Table 1). More detailed descriptions of the rivers are given in Almodóvar (1999) and Nicola & Almodóvar (2002).

Two or three sampling sites were selected within each of the 10 rivers, with sufficient distance between them to avoid migration, but to be homogeneous with respect to habitat structure and to cover different angling regulations. The sampling sites included exploited and unexploited reaches, with four different angling regulations, as described in Almodóvar *et al.* (2002), viz.: (1) preserved and catch and release sections (unexploited); (2) restricted and open regulation sections (exploited). Fish were sampled every third month from December 1992 to December 1998 at 25

Table 1. Principal physical habitat characteristics of the 10 rivers studied

	Hoz Seca	Cabrillas	Gallo	Guadiela	Dulce	Aguisejo	Jarama	Bornova	Cega	Eresma
River basin	Tagus	Tagus	Tagus	Tagus	Tagus	Douro	Tagus	Tagus	Douro	Douro
Mean elevation (m)	1360	1267	970	1010	885	1240	1213	1060	1250	1290
Lithology	Calcareous	Calcareous	Calcareous	Calcareous	Calcareous	Calcareous	Siliceous	Siliceous	Siliceous	Siliceous
Mean width (m)	8.6	4.3	9.0	5.0	4.9	2.4	5.9	4.0	5.8	6.3
Mean depth (m)	38.4	31.9	50.1	31.8	46.1	11.2	28.6	21.9	28.7	21.8
Mean water velocity (m s^{-1})	0.30	0.40	0.75	0.17	0.58	0.23	0.55	0.16	0.45	0.61
Mean cover (%)	15.8	29.4	38.3	77.5	43.7	61.2	18.7	45.0	12.8	27.7
Dominant substrate	Gravel	Cobble	Gravel	Sand	Sand	Sand	Cobble	Sand	Boulder	Boulder

localities by direct current electric fishing using a 220 W generator. Trout were anaesthetised with tricaine methane-sulphonate (MS-222) and their fork length (FL, to the nearest mm) and mass (to the nearest g) were measured. Scales were taken for age determination. The fish were placed in holding boxes to recover and then returned to the stream. Trout density was estimated by applying the three catch removal method (Zippin 1956) and the numerical age-composition was determined. Age structure complexity was assessed for each sampling site by means of Shannon–Weaver's diversity index $H = -\sum p_i \log_e p_i$, where p_i is the proportion of fish belonging to the ith class. Biomass was calculated following Mahon, Balon & Noakes (1979) and production was estimated using the increment summation method from Newman & Martin (1983). Measures of variance were computed according to Newman & Martin (1983). Growth was examined by assessing the mean length and weight of each age-class in autumn, as growth virtually ceases by that time of the year. Fecundity and trout density were used together with percentages of sexually mature trout (Nicola 1999; Nicola & Almodóvar 2002) to estimate the egg production of each cohort and the density of the breeding stock, according to Crisp (1994), for seven rivers during the period 1992–1998.

To compare mean values between unexploited and exploited sections, analyses of variance (ANOVA) was used, with subsequent Scheffé tests for comparison of means. Assumptions concerning data distributions were tested using a Shapiro–Wilk test and homogeneity of variances using a Levene test. The significance level for all statistical tests was set at $\alpha = 0.05$.

Results

Current conservation status and management practices

Brown trout is considered as vulnerable in the Spanish Red Data Book (Doadrio 2001). Likewise, this species is considered of 'special concern' in some regions of Spain. However, brown trout is not threatened at the international conservation level. Nowadays, the management of angling activity in Spain is regulated by the regional governments. However, there is great similarity in brown trout management regulations between regional laws (Table 2). At present, there are approximately 490 restricted regulation sections, covering ≈3110 km of river length. Spanish regional legislation also includes almost 1060 closed areas, designed to protect native populations of brown trout stocks by denying access to anglers, thus preserving their genetic uniqueness and their possibilities of reproduction. Additionally, regional governments have gradually included modern angling regulations in their legislation, resulting in about 305 catch and release sections.

Effects of fishery management on wild stocks

Brown trout populations in the rivers studied are short-lived, with a clear dominance of age groups 0+ to 2+ and a maximum longevity between 4 and 5 years. However, the unexploited areas showed a more complex age structure and longer life span than the exploited stocks. The age structure diversity was significantly higher (ANOVA, $F_{1,154} = 6.84$, $P < 0.01$) in the unexploited sections (mean 0.458) compared with exploited ones (mean 0.408). Likewise, significant differences in mean age were noticed between unexploited and exploited sections (ANOVA, $F_{1,154} = 6.84$, $P < 0.01$), with mean values of 1.3 and 1.1, respectively. A common feature of the exploited stocks was the absence of old fish, as harvest is selective towards larger specimens. The average proportion of legal-sized trout was usually low in all the populations (mean 11%) and varied considerably between rivers. There were no significant differences in this parameter according to fishing status (ANOVA, $F_{1,106} = 0.02$, $P > 0.05$), ranging from 2 to 62% in the unexploited sections and from 0 to 55% in the exploited ones.

Overall density, biomass and production of trout changed between 1992 and 1998 in the exploited sections for all the rivers studied (Table 3; Fig. 1).

Table 2. Mean (min–max) of the main management regulations established for the exploited recreational fisheries of brown trout (restricted regulation and open regulation sections) all over Spain. In addition, fishery regulations in the 10 rivers included in our data-set are given (Douro and Tagus river basins). Data are based on the annual regional laws

	Spain		Douro basin		Tagus basin	
	Restricted	Open	Restricted	Open	Restricted	Open
Fishing season (days)	145 (119–175)	145 (119–175)	126	126	146	146
Minimum size limit (cm)	22 (19–25)	21 (19–25)	24	20	24	22
Bag limit (trout day^{-1})	6 (4–10)	6 (3–10)	6	5	6	5
Number of anglers day^{-1}	9 (5–14)	No limit	11	No limit	5	No limit

Table 3. Mean (±SE) population parameters for brown trout in unexploited and exploited sections in the studied rivers from central Spain during the period 1992–1998. The results of the one-way ANOVA tests are given

	Unexploited	Exploited	F	P
Density (trout ha^{-1})	2665.8 ± 173.9	1669.2 ± 118.4	$F_{1,268}$ = 22.19	< 0.001
Biomass (kg ha^{-1})	100.0 ± 5.7	59.5 ± 3.9	$F_{1,268}$ = 33.80	< 0.001
Production (kg ha^{-1} yr^{-1})	92.2 ± 10.2	62.3 ± 5.7	$F_{1,78}$ = 6.84	< 0.05
Turnover ratio (yr^{-1})	1.15 ± 0.05	1.19 ± 0.05	$F_{1,75}$ = 0.17	> 0.05
Density legal-sized trout (trout ha^{-1})	186.2 ± 16.1	86.0 ± 10.4	$F_{1,266}$ = 27.17	< 0.001
Biomass legal-sized trout (kg ha^{-1})	28.5 ± 2.8	12.8 ± 1.8	$F_{1,266}$ = 21.64	< 0.001

There was a significant reduction in these parameters in almost all areas subjected to angling exploitation. Similar results were obtained when the density and biomass of legal-sized trout were analysed (Table 3; Fig. 1). Only the turnover ratio (P/B) did not seem to be affected by harvest (Table 3). Likewise, there was no consistent difference in mean biomass per individual according to fishing status (ANOVA, $F_{1,100} = 2.02$, $P > 0.05$).

Between 1992 and 1998, the breeding stock in the analysed populations showed significant differences (ANOVA, $F_{1,63} = 12.21$, $P < 0.001$) between exploited (mean 541.3 trout ha^{-1}, range 0–2133) and unexploited sections (mean 1065.4 trout ha^{-1}, range 71–2611). Likewise, mean egg production was significantly lower (ANOVA, $F_{1,63} = 14.55$, $P < 0.001$) in the exploited areas (mean 76 013 eggs, range 0–297 971) compared with unexploited ones (mean 151 973 eggs, range 17 092–382 825) (Fig. 2). Further, the contribution of each age-group to the breeding stock and to the total egg production was significantly different between unexploited and exploited sections (two-way ANOVA with age and fishing status as classification factors; breeding stock, interaction age-fishing status: $F_{4,51} = 3.89$, $P < 0.01$; egg production, interaction age-fishing status: $F_{4,51} = 10.82$, $P < 0.001$). Thus, in the exploited areas, trout in their third year (2+) made the greatest contribution to population fecundity (mean 73%) and to the breeding stock (mean 69%), whereas the 3+ group was of minor importance (17% of total fecundity, 10% of breeding stock) and 4+ spawners absent (Fig. 3). In the unexploited areas the contribution of older classes (3+ and 4+) to total egg production (mean 52%) and to the breeding stock (mean 34%) were higher, despite representing only an average of 7% of the population.

The mean length and weight for age of trout showed no significant differences between exploited and unexploited sections within each river (ANOVA, $P > 0.05$), except for the rivers Eresma, Cega and Jarama. In these cases the effect is probably because of the influence of environmental factors on growth (Almodóvar 1999; Nicola 1999; Nicola & Almodóvar, 2004). The mean length for age of brown trout showed a huge variation among the studied rivers. However, the minimum size limit varied within a narrow range (Fig. 4). As a consequence, the mean recruitment age, i.e. the age at which brown trout attain the minimum size limit, ranged between 2+ and 3+. Age at maturity, i.e. the age at which 50% of a cohort is mature, of both males and females in these rivers varies between 1+ and 2+ (Nicola & Almodóvar 2002). Therefore, almost all harvested trout have apparently spawned at least once in their life. However, trout from fast-growing populations potentially have less opportunities for future spawning than trout from slow-growing populations, as a result of a higher fishing-induced adult mortality rate (Fig. 4).

Discussion

The observed decrease in mean age, age diversity and abundance of legal-sized trout seems to be the usual outcome of angling exploitation on brown trout stocks (e.g. Avery & Hunt 1981; Büttiker 1989). Harvest is thus lowering the life span of the exploited populations because of the additional mortality of older individuals selected for by anglers. Braña, Nicieza & Toledo (1992) and Reyes-Gavilán, Garrido, Nicieza, Toledo & Braña (1995) found the same effects of angling on age structure in several mountain streams of northern Spain. Likewise, these authors observed a distinct reduction in the average number of legal-sized trout as angling pressure increased.

Disturbance of the population structure induced by angling can also affect the growth pattern, so that growth is usually favoured by harvest (Healey 1978, 1980; Donald & Alger 1989). However, this was not the case in the present study, where no differences were found in growth parameters. By contrast, Braña *et al.* (1992) found that brown trout exhibited faster growth in some exploited sections of northern Spanish rivers. Accordingly, Healey (1980) observed a

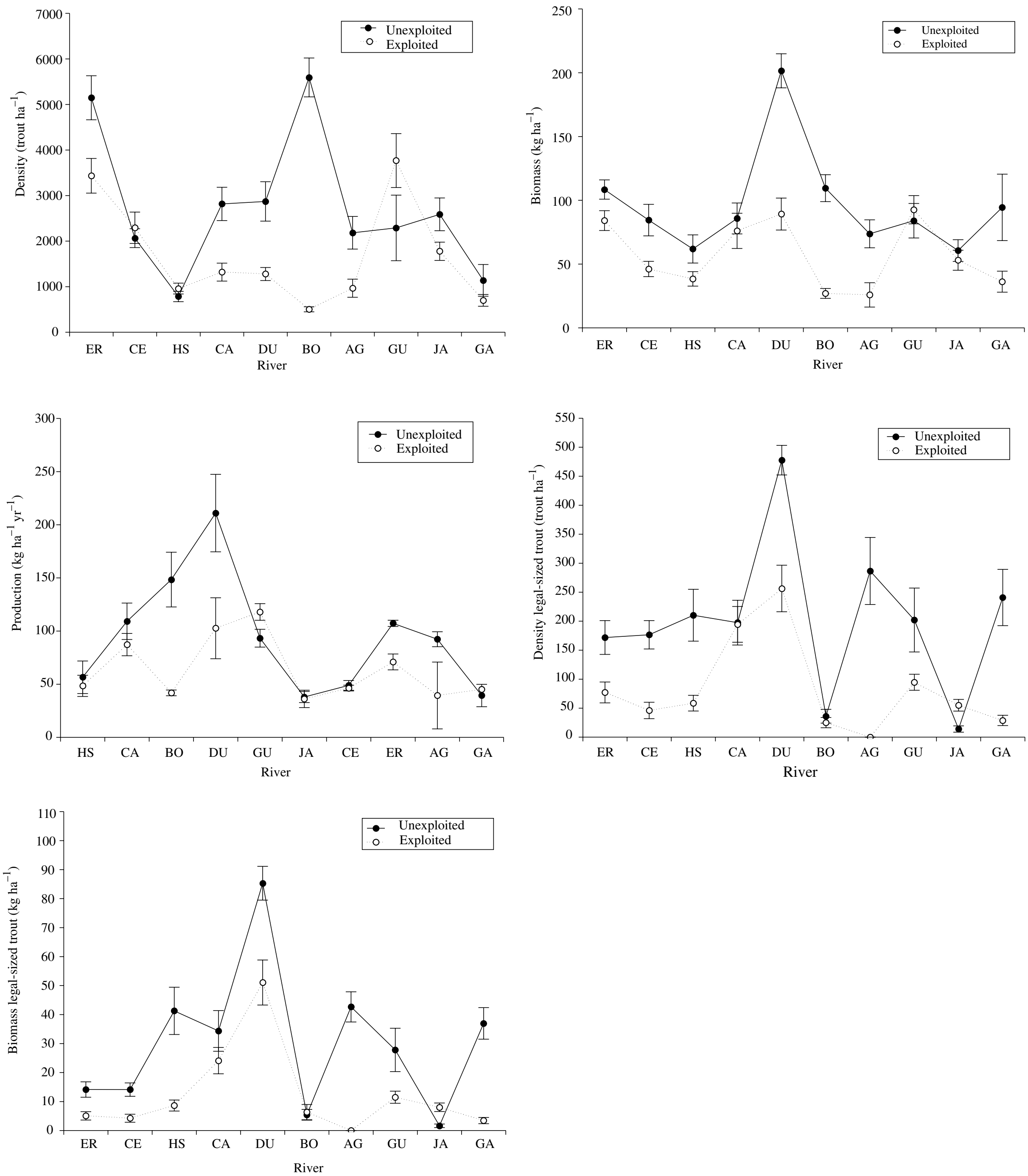

Figure 1. Mean ± SE density, biomass, production, density of legal-sized trout and biomass of legal-sized trout in unexploited and exploited sections of the 10 rivers analysed (River Eresma = ER, R. Cega = CE, R. Hoz Seca = HS, R. Cabrillas = CA, R. Dulce = DU, R. Bornova = BO, R. Aguisejo = AG, R. Guadiela = GU, R. Jarama = JA, R. Gallo = GA).

stimulation of growth in exploited populations of lake whitefish, *Coregonus clupeaformis* (Mitchell), which was proportional to the intensity of exploitation. Several authors found a similar pattern in brown trout *S. trutta* (Jensen 1977), brook trout, *Salvelinus fontinalis* (Mitchill), (Donald & Alger 1989) and Arctic charr, *Salvelinus alpinus* (L.) (Langeland 1986).

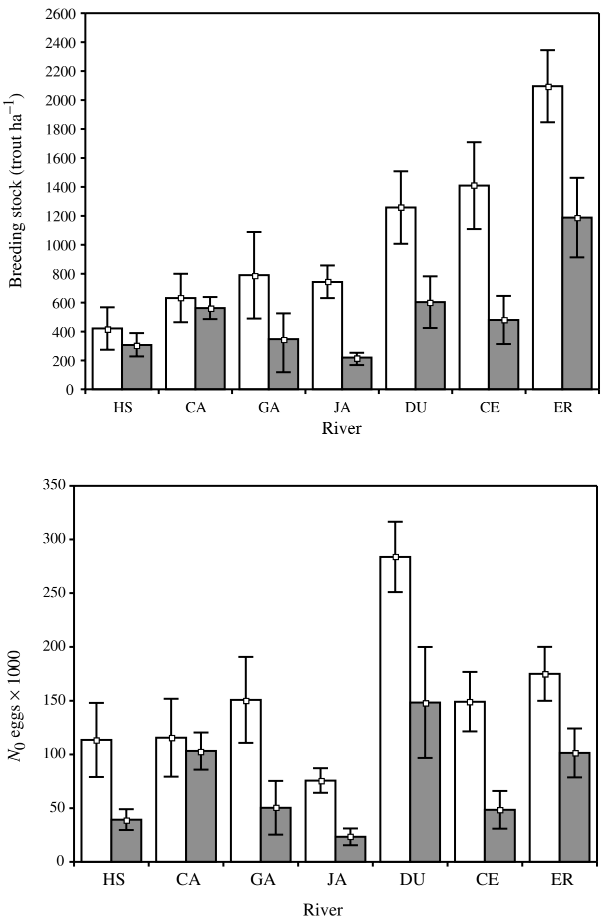

Figure 2. Mean (±SD) breeding stock and total egg production in the exploited (shaded bars) and unexploited (open bars) sections of the studied rivers during the period 1992–1998 (HS = River Hoz Seca, CA = R. Cabrillas, GA = R. Gallo, JA = R. Jarama, DU = R. Dulce, CE = R. Cega and ER = R. Eresma).

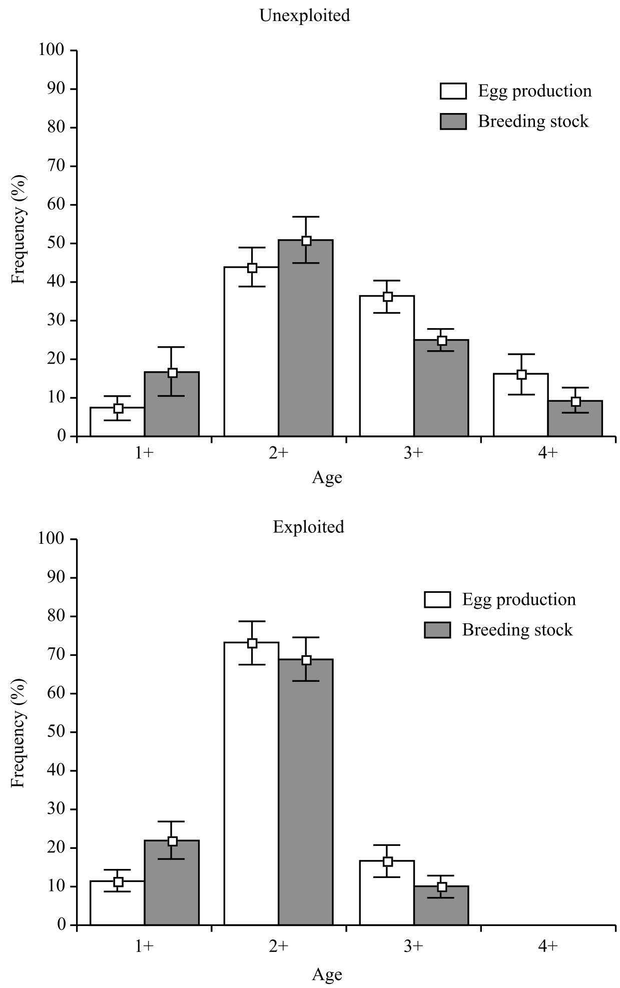

Figure 3. Mean (±SD) contribution of each age-class to breeding stock and to total egg production in unexploited and exploited sections of the studied rivers during the period 1992–1998.

In the studied rivers, the minimum size limit ensures that a great part of the individuals have reproduced at least once before removing them from the water. However, the findings show that fast-growing populations are more susceptible to angling harvest than slow-growing ones. Further, the same pattern was observed all over Spain, where brown trout showed a great variability in growth among rivers, irrespective of their geographical situation (Fig. 2). Thus, the age at which trout attain the minimum size limit was estimated to range between 1+ and 3+, while age at maturity of both males and females varied between 1+ and 2+ (Lobón-Cerviá, Montañés & de Sostoa 1986; García & Braña 1988; Lobón-Cerviá, Utrilla, Rincón & Amezcua 1997; Nicola & Almodóvar 2002). Therefore, current size limit control guarantees the first spawning of trout, but reduces their spawning chances in fast-growing populations because of higher adult mortality by angling. A reduced adult survival seems to select for earlier maturation and increased reproductive effort in exploited fish (Policansky 1993; Reznick 1993; Rochet 1998; Haugen 2000), but this does not seem to be the case in the populations studied.

As a result of concentrating exploitation on the larger trout, the reproductive age-classes seriously declined in the exploited areas. Furthermore, drastic decreases in the breeding stock and overall egg production in the exploited stocks during the 6 years studied were observed (Almodóvar *et al.* 2002). This decrease denotes that mortality produced by excessive angling is seriously depleting the mature stock in the studied rivers. As a consequence, natural recruitment may become insufficient for supporting fisheries.

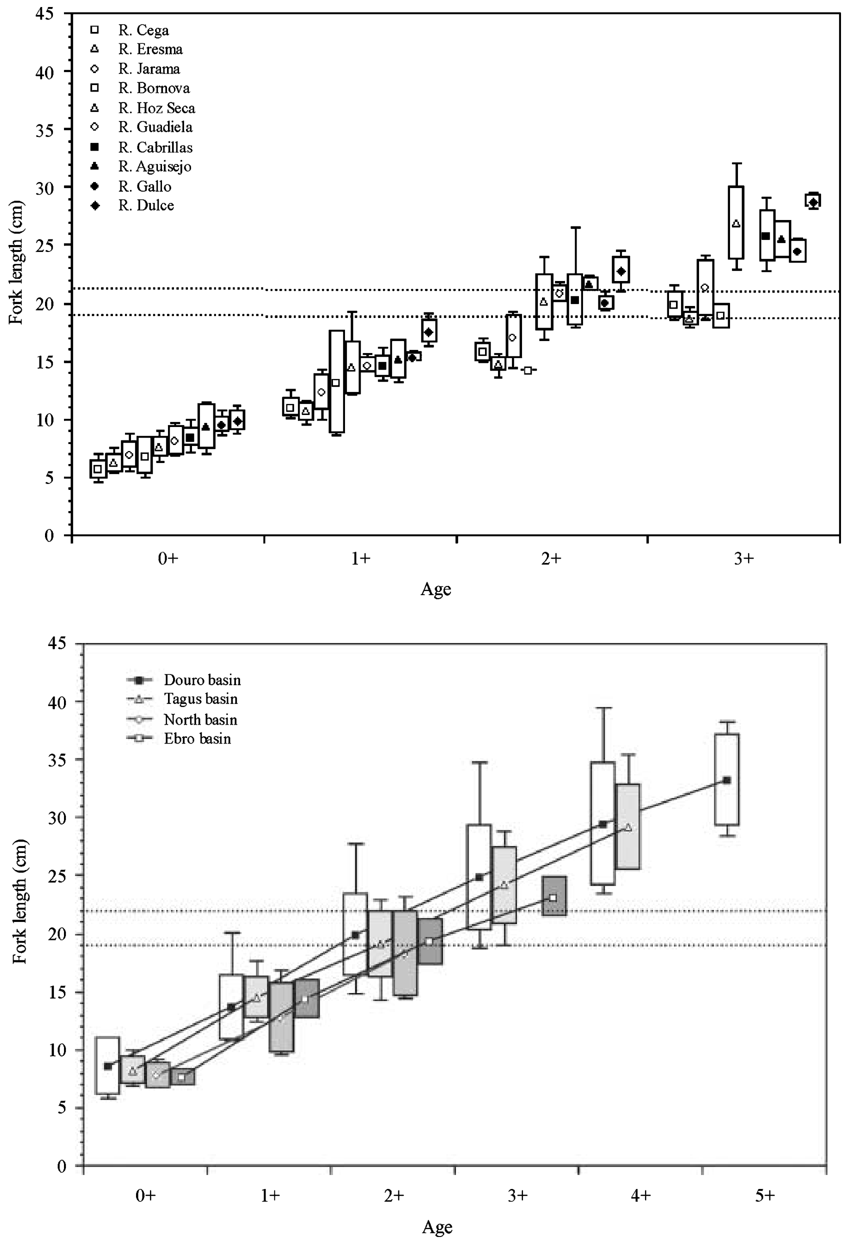

Figure 4. Growth in length (mean ± SD, min–max) of brown trout in the studied rivers (above) and in different river basins of Spain (below). This latter is based on the overall mean lengths for the corresponding studied rivers in each basin (Douro basin: River Ucero[1], R. Avión[1], R. Eresma[2], R. Cega[2], R. Aguisejo[2], R. Pisuerga[3], R. Arlanzón[3], R. Carrión[3], R. Esla[3], R. Cea[3], R. Porma[3], R. Bernesga[3], R. Órbigo[3]; Tagus basin: R. Hoz Seca[2], R. Cabrillas[2], R. Gallo[2], R. Dulce[2], R. Jarama[2], R. Bornova[2], R. Guadiela[2]; North basin: R. Chabatchos[4], R. Castañedo[4], R. La Viella[4], R. Choudral[4], R. Narcea[5]; Ebro basin: R. Gállego[6], R. Escarra[6]). The range of minimum size limit in these rivers found in Spanish legislation is indicated with a dashed line. [1]Lobón-Cerviá *et al.* (1986), [2]Present study, [3]García de Jalón & Serrano (1985), [4]Lobón-Cerviá *et al.* (1997), [5]Braña *et al.* (1992), [6]García de Jalón, *et al.* (1986).

The decline of overall brown trout abundance and production in exploited stocks can be directly attributed to overfishing. Moreover, annual angling exploitation in some of the studied rivers is considered to be dangerous to maintain the populations in a healthy state (Almodóvar *et al.* 2002). These findings agree with Hunt (1981) and Anderson & Nehring (1984) based on exploited populations of brown trout. In contrast, Braña *et al.* (1992) observed no significant differences in trout density between fished and unfished sections in northern Spanish rivers. However, these authors pointed out that the density values from unexploited sections were less variable than those from fished areas. Likewise, Reyes-Gavilán *et al.* (1995) found that the density of legal-sized trout was higher in unfished reaches, but they did not find significant differences in overall density and biomass in relation to the fishing regime. These authors also detected differences in the mean biomass per individual according to fishing status, with higher values in restricted exploitation sections than in open regulation areas. However, this pattern was not observed in the present study.

To sum up, the effects of fishery management on population dynamics, production and life-history features show different patterns among Spanish rivers and seem to depend on the environmental and biological characteristics of the populations. Therefore, fishing regulations should be adapted to the diverse ecological conditions of the populations and should be river-specific. Furthermore, sustainable management of stocks should be urgently considered to avoid the current decline and to achieve a balance between exploitation and conservation. One of the primary objectives for the future should be to avoid scientific knowledge to management, so that regulations are not detrimental to the exploited populations. The implementation of more restrictive harvest regulations, like catch and release or slot size limits (Favro, Kuo & McDonald 1980; Jensen 1981), may prevent overexploitation of stocks, thus maintaining the abundance of large trout and improving the natural recruitment of populations. This analysis suggests that a slight increase in older trout abundance results in a great increment of population fecundity, as female fecundity increases with body size (Nicola & Almodóvar 2002). This may avoid the supplementation of populations with non-native trout, which has caused a negative genetic impact on native stocks throughout Spain (reviewed in Almodóvar *et al.* 2001). As Olver, Shuter & Minns (1995) suggested, the key to conservation is sustainability of naturally reproducing wild stocks of native fish, as these stocks embody thousands of years of evolutionary adaptations to local environments. Therefore, a complete assessment of the contribution of natural recruitment and a better understanding of the carrying capacity of the rivers is required.

Finally, to fix size limits and harvest regulations a long-term monitoring of populations and angling activity is needed. The ultimate objectives should be to test previous mathematical models (García de Jalón 1996) and to develop new ones to integrate existing data and to simulate the response of fish populations to changing management. Quantitative models for inland fisheries are well developed and are widely used to predict how fish populations change when management regulations are altered (e.g. Clark, Alexander & Gowing 1980; Espegren, Miller & Nehring 1990; Quinn, Korver, Hicks, Monroe & Hawkins 1994). However, some authors (Taylor 1981; Schnute & Richards 2001) indicate that these models are usually too complicated to be useful tools to fishery managers, therefore more simplified and realistic models are needed.

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