Chapter 31
Effects of fishery management on populations of brown trout, *Salmo trutta*, in central Spain

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Abstract

Brown trout, *Salmo trutta*, in central Spain is currently threatened by overfishing, habitat destruction and stocking with allochthonous stocks. The effects of angling exploitation were assessed in five rivers between 1992 and 1998 by comparing population and catch statistics within exploited and unexploited areas. The main effects of angling were a decrease in density, biomass and production in the exploited stocks. Likewise, the number of legal-sized trout was <10% of the total populations. Sport fishing parameters showed that fishing pressure was high in the majority of these rivers, resulting in an alteration of population maintenance. A depletion in the breeding stock and egg production was also observed in the exploited sections. Moreover, the stocking of allochthonous stocks caused a significant decrease of the original intraspecific variability. Two-thirds of populations analysed showed genetic introgression and gene flow between native and allochthonous strains. A summary of conservation guidelines are proposed in relation to particular threats.

Keywords: angling impact, conservation, genetic introgression, management, *Salmo trutta*.

31.1 Introduction

Brown trout, *Salmo trutta* L., is one of the most genetically sub-structured vertebrate species, and several genetic studies suggest that a large part of the evolutionary diversity corresponds to southern European countries bordering the Mediterranean (Allendorf & Leary 1988; Ferguson 1989). In Spain, this species is an important economic and social resource, which provides valuable sport fisheries. Brown trout is considered as 'vulnerable', in the Spanish and Portuguese Red Books of Vertebrates. Likewise, this species is considered of 'Special Concern' in some regions of Spain. However, the brown trout is not threatened at the international conservation level. On the other hand, the high genetic diversity and fragmentation of brown trout populations in central Spain requires management at the population level. In central Spain, brown trout is threatened by habitat destruction, water pollution and introduction of exotic species (Elvira 1996). Flow modification is one of the most widespread human disturbances in the headwaters of Spanish rivers, and an important cause of the decline of

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central populations (Almodóvar & Nicola 1999). Additionally, the Spanish populations are currently overexploited (Braña, Nicieza & Toledo 1992; Reyes-Gavilán, Garrido, Nicieza, Toledo & Braña 1995; Almodóvar & Nicola 1998) and their genetic diversity is threatened by stocking with non-native trout from central and northern Europe (García-Marín, Jorde, Ryman, Utter & Pla 1991; Morán, Pendás, García-Vázquez, Izquierdo & Lobón-Cerviá 1995; García-Marín & Pla 1996; Cagigas, Vázquez, Blanco & Sánchez 1999; Machordom, García-Marín, Sanz, Almodóvar & Pla 1999; Machordom, Suárez, Almodóvar & Bautista 2000). In this study, the current impacts on brown trout populations in central Spain are assessed. The primary objective was to evaluate the effects of sport fishing on population structure and production. Additionally the genetic impact of stocking with allochthonous stocks on local populations was determined. Finally, some proposals for conservation and management are given.

31.2 Materials and methods

31.2.1 *Sport fishing and trout populations*

This study was carried out on five rivers, which are tributaries to the River Tagus (Hoz Seca, Cabrillas, Gallo, Dulce and Jarama) (Fig. 31.1). These are non-polluted streams and brown trout is the dominant species throughout the study area. The crystalline River Jarama originates at elevations close to 1200 m above sea level. The rest of the rivers flow through limestone catchments at elevations from 900 to 1400 m above sea

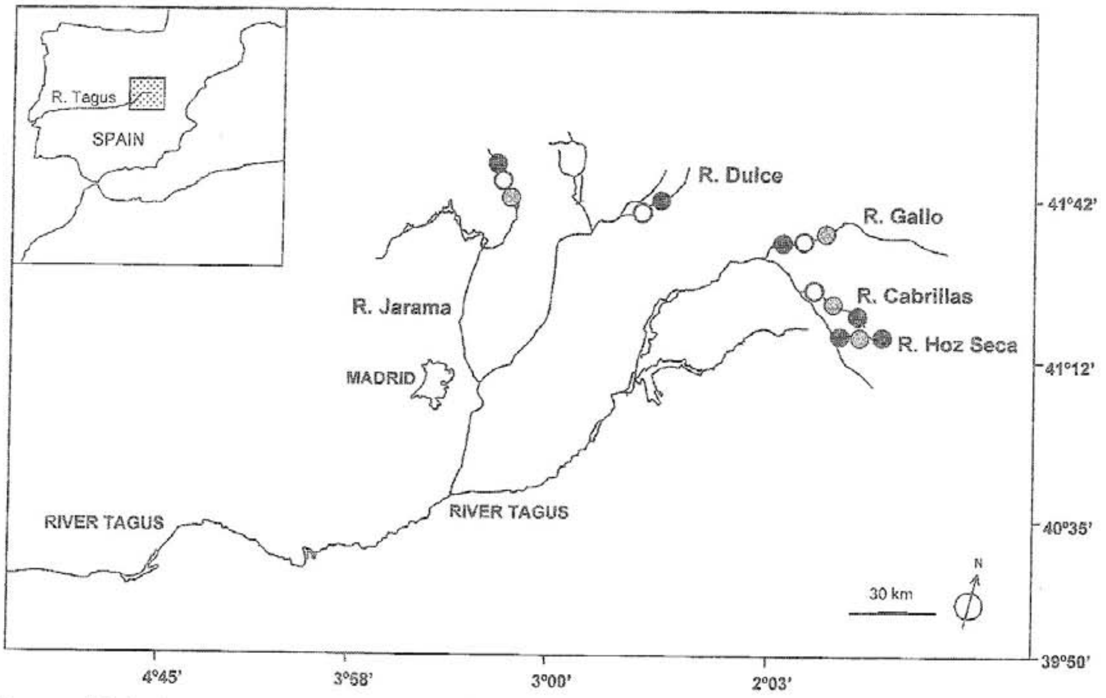

Figure 31.1 Map of the study area showing sampling sites in the studied rivers (black, preserved, catch and release; grey, restricted regulation; white, open regulation)

level. Two or three sampling sites were selected in each river with enough distance between them to avoid any migration, to be quite homogeneous with respect to habitat structure and to cover different angling regulations.

The sampling sites included exploited and unexploited sections, with four different angling regulations concerning daily bag limit, number of anglers per day and type of gears:

- preserved sections: unexploited, fishing activities are forbidden;
- catch and release sections: unexploited, no limitation in number of anglers per day, fly-fishing only;
- restricted regulation sections: exploited, daily bag limit of five trout, four to six anglers per day, only artificial lures permitted;
- open regulation sections: exploited, daily bag limit of six trout, no limitation in number of anglers per day, only artificial lures permitted.

During the 1996 and 1997 fishing seasons (March–August) a creel-survey was conducted to determine the use of the fishery and to evaluate angler impacts. A total of 415 anglers were surveyed. Fishing pressure was estimated by the number of anglers per hectare per year and the number of hours fished per hectare per year. Harvest rate was calculated as the mean number of trout kept per hectare per year. Exploitation rate was determined considering the biomass of legal-sized trout and the total harvest during the fishing season. A Kruskal–Wallis analysis of variance was applied to compare these parameters among rivers. Multiple comparisons were carried out using Dunn's procedure (Zar 1999).

Fish were sampled every third month from 1992 to 1998 at 14 localities by electric fishing. Trout were anaesthetised with tricaine methane-sulphonate (MS-222 SANDOZ) and their fork length (nearest mm) and weight (nearest g) were measured. Scales were taken for age determination. Fish density (trout ha^{-1}) was estimated by applying the removal method (Zippin 1956). Biomass ($kg\,ha^{-1}$) was calculated following Mahon, Balon and Noakes (1979). Production ($kg\,ha^{-1}\,year^{-1}$) was estimated using the increment summation method from Newman and Martin (1983). Measures of variance were computed according to Newman and Martin (1983). Fecundity and density values were used in conjunction with percentages of sexually mature trout (Nicola & Almodovar, in press) to compute the egg output of each cohort and the density of the breeding stock during each year (Crisp 1994). One-way ANOVA was used to compare mean values between unexploited and exploited sections. 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 $\alpha = 0.05$.

31.2.2 *Genetic introgression*

Estimates of genetic introgression in five Spanish rivers were determined to assess the effect of stocking on native populations. In addition, published data from six populations from central Spain (Machordom *et al.* 1999) are presented. Introgression of allochthonous genes was estimated using the diagnostic *LDH-5** locus. The *LDH-5*90* allele at this locus is routinely used in southern European regions to identify the presence of commercial strains of hatchery-reared fish (García-Marín *et al.* 1991). Hardy–Weinberg (H–W) equilibrium was tested and an exact-test was employed to analyse heterozygote deficiency (Rousset & Raymond 1995) using GENEPOP v. 3.2a.

31.3 Results

The mean number of anglers (fishing pressure measured as number of fishing hours) did not differ significantly ($P > 0.05$) between the rivers studied (Table 31.1). However, despite the harvest rate being similar among the different rivers, the exploitation rate was significantly different ($\chi^2 = 22.30$, $P < 0.001$).

The age structure was significantly different between harvested trout and the legal-sized stock in nearly all the studied rivers (Fig. 31.2), with harvest being size selective towards on the larger specimens. Age 3+ brown trout made up 45.9 ± 24.6% of the harvest, but 56.5 ± 16.2% of the populations. Age 4+ accounted for 40.0 ± 17.0% of the harvest and a similar proportion in the populations (38.5 ± 13.6). Ages 5+ onwards accounted for the remaining annual harvest. The 2+ trout were not harvested, probably due to the late recruitment of this age class into the legal-sized stock during the fishing season. The length of the harvested trout was also significantly different among rivers, but a subsequent comparison of means revealed that the differences were due to the lower values found in rivers Dulce and Jarama, which were significantly different from the rest (Dunn test, $P < 0.05$). The scarcity of large trout in the River Dulce suggests that angling may remove large numbers of fish before they have the opportunity to grow to a large size, because the growth in this river is the highest within the study area (unpublished data). Overexploitation of the largest trout had a direct consequence on the reproduction in these rivers. The breeding stock showed significant differences ($F_{1,43} = 7.23$, $P < 0.05$) between exploited (401.5 trout ha^{-1}) and unexploited sections (745.9 trout ha^{-1}). Likewise, mean egg production was significantly lower ($F_{1,43} = 5.23$, $P < 0.05$) in exploited areas (148 518 eggs) compared with unexploited ones (276 677 eggs). This negative effect of angling on reproduction was

Table 31.1 Estimated means and ranges of sport fishery statistics at the five rivers studied

River	No. of anglers ($ha^{-1} year^{-1}$)	Fishing hours ($ha^{-1} year^{-1}$)	Harvest ($ha^{-1} year^{-1}$)	Harvest length (cm)	Exploitation rate (%)
Hoz Seca	7.7 (4.6–23.0)	19.0 (1.2–36.9)	4.6 (0–27.6)	26.7 (24.0–35.0)	19.7
Cabrillas	24.4 (7.1–63.5)	86.6 (3.0–241.5)	12.8 (0–42.3)	26.5 (22.0–42.0)	11.0
Gallo	26.0 (9.3–101.8)	84.2 (2.3–419.4)	18.8 (0–101.8)	26.7 (22.0–46.0)	19.0
Dulce	19.6 (7.6–114.6)	50.8 (7.6–120.3)	9.5 (0–84.0)	23.9 (22.0–32.0)	8.3
Jarama	20.1 (9.8–88.3)	77.6 (5.7–496.6)	13.4 (0–68.7)	25.4 (22.0–40.5)	34.3
	$H_{4,162} = 17.22$**	$H_{4,157} = 8.87$ n.s.	$H_{4,162} = 6.75$ n.s.	$H_{4,265} = 13.37$**	

The results of the Kruskal–Wallis test are given (** = $P < 0.01$, n.s. = non-significant).

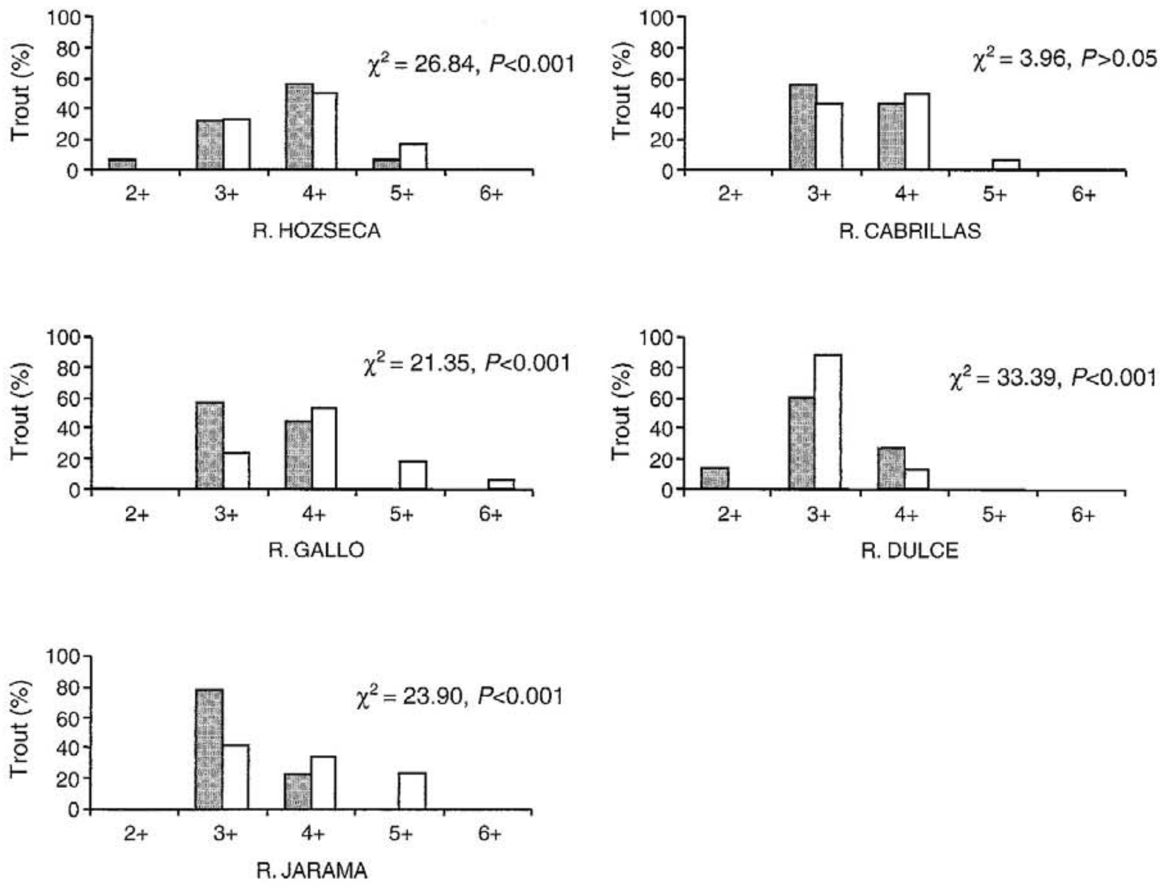

Figure 31.2 Per cent angler harvest by age group (creel-surveys, white) and age distribution of legal-sized trout (sampling, grey) in the five rivers studied. The results of the chi-square test are given

also evident when comparing the change in the breeding stock and egg production during the study period. A marked reduction of these characteristics was observed in the exploited areas throughout the 5-year study.

Angling pressure and overexploitation contributed to a serious decline of brown trout abundance in the exploited sections (Table 31.2). In addition, production was considerably lower in the exploited areas. Only the turnover ratio did not show any consistent differences. The density and biomass of legal-sized trout in all the study rivers were low, averaging about 10% of the total population in each river, with the lowest values in exploited areas.

Stocking with allochthonous strains has disrupted the original genetic integrity of wild trout populations in central Spain. The analysis of the *LDH-5** locus in the studied populations revealed four different electromorphs. Three of them (*LDH-5*85, LDH-5*100* and *LDH-5*110*) indicate native trout, while *LDH-5*90* was fixed in all stocked trout. Only five populations did not exhibit genetic contamination, while 10 had some frequency of the non-native allele *LDH-5*90* (Table 31.3). Most of the introgressed populations did not show significant deviations from H–W equilibrium. Only the River Cega (Navafría) displayed a significant heterozygote deficiency.

Table 31.2 Mean (± s.e.) population statistics for brown trout in unexploited and exploited sections in the studied rivers

	Unexploited	Exploited		Probability
Density (trout ha^{-1})	2099.0 ± 188.5	1234.4 ± 85.9	$F_{1,162} = 17.42$	<0.001
Biomass (kg ha^{-1})	104.3 ± 8.8	61.0 ± 5.4	$F_{1,162} = 17.61$	<0.001
Production (kg ha^{-1} $year^{-1}$)	96.0 ± 16.5	62.5 ± 7.6	$F_{1,48} = 3.92$	<0.05
Turnover ratio ($year^{-1}$)	1.2 ± 0.1	1.1 ± 0.1	$F_{1,48} = 0.09$	>0.05
Density legal-sized trout (trout ha^{-1})	236.0 ± 25.3	128.4 ± 17.1	$F_{1,138} = 12.45$	<0.001
Biomass legal-sized trout (trout ha^{-1})	41.9 ± 4.6	20.9 ± 3.1	$F_{1,138} = 14.39$	<0.001

The results of the one-way ANOVA tests are given.

Table 31.3 Introgression frequencies for the diagnostic *LDH-5** locus from the studied populations

Sampling sites	*n*	Basin	*LDH-5*90*	H–W
Cega (Los Chorros)	19	Duero	0.000	–
Cega (Navafría)	19	Duero	0.053	$P < 0.05$
Hoz Seca (Peralejos)	20	Tagus	0.000	–
Hoz Seca (Orea)	20	Tagus	0.050	n.s.
Cabrillas (Checa)	20	Tagus	0.000	–
Cabrillas (Taravilla)	22	Tagus	0.045	n.s.
Gallo	20	Tagus	0.075	n.s.
Jarama (Hayedo)	20	Tagus	0.000	–
Jarama (Hiruela)	24	Tagus	0.000	–
[a]Eresma (Casa de Peñón)	25	Duero	0.020	n.s.
[a]Eresma (Boca del Asno)	20	Duero	0.025	n.s.
[a]Aguisejo	19	Duero	0.211	n.s.
[a]Dulce	20	Tagus	0.100	n.s.
[a]Bornova	17	Tagus	0.059	n.s.
[a]Guadiela	19	Tagus	0.237	n.s.

Goodness-of-fit of the observed introgression frequency values to the H–W equilibrium are given (n.s.=non-significant). [a]Data from Machordom *et al.* (1999).

31.4 Discussion

The fishing pressure observed in the different rivers studied was comparable to that found in other brown trout populations (Wiley & Dufek 1980; Avery 1990; Hunt 1991, review). The harvest and exploitation rates were analogous to those described by Wiley and Dufek (1980), Avery and Hunt (1981) and Avery (1990), who found mean values between 18% and 37%. Avery (1990) suggested that the annual angler exploitation of trout should not exceed 40% of the legal-sized fish if the population is to remain healthy. Therefore, the high rate found in the River Jarama suggests an overexploitation of this population, which was more evident when analysing the present breeding stock.

The decrease in the breeding stock and total egg production observed over the study period denotes that angling harvest is depleting the mature stock in the studied rivers. If this trend continues, the number of parent cohorts would not be sufficient to ensure full utilisation of the available spawning and juvenile habitat.

Angling exploitation was found to be responsible for the lower values in abundance parameters observed in the exploited sections. This finding agrees with Anderson and Nehring (1984) who found that fish abundance in exploited areas was comparatively lower than the unexploited ones in a Colorado river. In contrast, Braña *et al.* (1992) observed no apparent changes in abundance between fished and unfished sections in northern Spanish rivers. Angling effects seem to show different patterns among areas and thus fishing regulations should be adapted to the diverse ecological conditions of the populations.

The genetic introgression by allochthonous genes of hatchery origin occurred in 67% of the analysed populations. Most of the introgressed populations were at H–W equilibrium, which suggests that gene flow between non-native and wild stocks exists. The lack of *LDH-5*90/100* heterozygotes observed in the River Cega could imply a very low survival of hatchery fish (Morán, Pendás, García-Vázquez & Izquierdo 1991; Martínez, Arias, Castro & Sánchez 1993) or strong assortive mating between hatchery and wild stocks in this population.

31.4.1 *Conservation and management proposals*

Overexploitation and stocking with allochthonous trout have become so great in some rivers that urgent conservation measures are needed. Guidelines for the conservation and management of central Spain brown trout populations are needed and these should include the following elements:

(1) The implementation of more restrictive harvest regulations, like catch and release or slot limits (harvest of fish between two specified lengths, Favro, Kuo & McDonald 1980; Jensen 1981), are recommended. Catch and release seems to be effective in maintaining the abundance of large trout within the fishery (Anderson & Nehring 1984; Hunt 1991; Almodóvar & Nicola 1998). Slot limits also reduce the harvest of larger trout (Power & Power 1996), which would contribute to higher fecundity and presumably increases in the number and quality of recruits.

(2) The use of creel-surveys should be encouraged, since they proved to be an essential tool to evaluate fishing pressure and harvest. Although this type of information is invaluable for effective management of populations, its application in Spanish rivers is still rare.

(3) A research-management cooperation is needed to achieve a more comprehensive approach to the conservation of trout populations. Harvest regulations should be focused on biological data gained from long-term monitoring.

(4) Management actions should not imply losing or disrupting genetic diversity, as such effects are irreversible. Therefore, stocking with allochthonous strains should be avoided. When populations must be stocked it is best to use material from the population itself.
(5) Conservation and management efforts should be centred on the genetic differences among populations within the species, as proposed by Machordom *et al.* (2000) for some Spanish rivers.

Acknowledgements

This study was supported by the Spanish INIA under Project SC-95/005 and a post-graduate fellowship (to J.S.). Dr B. Elvira provided intellectual stimulus, thoughtful advice, and helpful review of the manuscript. We are especially indebted to Dr A. Machordom for her contribution to genetic analyses. We are most grateful to the regional Environmental Agencies who have permitted populations studies to be conducted over many years.

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Conservation of Freshwater Fishes: Options for the Future

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Iowa State University Press
A Blackwell Science Company
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First published 2002

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A catalogue record for this title
is available from the British Library

ISBN 0-85238-286-3

Library of Congress
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