Knowledge and Management of Aquatic Ecosystems (2010) 399, 02 http://www.kmae-journal.org

DOI: 10.1051/kmae/2010030

Population size structure indices and growth standards for *Salmo (trutta) trutta* Linnaeus, 1758 in Central Italy

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Received March 29, 2010 / Reçu le 29 mars 2010
Revised July 28, 2010 / Révisé le 28 juillet 2010
Accepted August 2, 2010 / Accepté le 2 août 2010

ABSTRACT

Key-words: *growth, von Bertalanffy model, population structure, proportional stock density, trout, Water-Framework Directive*

The purpose of this study was to provide reference data on the growth and population structure of brown trout *Salmo* (*trutta*) *trutta* Linnaeus, in Central Italy. Standards for growth (percentiles and a standard growth model) were developed from the von Bertalanffy growth model by using length-at-age data obtained from 122 sampling sites in the River Tiber basin. Length-frequency indices provide a numeric estimation for deviations of the population structure from a balanced population. We adapted the traditional North American *Relative Stock Density* (RSD) and *Proportional Stock Density* (PSD) indices to brown trout populations in Central Italy by means of two methods. In the first method, the benchmarks of length categories were established by using percentages applied to the largest individual in the dataset. In the second method, asymptotic length and size at maturity were used to define the length categories for index calculation. Both methods were tested on length-frequency data from 263 sampling sites in the River Tiber basin. The results showed that the PSD calculated by the first method provided a better insight into the population structures of brown trout.

These results provide tools that will help ichthyologists and fish managers to compare the growth and population structure of brown trout throughout Central Italy.

RÉSUMÉ

Indices de structure en taille de populations et critères de croissance pour *Salmo (trutta) trutta* Linnaeus, 1758 en Italie Centrale

Mots-clés : *croissance, modèle de von Bertalanffy, structure de population, proportional stock density, truite,*

Le but de cette étude a été de fournir des données de référence sur la croissance et la structure de population de la truite brune *Salmo* (*trutta*) *trutta* Linnaeus, en Italie Centrale. Des critères de croissance (percentiles et un modèle de croissance standard) ont été développés à partir du modèle de croissance de von Bertalanffy en utilisant les données taille-âge obtenues à partir de 122 sites échantillonnés dans le bassin de la rivière Tibre.

Les indices taille-fréquence fournissent une estimation numérique des écarts de la structure d'une population par rapport à une population équilibrée. Nous avons adapté les indices traditionnels nord-américains *Relative Stock Density* (RSD) et *Proportional Stock Density* (PSD) aux populations de truite brune en Italie Centrale selon deux méthodes. Dans la première méthode, les références des catégories

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de longueur ont été établies par des pourcentages appliqués par rapport à la longueur maximale du jeu de données. Dans la seconde méthode, la longueur asymptotique et la taille de première maturité ont été utilisées pour définir les catégories de longueur du calcul d'indice. Les deux méthodes ont été testées sur les données de fréquences de longueur des 263 sites échantillonnés dans le bassin de la rivière Tibre. Les résultats montrent que le PSD calculé par la première méthode fournit une meilleure appréciation des structures de populations de truite brune.
Ces résultats constituent un outil qui peut aider les ichtyologistes et les gestionnaires de pêcheries à comparer la croissance et la structure des populations de truite brune en Italie Centrale.

INTRODUCTION

Evaluation of the characteristics of a fish population often involves making comparisons with standard reference conditions or between different localities. A variety of indices have been developed for this purpose. The availability of standardised methods of comparing the characteristics of different fish populations increases communication among ichthyologists, improves the efficiency of data analysis and provides information to support management intervention (Jackson *et al*., 2008). In most fish population evaluations, length-frequency distributions are used to assess the size structure. However, these can often be difficult to interpret because there are few standards by which to assess whether the length-frequency is optimal or expected for a given situation. The most common means of summarising length-frequency distributions is to use a length-structure index. One of the first attempts to evaluate the quality of the structure of fish populations by means of length-frequency data was made by Anderson (1976), who introduced the concept of *Proportional Stock Density* (PSD). PSD is the percentage of stock-length fish that are also longer than the quality length; fish of stock length have little recreational value, while quality length is the minimum size of specimens that most anglers like to catch.

The main criticism levelled against PSD is that it compresses the entire distribution of the lengths of a fish population into a single number, thereby engendering a probable loss of information (Gabelhouse, 1984). Another index (*Relative Stock Density*) was therefore developed; this is based on five length categories and enables the population structure to be evaluated in greater detail (Gabelhouse, 1984).

The European "Water Framework Directive" (EU-WFD) (EU, 2000) was adopted in December 2000 to protect and improve the quality of all surface water resources. Its main target is to achieve a minimum 'good ecological status' in all waterbodies. The WFD distinguishes five different ecological classes, which are defined on the basis of a wide array of biotic variables, including the composition, abundance and population structure of fish communities. The ecological state of a waterbody is defined in relation to its deviation from the reference condition. In accordance with the WFD, the Lake Fish Index (Volta and Oggioni, to appear) has been proposed for the assessment of the ecological status of the Italian lakes. In this multimetric index, Proportional Stock Density is used to evaluate the quality of the structure of fish populations. Although both PSD and RSD are frequently used in North America, they are only rarely used in Europe. For this reason, with regard to Italian brown trout populations, the thresholds that define the length categories needed to calculate these indices are not as yet available in the literature.

In this context, the aim of the present study was to define the length categories necessary in order to calculate the PSD of brown trout *Salmo* (*trutta*) *trutta* Linnaeus, 1758 in Central Italy.

Growth is one of the most frequently studied characteristics of fish, since it is a good indicator of the health of both individual specimens and whole populations. The growth analysis of a fish population is particularly important because it provides an integrated evaluation of the environmental and endogenous conditions that act on the fish (Kocovsky and Carline, 2001). Thus, drawing up standard reference criteria enables an objective judgement to be made on the growth quality of a population. Such criteria also constitute a valid means of assessing the appropriateness of the choices made by those responsible for the management of fish resources. Although there are numerous fish populations for which the length-age relationship of the specimens has been defined, few techniques enable the growth rates of different populations to be judged and compared (Hubert, 1999). One of the first attempts to construct reference curves to describe growth was made by Hickley and Dexter (1979), who utilised length and age data; these curves provided the reference lengths at each age of some British fish species. Casselman and Crossman (1986) used the von Bertalanffy growth model to estimate the reference lengths-at-age for *Esox masquinongy* Mitchill, while for *Ictalurus punctatus* (Rafinesque) Hubert (1999) used the percentile values of mean length-at-age of 102 North American populations. Similar methods were adopted by Quist *et al*. (2003) to develop the standard percentiles for *Sander vitreus* (Mitchill) and by Jackson and Hurley (2005) for *Pomoxis annularis* Rafinesque and *P. nigromaculatis* (Lesueur) in North America.

Angling for brown trout is one of the most important and popular recreational fishing activities in Italian rivers. Knowledge of population dynamics, growth and production is essential for the conservation and effective management of brown trout stocks. Therefore, a further objective of this research was to provide a reference model for this species in order to evaluate the growth quality of a given population.

MATERIALS AND METHODS

The River Tiber is the third-longest river in Italy, rising on Mount Fumaiolo (about 1270 m a.s.l.) in the Apennine mountains in Emilia-Romagna and flowing 406 km through Umbria and Lazio to the Tyrrhenian Sea. The basin, the second-largest Italian catchment, is surrounded by two major mountain chains (Appennino Umbro-Marchigiano and Appennino Tosco-Laziale) and lies in seven administrative regions (Lazio, Umbria, Toscana, Marche, Emilia-Romagna, Abruzzo and Molise); it stretches over more than 17 000 km^2, with an average elevation of 524 m. The study, which was conducted between 1992 and 2008, examined the upper and middle portions of the River Tiber. The study area was located in the regions of Umbria, Tuscany and Lazio, from the source of the Tiber to its confluence with the River Aniene. The study area included numerous tributaries, the most important ones being the River Nestore (watershed = 1033 km^2), the River Paglia (1338 km^2), the River Chiascio (5963 km^2) and the River Nera (4280 km^2). A total of 32 streams and rivers were included in the study (Figure 1). Most of the sampling sites investigated are situated in the mountainous stretches of the water courses and all are defined as trout zones according to Huet (1962); the sampling sites are located at a mean elevation of 427 m a.s.l., 26 km downstream of the source and receive water from a drainage area of approximately 203 km^2 (on average). Water discharge averages 9 m^3·s^{-1}, mean stream width is 7 m and mean water depth is 40 cm. Detailed physico-chemical and morphological characteristics of the streams studied are reported in Appendix 1 (available online). More detailed information on the characteristics of the River Tiber basin and its fish populations is available in Lorenzoni *et al*. (2006).

To generate reference growth data for brown trout, length-at-age data were collected from 122 sampling sites for a total of 29 519 specimens. Trout were captured by means of electrofishing with electric stunning devices of different powers, according to the features of the stretch of water involved; during the sampling of each population, the specimens caught were measured [total length, TL (cm) (± 0.1 cm)] (Anderson and Neumann, 1996) and scale samples for age determination were taken from the body area, as described by Devries and Frie (1996). When large numbers of specimens were sampled, scales were only collected from a subsample per 1-cm length increment. Age determination by means of scale analysis was confirmed and integrated by applying Petersen's length-frequency method (Bagenal and Tesch, 1978).

To transform age and length data into growth curves, we used the von Bertalanffy (1938) growth model:

$$TL_t = L_\infty \left\{ 1 - e^{[-k(t-t_0)]} \right\}$$

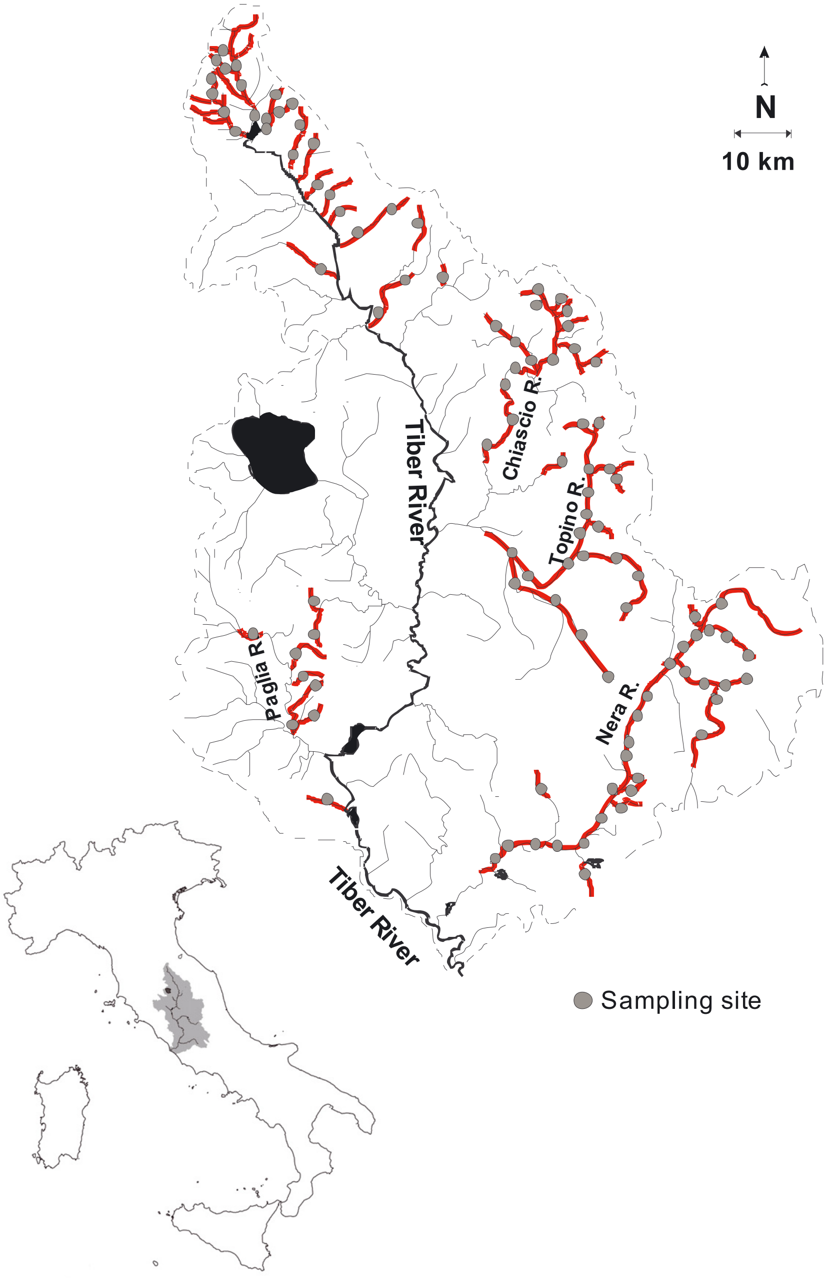

Figure 1
Study area. The brown trout distribution (river areas highlighted in red) and the sampling sites (grey dots) are reported.

Figure 1
Zone d'étude. La distribution de la truite brune (parties de rivière en rouge) et les sites d'échantillonnage (points gris) sont figurés.

where TL_t is the theoretical total length (in cm) at age t, k is the rate at which the asymptotic length L_∞ is approached, and t_0 is the theoretical age (in years) at which the length of the specimen is zero. The index of growth performance phi-prime ϕ' was calculated by means of the equation of Pauly and Munro (1984) $\phi' = \log_{10}(k) + 2\log_{10}(L_\infty)$, where k and L_∞ are the von Bertalanffy growth parameters; this index facilitates intra- and inter-species comparison of growth performance (Pauly and Munro, 1984).

For each sampling site, the von Bertalanffy growth parameters were calculated by using the mean length-at-age. These parameters enabled the predicted age-specific length to be produced for each sample. However, we truncated the dataset to include only the 1–10 age classes, as few sampling sites contained specimens older than 10 years (Jonsson *et al*., 1999). A number of brown trout populations do not have asymptotic growth trajectories; therefore, the L_∞ and k parameters calculated by means of this equation may be unrealistic (Živkov *et al*., 1999). To ensure that our analyses were not skewed by such data, we excluded populations with L_∞ greater than 50% larger than the maximum length observed in each population.

The reference growth data were computed from the distribution of calculated length-at-age, according to Britton (2007): all lengths at each age were collated and split by percentiles. Estimated percentiles of length-at-age included the 10th, 30th, 50th, 70th and 90th. A von Bertalanffy growth standard curve was estimated for each percentile. The growth of a population is deemed to be very poor if the lengths-at-age of its specimens are below the curve of the 10th percentile; poor if they fall between the 10th and 30th percentiles; normal if they are between the 30th and the 70th; good if they are between the 70th and the 90th, and very good if they exceed the 90th percentile. The values representing the expected length-at-age were based on the 50th percentile.

To develop standards for evaluating population size structure, *Relative Stock Density* (RSD) (Gabelhouse, 1984) and *Proportional Stock Density* (PSD) (Anderson, 1976) were calculated as follows:

RSD = (number of fish ≥ minimum specified length/number of fish ≥ minimum stock length) × 100

PSD = (number of fish ≥ minimum quality length/number of fish ≥ minimum stock length) × 100

where specified lengths are the length categories “quality”, “preferred”, “memorable” and “trophy”.

Length categories were determined by means of two different approaches. Gabelhouse (1984) suggested that minimum stock, quality, preferred, memorable and trophy lengths can be calculated from lengths ranging from 20–26%, 36–41%, 54–55%, 59–64% and 74–80% of the world-record length, respectively. According to Gabelhouse (1984), the world-record length for brown trout is ≈ 100 cm; however, to calculate length classes, we used a more realistic maximum length of 60 cm, the largest fish in our dataset (Milewski and Brown, 1994; Zick *et al*., 2007). The adapted PSD and RSD for brown trout in this study were therefore calculated on the basis of a maximum length of 60 cm and a minimum threshold of the arithmetic mean for each of five categories (Zick *et al*., 2007) (method 1).

The mean length at which fish of a given population reach sexual maturity is an important biological parameter for their management (Jennings *et al*., 1998). Froese and Binohlan (2000) observed that the age at first maturity is primarily a function of size. On the basis of this criterion, and according to Gassner *et al*. (2003), two specific thresholds were defined in the second approach:

$L_\infty mean$: expressed as the mean of the values of L_∞ of the 122 sampling sites analysed in order to draw up the standard growth model;

Length at maturity (Lm)*:* calculated from L_∞ mean by applying the equation $\log_{10} Lm = 0.8979 \log_{10} L_\infty - 0.0782$ (Froese and Binohlan, 2000).

On the basis of these thresholds, the length classes were defined as follows (Gassner *et al*., 2003) (method 2):

Stock (S) = $Q - ((T - Q)/3)$

Quality (Q) = Lm

Preferred (P) = $Q + ((T - Q)/3)$

Memorable (M) = $Q(((T - Q)/3)2)$

Trophy (T) = 80% of the $L_\infty mean$.

To date, no validated target values for balanced brown trout populations are available for RSD-Preferred, RSD-Memorable and RSD-Trophy. For this reason, both methods were tested

Table I
Descriptive statistics of the parameters of the von Bertalanffy equation calculated on 122 sampling sites.

Tableau I
Satistiques descriptives des paramètres de l'équation de von Bertalanffy calculés sur les 122 sites échantillonnés.

	Mean	Median	Minimum	Maximum	Std. Dev.
***k* (yr – 1)**	0.23	0.20	0.07	0.63	0.11
L_∞ (cm)	44.72	42.71	23.02	89.47	12.98
t_0 (yr)	–0.53	–0.57	–1.56	0.67	0.37

on the length classes for the PSD (RSD-Quality) using brown trout length-frequency data from 263 sampling sites in the River Tiber basin.

Carline *et al*. (1984) suggest that PSD increases with growth. To assess the efficacy of the two methods proposed, the PSD values of brown trout calculated were plotted as a function of mean length for each sampling site and the regression parameters are discussed.

In addition, the sampling sites were disaggregated on the basis of angling regulations (catch & release, fished and unfished). For each sample, the length data were divided into length groups with incremental steps of 2 cm; the percentage of fish in each length group from each sampling site was then averaged to construct a length-frequency histogram for each type of management. Moreover, on the basis of the thresholds for stock and quality length calculated by both methods, for each sampling site the PSD values were estimated and averaged according to angling regulations. These mean values were combined with analysis of the above-mentioned length-frequency histogram in order to ascertain which of the two methods proved to be more responsive to management actions.

The reference status of balanced brown trout populations was defined as a value of 35 to 65 for PSD (Gabelhouse, 1984; Willis *et al*., 1993; Gassner *et al*., 2003; Volta, to appear).

RESULTS

Growth data were obtained on a total of 29 519 specimens from 122 sampling sites. Table I reports the descriptive statistics of the von Bertalanffy growth function (VBGF) parameters calculated for the 122 samples analysed. For each sample, the related VBGF parameters (Appendix 2, available online) were used to calculate the predicted age-specific lengths; the resulting percentiles of calculated length-at-age are presented in Appendix 3 (available online). These values were used to generate the standard growth curves (Figure 2), the equations of which are reported in Table II together with the index of growth performance (ϕ').

Table III shows the benchmark length categories for the calculation of stock density indices, as estimated both by percentage of maximal length (method 1) and by size at maturity and asymptotic length (method 2). During this study, the biggest specimen caught was 60 cm in total length. The percentage classification for each length category of Relative Stock Density (RSD) was taken from Gabelhouse (1984), but was calculated on the basis of this maximal length (method 1). With regard to the second approach to calculating the stock density indices, the mean asymptotic length (L_∞*mean*) and length at maturity (*Lm*) were estimated: these were 44.72 cm and 25.34 cm, respectively. The thresholds calculated in this way were applied to a total of 34 645 specimens from 263 sampling sites. When method 1 was used, it was possible to calculate PSD for all sampling sites analysed. However, when stock and quality lengths calculated by means of method 2 were used, it was not possible to calculate PSD for 19 samples, as all their specimens were smaller than the stock length (number of sampling sites = 244; number of specimens = 33 926).

The calculation of PSD yielded values between 0 and 100 by both methods. The mean PSD value (± SE) estimated by means of method 1 was 20.28 ± 1.18, while method 2 produced different results (mean PSD value ± SE = 37.84 ± 1.67). The differences in the mean values

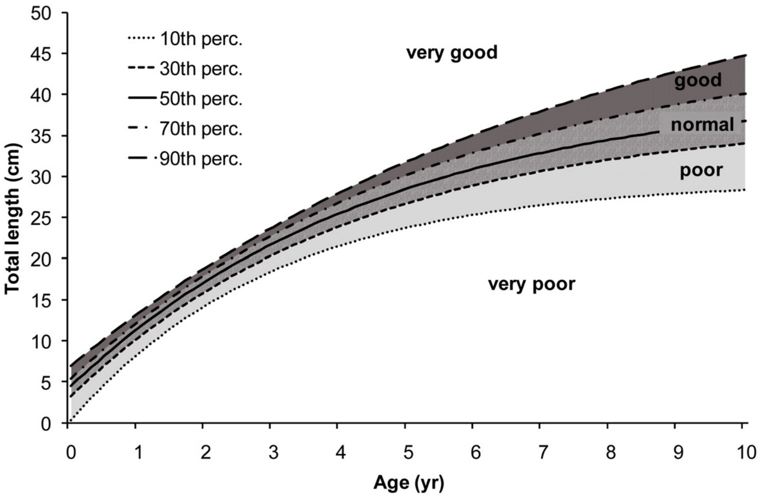

Figure 2
Standard growth curves.

Figure 2
Courbes de croissance standard.

Table II
Reference equations for standard von Bertalanffy growth curves and the corresponding ϕ' values.

Tableau II
Équations de référence des courbes de croissance de von Bertalanffy et les valeurs de ϕ'.

	Reference equation	ϕ'
10th perc.	$TL_t = 29.43 \{1 - e [-0.33 (t + 0.03)]\}$	2.45
30th perc.	$TL_t = 37.22 \{1 - e [-0.24 (t + 0.39)]\}$	2.51
50th perc.	$TL_t = 40.98 \{1 - e [-0.22 (t + 0.53)]\}$	2.56
70th perc.	$TL_t = 46.67 \{1 - e [-0.18 (t + 0.67)]\}$	2.60
90th perc.	$TL_t = 58.42 \{1 - e [-0.13 (t + 0.96)]\}$	2.66

Table III
Classification of the length classes and minimum thresholds for index calculation.

Tableau III
Classification des classes de longueur et seuils minimums pour le calcul de l'indice.

		Method 1		Method 2
Length category	% of maximal length (60 cm)	Length classes (cm) based on maximal length	Minimum thresholds (cm)	Minimum thresholds (cm)
Stock	20–26	12.0–15.6	14	22
Quality	26–41	21.6–24.6	23	25
Preferred	45–55	27.0–33.0	30	29
Memorable	59–64	35.4–38.4	37	32
Trophy	74–80	44.4–48.0	46	36

of PSD yielded by the two methods proved to be highly significant (t-test: $t = -8.693$; $p = 0.000$). On the basis of the defined range for a balanced population ($35 \leq \text{PSD} \leq 65$), the PSD values calculated by means of method 1 indicated that only 16.0% of the samples were well structured; by contrast, method 2 yielded a percentage of 37.7% (Table IV).

To assess the relationship between PSD and growth, the PSD values were regressed on mean length for each sampling site (Figure 3). Both methods displayed a highly significant

Table IV
Frequencies of PSD values in the sampling sites analysed in the River Tiber basin.

Tableau IV
Fréquence des valeurs de PSD dans les sites échantillonnés étudiés dans le basin de la rivière Tibre.

	Method 1		Method 2	
	Number of sampling sites	%	Number of sampling sites	%
PSD $<$ 35	215	81.7	118	48.4
35 $\leq$ PSD $\leq$ 65	42	16.0	92	37.7
PSD $>$ 65	6	2.3	34	13.9

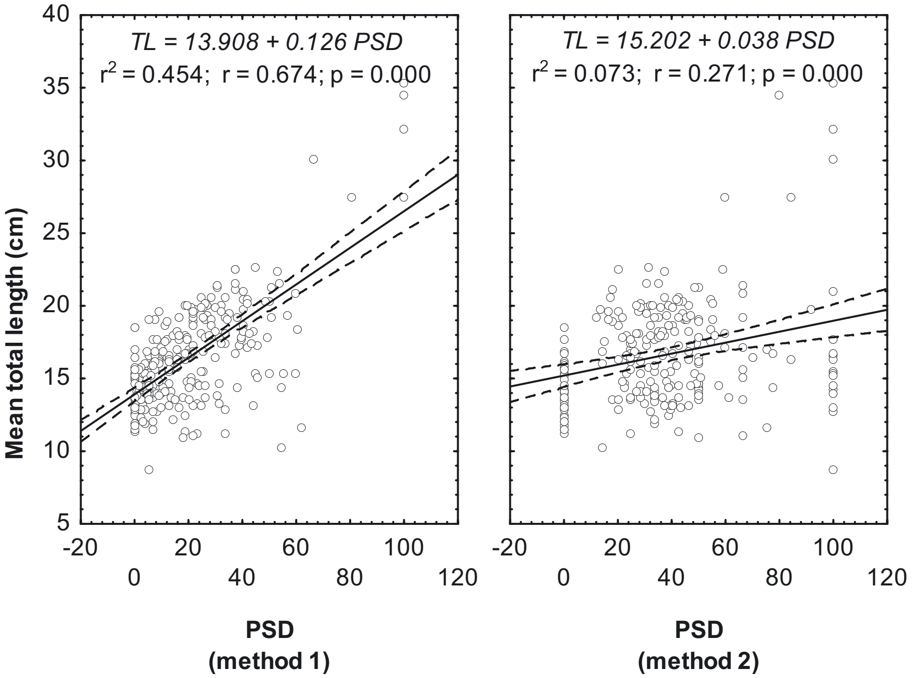

Figure 3
Relationship between mean total length of samples analysed and related proportional stock density (PSD). Slashed lines denote 0.95 confidence intervals.

Figure 3
Relation entre la longueur totale moyenne des échantillons analysés et le PSD. Les lignes en pointillé figurent l'intervalle de confiance à 95 %.

relationship between PSD and length but method 1 yielded a higher correlation coefficient (r), r-squared (r^2) and slope than method 2.

To test method 2, 19 fished sampling sites were excluded from the dataset; for these samples it was not possible to calculate PSD because all specimens were below the stock length. However, the length-frequency distributions of the samples used to test the two methods were very similar.

The differences between the PSD values yielded by the two methods were even more marked when the samples analysed were disaggregated according to the various criteria utilised in the management of brown trout in the area investigated. The unfished and fished samples were composed of smaller specimens than those of the "catch & release" sampling sites (Table V). The differences in the mean total length proved to be highly significant among the three types of management (ANOVA: $F = 849.16$; $p = 0.000$). Figure 4 shows a histogram of the cumulative length frequencies in the overall sample broken down by type of management.

Table V
Descriptive statistics of the total length (TL) distribution of the sample disaggregated by fishing regulation.

Tableau V
Statistiques descriptives de la distribution en longueur totale (*TL*) selon les différentes gestions halieutiques.

Fishing regulation	Number of individuals	Mean	Median	Minimum	Maximum	Std. Dev.
Unfished	7636	14.77	14.00	2.50	43.80	6.08
Fished	19 698	15.04	14.60	3.00	58.00	5.52
Catch & release	7311	18.10	19.00	3.40	60.00	6.20

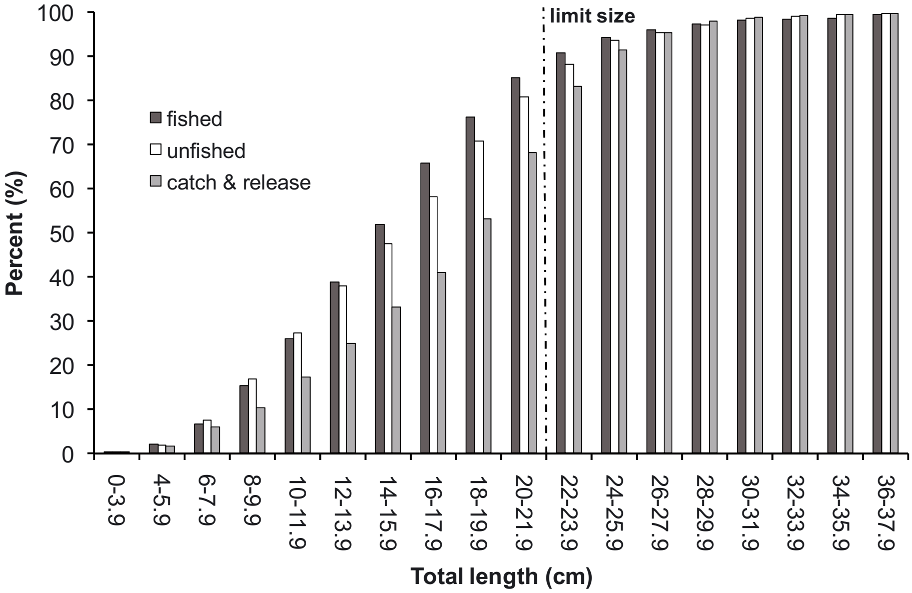

Figure 4
Cumulative length-frequency distribution calculated on 263 trout populations disaggregated by fishing regulation. The dashed line indicates the limit size for brown trout in the study area.

Figure 4
Distributions cumulées de fréquence de longueur caculées sur 263 populations de truite selon le mode de gestion halieutique. La ligne pointillée représente la limite minimale de capture dans la zone d'étude.

The figure clearly shows that large specimens were more frequent in the samples from "catch & release" sites than in those from either fished or unfished waters. Indeed, in the samples from exploited areas a mean of 50% of specimens were less than 14 cm long and a mean of 85% were below the legal-limit size (22 cm); in the unfished areas, 50% of the specimens were below 16 cm and 81% below the limit size, while in areas where a catch & release regulation was in force, specimens longer than 18 cm accounted for 50% of the stock and only 68% were smaller than the legal-limit size.

By contrast, the analysis of PSD according to the two methods yielded different results. Figure 5 reports the mean PSD values calculated by means of both methods in the sampling sites broken down by fishing regulation. By method 1, the mean PSD values (± SE) were 24.20 ± 2.67, 31.97 ± 2.07 and 16.78 ± 1.45 for samples from unfished, catch & release and fished areas, respectively. The differences in the mean values proved to be highly significant (ANOVA: $F = 12.35$; $p = 0.000$). By method 2, the mean PSD values (± SE) for unfished, catch & release and fished sampling sites were 39.79 ± 3.20, 38.14 ± 1.78 and 37.26 ± 2.33, respectively. In this case, the differences in the mean values were not significant (ANOVA: $F = 0.16$; $p = 0.852$).

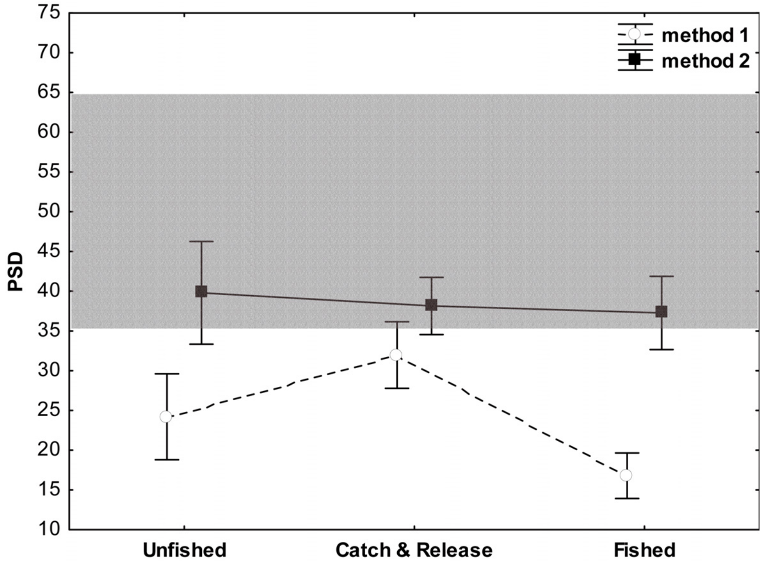

Figure 5
Mean PSD values calculated with both methods and disaggregated by fishing regulation (the vertical bars indicate the 95% confidence intervals). The shaded area indicates the reference range values for a balanced population.

Figure 5
Valeurs moyennes de PSD selon les deux méthodes et selon le mode de gestion (les barres verticales indiquent l'intervalle de confiance à 95 %). La zone ombrée indique les valeurs de référence pour une population équilibrée.

DISCUSSION

The reference values reported in this study reveal a considerable variability in growth among the various populations. The biological and environmental causal factors of phenotypic variability in growth are numerous and often correlated; in addition to genetic factors, they include temperature, intra- and inter-species competition, habitat, availability of food, trophic status and type of management (Cowx, 2000).

Although individuals within the same population may display considerable variations in the length reached at a given age (Pilling *et al.*, 2002), parameters of mean growth are very often adequate in describing the characteristics of a fish population (Sainsbury, 1980). Comparative instruments that enable such parameters to be assessed, thanks to their ease of interpretation and their role in clarifying the factors that cause differences in growth rates among populations, constitute a precious source of information on both the environmental factors and management activities that influence growth.

Comparing growth curves is not easy and contradictions may arise when growth curves cross one another; indeed, the difference in growth rate established in young fish does not persist throughout life, and initially slow-growing fish may surpass initially fast-growing fish, and finally reach a greater length at age. Although some authors use the von Bertalanffy *k* parameter as an index of growth rate (Francis, 1996), none of the von Bertalanffy growth function parameters has, by itself, the dimensions of growth. The growth performance index, which is widely used for comparing growth in fish and invertebrates, can be considered a convenient and robust tool for the comparison of growth parameters of different datasets. The reference values of ϕ' reported in this study confirm the judgement provided by the standard growth curves. Indeed, the values of ϕ' increased concordantly with the quality of the growth expressed by the related reference curves. Moreover, the reference values of the growth performance index (ϕ') presented, together with the von Bertalanffy growth function parameters, may constitute a further means of concisely evaluating the overall growth quality of a given brown trout population in comparison with the standards that are typical for the species in the study area.

Unlike growth, for which standards are very scarce, a variety of metrics have been developed in recent years to describe and compare the structure of fish populations. Indeed, age structure is widely used to assess the biotic integrity of a fish population, and constitutes, for example, in accordance with the “Water Framework Directive” (EU, 2000), one of the fundamental parameters to be considered when fish are used as biological indicators.

Length-frequency indices are widely used to assess size structure in freshwater sport-fish populations (Anderson, 1976) through the application of standards for specific species. North American PSD and RSD indices are based on the all-tackle world-record lengths (Anderson and Weithman, 1978; Gabelhouse, 1984). Brown trout is known as a particularly variable fish species, displaying a wide range of maximal sizes depending on the environmental variability. For this reason, it is rather difficult to define a universal maximum length for all populations in Central Italy. On the other hand, providing a specific length-categorisation system for each type of river would make the application of PSD arduous, the interpretation of results unclear and comparisons difficult; in this way, one of the main advantages of using this index would be lost. As the length classes published in the literature would not be suitable for stream-dwelling brown trout, here they had to be adapted to regional conditions. The length class thresholds that we used to calculate the RSD were estimated as percentages of the maximum length observed not worldwide ($LTmax \approx 100$ cm), as proposed by Gabelhouse (1984), but locally ($LTmax = 60$ cm) (method 1).

Analysis of the results obtained by applying the PSD index to the populations of the River Tiber basin reveals that the choice of the method used to establish the threshold values significantly conditions the assessment of the quality of the population structure. Balanced populations are intermediate between the extremes of a large number of small fish and a small number of large fish and indicate that the rates of recruitment, growth and mortality may be satisfactory (Anderson and Wheithman, 1978); this situation is fairly similar to that of an unexploited population. Fish populations that display PSD values between 35 and 65 are generally considered to be balanced (Gabelhouse, 1984; Willis *et al*., 1993; Gassner *et al*., 2003; Volta, to appear). Values below 35 indicate a shortage of adults in the population, while values above 65 indicate an excess of adult specimens, a probably insufficient level of reproduction or excessive mortality among younger individuals.

The two methods used in our study to calculate the reference values yielded fairly dissimilar thresholds. The values calculated by means of method 1 were similar to those reported by Milewski and Brown (1994) for stream-dwelling brown trout in North America. By contrast, the stock length yielded by method 2 (22 cm) seems to be too high with regard to the local conditions, as according to Gablehouse (1984) minimum stock length is often the size at or near which fish reach maturity; indeed, in the Tiber River basin the length at maturity for *Salmo trutta* is approximately 15 cm (Bicchi *et al*., to appear). In this context, however, in order to determine length at maturity, we chose to utilise the more general formula proposed by Froese and Binohlan (2000), since the aim of the present study was to pick out a general method, from among those reported in the literature, that might be adopted as a model and, if possible, also applied to other fish species, regardless of whether their length at maturity is known. Furthermore, the adoption of such a high threshold makes it impossible to calculate the PSD of populations in which all the specimens are below the stock length; in this research, 19 of the 263 samples studied were excluded because all specimens were smaller than the stock length.

When stock and quality length calculated by means of the two methods were used to compute the PSD, they gave rise to very different assessments of the quality of the population structure. In the present study, the mean PSD values yielded by method 2 were higher than those yielded by method 1. This seems to be due to the fact that the thresholds for stock and quality length according to method 2 are very close together (22 and 25 cm, respectively); thus, the number of specimens larger than the stock size is very close to that of quality-size specimens. By contrast, the thresholds calculated by means of method 1 are farther apart;

therefore, the difference between the number of specimens larger than the stock size and that of the number of specimens larger than quality size is greater.

As growth increases, PSD tends to increase; this has been found for largemouth bass (Guy and Willis, 1990), bluegill (Novinger and Legler, 1978), northern pike (Willis and Scalet, 1989) and yellow perch (Willis *et al*., 1991). In our study too, we established a significant positive relationship between growth and PSD, as calculated by means of both methods. However, analysis of the two regression parameters seems to indicate that method 1 is more sensitive to changes in the average size of specimens, and hence is better able to highlight the differences in the length-frequency distributions of the populations analysed.

This discrepancy was even more marked when the populations were disaggregated according to the various management criteria applied in Italy. Sport fishing is a potent ecological force, which exerts strong direct and indirect effects on aquatic ecosystems (Kitchell and Carpenter, 1993). One of the effects of angling upon fish populations is a significant reduction in age-structure complexity, life span and the percentage of individuals above the legal-limit size (Braña *et al*., 1992). PSD quantifies length-frequency data, and its values can be affected by angling effort (Bailey and Hubert, 2003) and angling regulations (Allen and Pine, 2000; Stone and Lott, 2002). Among population variables, PSD has been shown to be more responsive to management actions, such as minimum length limits, than other variables such as density, biomass, catch and yield (Allen and Pine, 2000). The results of the present study showed that, when the sampling sites were disaggregated according to the various fishing regulations, method 1 was better able to reveal the differences in length distribution among the various types of management than method 2. In the areas subject to “catch & release” regulation, the specimens were larger than in fished or unfished areas; however, method 2 did not reveal any differences in the mean PSD values of samples taken in these different areas. By contrast, method 1 revealed significant differences, the mean PSD values of samples from “catch & release” areas being higher than those of samples from unfished or fished areas. In this case, too, the results could be explained by the greater difference between stock and quality length calculated by means of method 1 in comparison with method 2.

No validated target values for balanced brown trout populations are available for RSD-Preferred, RSD-Memorable and RSD-Trophy. For this reason, the thresholds calculated for these length classes have not been discussed. They have, nevertheless, been provided, as they may contribute to the development and diffusion of these indices.

On the whole, this first attempt to adapt PSD and RSD to the local conditions of the River Tiber basin showed that these indices are a useful tool in the analysis of length frequencies in the populations of *S. trutta* in the area investigated. Important future tasks will be to test these methods on the largest possible number of *S. trutta* populations, to determine the optimum sample size, to define the target values for balanced populations also for RSD, and to correlate these indices with other parameters such as, for example, body condition. Moreover, it will be important to increase investigations by extending the application of these indices to other fish species.

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APPENDIX 1

Physico-chemical and morphological characteristics of the sampling sites.
Available at https://bio.unipg.it/download/VBGFSalmo/Appendix1.pdf

APPENDIX 2

Populations used to generate reference growth data for brown trout and corresponding von Bertalanffy parameters.
Available at https://bio.unipg.it/download/VBGFSalmo/Appendix2.pdf

APPENDIX 3

Age and percentile distribution of calculated length (cm) for constructing standard growth curves.
Available at https://bio.unipg.it/download/VBGFSalmo/Appendix3.pdf