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RESEARCH ARTICLE

Growth and diet of the pikeperch *Sander lucioperca* (L.) in two French reservoirs

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Abstract. The pikeperch *Sander lucioperca* (L.) is present in numerous French water bodies. However, few studies have focused on the biology and ecology of the species and, as a result, references are lacking to assess its adaptation to lacustrine environments. The growth and diet of pikeperch were investigated in two reservoirs located in southern France. The fish at both sites show similar growth rates to those reported in other European countries, but slower than those observed in the Camargue. It is faster in the warm, eutrophic waters of the Treignac Reservoir than in the deeper, oligotrophic waters of Castillon Reservoir. A late shift to piscivory with strong cannibalism was observed at both sites, and the condition factors were low. These elements suggest successful adaptation to these environments though shortages of prey fish are likely to occur.

Keywords: pikeperch (*Sander lucioperca),* condition, diet, environmental factors, growth, reservoir

Introduction

The pikeperch *Sander lucioperca* L. is native to the Black Sea of Asia Minor (Campbell 1992). In France the first recorded catch was registered in 1912 in the canal between the Marne and the Rhine (Daszkiewicz 1999). It has now extended its distribution to most parts of the hydrographic network of the French lowlands (Goubier 1972).

Direct underwater observations of pikeperch spawning behavior showed that its reproduction could take place deep in lakes and did not need macrophytic substrates (Laurent et al. 1973). Therefore, the species sensitivity to water level fluctuations is lower than that of the pike *Esox lucius* L., which is frequently artificially maintained in reservoirs by stocking (Argillier et al. 2002). Thus, it could be interesting to develop sustainable, sport fishery of pikeperch in reservoirs. However, pikeperch represents only 13% of the fish introduced in lakes and is seldom targeted by management operations in France (Argillier et al. 2002). Moreover, limited reference data are available to assess the potential of the species in France (in the southern part of its distribution area), particularly in lentic systems, as most of the literature originates from northern and eastern Europe (Draulans et al. 1985, Petrova and Zivkov 1988). The ecology of the species has been investigated at a few sites in France. The growth of pikeperch in the Vaccares Mediterranean littoral lagoon was faster than in other European countries (Goubier 1975). Gerdeaux (1986) noted a slow growth rate for the pikeperch in the Creteil gravel pit (located in the Seine river basin) in comparison with

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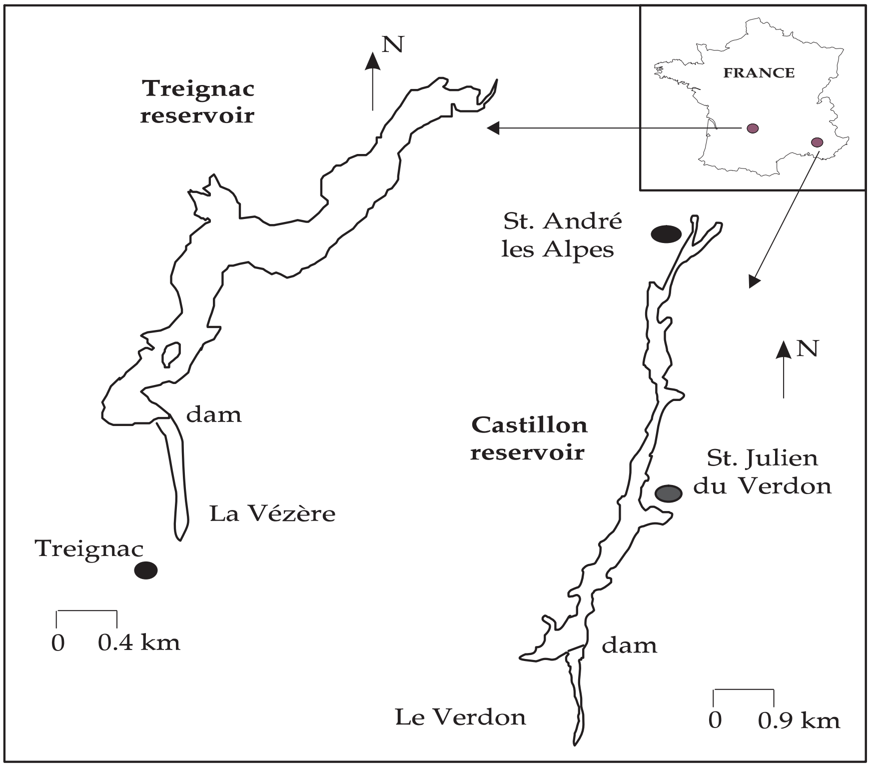

Figure 1. Geographic location of the study sites.

data from other locations in Europe and suggested that food shortage was the explanation.

The present study aims at contributing to the knowledge of pikeperch growth and diet in French lentic systems. These biological traits were investigated in two reservoirs in southern France where the species has been introduced. According to the literature regarding its ecological requirements, one of the study sites displays much more favorable conditions for the development of a pikeperch population than the other one. The results are compared with available European data and discussed from the point of view of fishery management.

Study sites

The Castillon and Treignac reservoirs are located in southern France (Fig. 1). They are both stratified in summer without oxygen depletion. Their main physicochemical characteristics are presented in Table 1. The area of the lakes were measured on 1/25,000 scale maps. Transparency, surface temperature and trophic status (Barbe et al. 1990) were measured following the collection of ichthyological data. Other characteristics of the sites were obtained from dam operators.

Table 1
Main characteristics of the studied reservoirs

	Castillon	Treignac
Basin	Rhône	Garonne
Altitude (m)	880	513
Surface area (ha)	450	101
Volume ($10^6 m^3$)	270	7.5
Depth max - mean (m)	95 - 33	22.5 - 7.4
Water level range (m)	40	12
Mean residence time (days)	224	12
Transparency (Secchi disc) (m)	3 – 10	< 2
Max surface temperature (°C)	22	25
Trophic status	Oligotrophic	Mesotrophic

Castillon Reservoir

Castillon is the farthest upstream of the five hydropower reservoirs along the Verdon River. Its inflow hydrological regime is typically alpine, with floods during both the spring snow melt and fall thunderstorms. The demand for hydroelectric generation is mostly in winter, so the water level is kept high from April until September for recreational purposes.

Fluctuations in water level and the steep slope of the shore result in a purely mineral littoral substratum (sand, slabs, cobbles) which prevents any macrophytic colonization. Therefore, littoral habitats are poorly diversified and provide limited shelter for prey species.

The fish fauna includes 19 species and is dominated by cyprinids, mostly bleak *Alburnus alburnus* (L.), bream *Abramis brama* (L.), white bream *Blicca bjoerkna* (L.) and roach *Rutilus rutilus* (L.). Their cumulated numerical relative abundance, estimated from the gillnet survey method described below, was assessed at between 80 and 90%. Brown trout *Salmo trutta* L. was assessed at between 6 and 12%, depending on the season (spawning migrations in fall). The relative abundances of pikeperch, pike and perch *Perca fluviatilis* L. were below 2% (Argillier et al. 2000).

Treignac Reservoir

The Treignac is the second hydroelectric reservoir on the upper Vézère River. Most of its inflow occurs during fall and winter rains due to oceanic influences. It is kept full during summer, and the water level is governed by demands for electric production during the remainder of the year.

The lands inundated by the upper part of the reservoir were grass meadows with gentle slopes. This organic bottom allowed for the settlement of macrophytic vegetation, which is locally dense and dominated by *Carex* sp. The deepest area covers former forests with steeper slopes and less organic soils. Therefore, this site presents a more diversified physical habitat than Castillon.

A total of 10 species was identified and their respective abundances were estimated using gillnet catches. The most abundant in number are cyprinids (84%) like roach, rudd *Scardinius erythrophthalmus* (L.), common carp *Cyprinus carpio* L. and tench *Tinca tinca* (L.). Perch, pikeperch and pike account for 8, 6 and 2%, respectively (Argillier et al. 1997).

Material and Methods

The fish sampling scheme was stratified by habitats, each of which was fished three times by vertical gillnet series or multimesh gillnets (Degiorgi 1994). The latter were used in the littoral habitats at a depth of 2 m. They were 2 m high and were composed of 2 m long panels of different mesh sizes (knot to knot of 10, 15, 20, 30, 40, 50 and 60 mm). Vertical gillnet series of similar mesh sizes were used in the central habitats. Each net was 2 m wide and its length corresponded to the habitat depth. All the gear were set overnight for approximately 12 hours. Two surveys were performed in Castillon in May and September 1999, during which 31 and 20 pikeperch were caught, respectively. Treignac was sampled once in July (38 individuals) before the dam was drained in September 1997, when 40 more fish were caught.

The total length (L in mm) and weight (W in g) of each fish were measured to the nearest millimeter and gram. The length-weight relationship was expressed by the equation $W=a\,L^b$ where a is the intercept and b the slope of the regression line after log-transformation. Condition factors (K) were calculated using the following expression: $K = 10^5\,W\,L^{-3}$ (Anderson and Gutreuter 1983) with no differentiation between males and females.

Scales were collected for age determination. All annuli were clearly defined and the reproducibility of age readings was checked as suggested by Chang (1982). Age determination (in month) was corroborated through length-frequency mode analysis. Growth, without distinction between the genders, was studied by means of a comprehensive model derived from the hypothesis of a proportionality between the acceleration in growth (d^2Y/dt^2), the growth rates (dY/dt) and a linear function of the growth rate (dY/Ydt) (Schnute 1981):

$$\frac{d^2Y}{dt^2} = \frac{dY}{dt}\left[-a + (1-b)\frac{1}{Y}\frac{dY}{dt}\right]$$

where a and b are constants.

This model includes numerous historical models as special cases (Schnute 1981) and the fitting was processed by non-linear regression based on the least squared errors using the Matlab® software optimization procedure.

The stomachs were removed from freshly caught fish during each survey (47 for Castillon and 38 for Treignac) and preserved in a 4% formalin solution. Each stomach was emptied and its contents scrutinized under a binocular microscope. Arthropod prey were determined to the taxonomic level of order and fish prey to the level of species. Although the total of each type of prey was counted, it could not be weighed because of the advanced stage of digestion.

The percentages of occurrence and abundance were used simultaneously to calculate the index of preponderance proposed by Mohan and Sankaran (1988) and modified in accordance with Amundsen et al. (1996) to include the prey count as input data. The index for prey type *i* was expressed as:

$$Ip_i = \frac{Vi\,Oi}{\sum(Vi\,Oi)}$$

where Vi and Oi are the percentages of numerical abundance and occurrence, respectively.

The feeding trends were then described using the graphic method described by Costello (1990). These feeding patterns were studied for three size classes to assess the shifts during growth. The threshold total lengths were 250 and 330 mm, which allowed for homogeneous between-class distribution for both sites.

Results

Length-weight relationship and condition

The length-weight relationship was estimated for samples collected from Castillon in spring and fall and from Treignac in summer. The best fitting equations are:

Castillon - May: $L = 1.91\ 10^{-6}\ W^{3.25}$ ($n = 31$; $r^2 = 0.998$);

Castillon - September: $L = 3.23\ 10^{-6}\ W^{3.15}$ ($n = 20$; $r^2 = 0.995$);

Treignac - July: $L = 4.87\ 10^{-6}\ W^{3.05}$ ($n = 38$; $r^2 = 0.990$).

Growth was positively allometric at both sites. The highest value observed in May at Castillon corresponded to the pre-spawning period.

Treignac fall data were for large fish captured downstream during the dam drainage operation. Their unbalanced size distribution means that it was impossible to fit a reliable equation.

Condition factors ranged from 0.58 for the smallest individuals to 1.20 for the largest ones collected during dam drainage (Fig. 2). The bimodal size distribution of Treignac pikeperch did not allow for the calculation of a satisfactory regression equation between the condition factor and the total length for the total site population. This means that we could not make a valid site comparison. Nevertheless, for individuals below 500 mm in total length and despite a non-significant difference in the regression slopes (ANCOVA, P = 0.742), condition factors were lower in Treignac than in Castillon.

Modeling growth

The best fitting curve (based on the least square errors) for the age – length scatterplot was the Richards model for both sites:

$$L(t) = L_\infty (1 - be^{-a(t-T)})^{\frac{1}{b}}$$

The corresponding curves are presented in Fig. 3 and the equation parameters in Table 2.

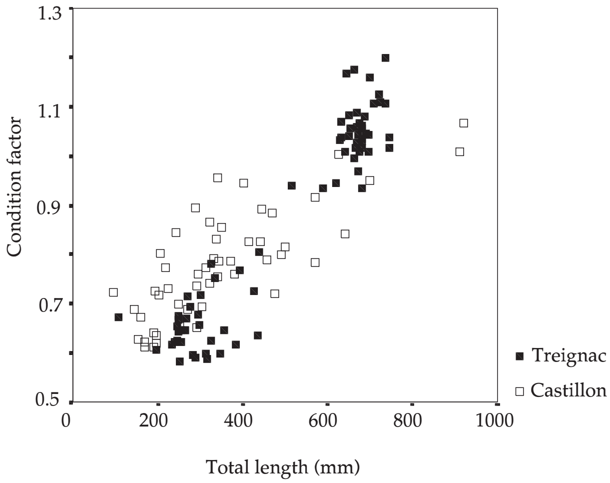

Figure 2. Relationship between total length (mm) and condition factor for pikeperch. Regression analysis is significant in both sites (Castillon: $K= 0.49\ 10^{-3}L + 0.61$, $r^2 = 0.62$, $p < 0.001$; Treignac: $K= 0.98\ 10^{-3}L + 0.38$, $r^2 = 0.90$, $p < 0.001$).

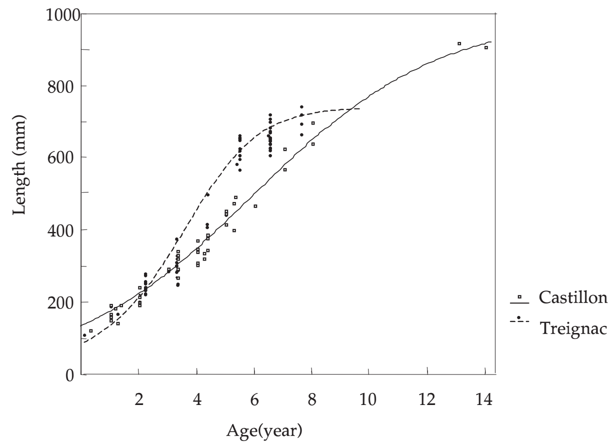

Figure 3. Richards growth curve for pikeperch in Castillon and Treignac reservoirs.

Table 2
Parameters of the Richards growth models. *L* is asymptotic length in mm, *T* is the age at growth slow down given in months, *a* and *b* are constants

	Castillon	Treignac
L	986	774
a	0.03	0.07
b	-0.93	-1.61
T	68.5	44.7

The total sample from Castillon was 51 fish ranging from 0^+ to 14^+. The age distribution showed that no cohort was missing until the age of 8 years. The two fish over 10 years provided valuable information to fit the upper part of the curve.

Figure 4 shows that the model produced a satisfactory age – length relationship for the whole range of data. The regression (n = 51, $r^2 = 0.90$) intercept between the predicted and observed values (Fig. 4a) did not differ significantly from zero. The residuals (Fig. 4b) were normally distributed and the relationship between the residuals and the predicted values (Fig. 4c) gave no clear sign of dependence.

In Treignac, age reading was done on 78 fish ranging from 0^+ to 7^+. The growth curve (Fig. 3) was correctly fitted but did not provide the same accuracy for the total age range. The size of fish under two years of age was systematically underestimated, whereas that of 3- and 4-year-old fish tended to be overestimated.

The difference in length at the same age between the two sites was 166 mm for 6-year-old fish, but it was minimal at early stages (Table 3).

Stomach contents

The study of the non-empty stomachs (79% of the total sample) showed that Castillon pikeperch fed on five arthropod orders and six fish species (Table 4). However, this wide food spectrum was dominated by Cyprinids with a preponderance index of 0.55 (Table 5). Bleak, the most abundant fish species in the reservoir, represented 31% of the ingested items.

In Treignac, the vacuity index (number of empty stomachs / total number of stomachs) was 21%, which was similar to Castillon. Three arthropod orders and three fish species were identified in the diet of the Treignac pikeperch (Table 6). The most common prey were arthropods and percids with preponderance indexes of 0.55 and 0.43, respectively (Table 5). The only arthropods eaten were insects - Plecoptera and Trichoptera represented

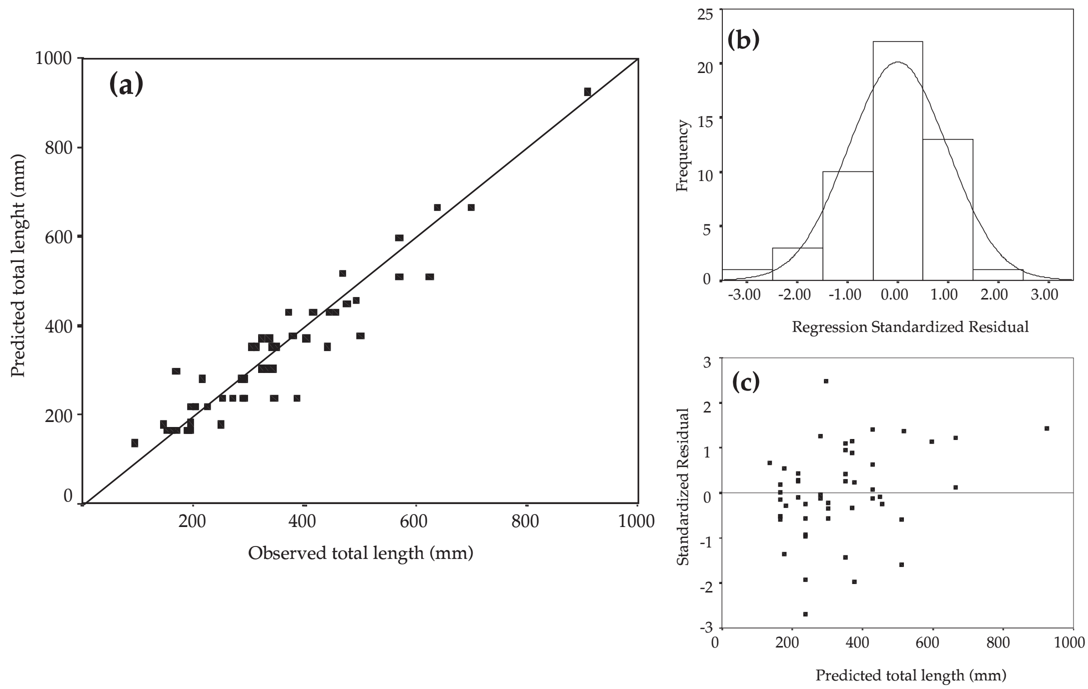

Figure 4. Castillon growth model validation. (a) Scatterplot between predicted and observed total length values. The diagonal line illustrates points at which the predicted value equals the observed value. (b) Distribution of standardized residuals. (c) Relationship between residual values and predicted total length.

Table 3
Growth of pikeperch in different sites

	Total length (mm) at age (years)									
Locality and author	1	2	3	4	5	6	7	8	9	10
Lake Peipsi - Estonia (Kangur and Kangur 1996)	123	193	302	375	417	495	507	590	619	665
Archipelago Sea - Finland		192	220	250	330	354	379	397	422	443
Gulf of Finland (Lehtonen 1983)		188	258	319	382	400	416	442	488	512
Lake Vänern - Sweden	112	207	292	350	416	470	510	554	600	636
Lake Hjälmaren - Sweden	110	218	303	339	369	394	460	543	603	
Lake Ivösjön - Sweden	138	248	352	442	511	570	635	677	732	763
Lake Vombsjön - Sweden	108	221	321	392	459	512	554	602	640	660
Lake Orsjön - Sweden (Svardson and Molin 1973)	83	126	170	225	267	300	331	364	411	450
Gravel pit Créteil - France (Gerdeaux 1986)	91	201	316	417	491	546	595	-	-	-
Vaccares lagoon - France (Goubier 1975)	230	425	515	590	660	710	-	-	-	-
Castillon	166	217	279	351	429	510	590	665	731	788
Treignac Predicted values from growth equations	137	218	331	464	587	676	727	-	-	-

69% of this kind of prey. The predation of carnivorous fish was restricted to perch (1/3) and pikeperch (2/3).

Costello diagrams (Fig. 5) and preponderance indexes (Table 5) clearly show dietary shifts with fish growth. This trend, common to both sites, can be summarized by increasing piscivory and specialization with fish size.

Table 4

The percentage occurrence (% F) and number proportion (% A) of prey in the diet of the three size groups of pikeperch from Castillon. n is the number of non-empty stomachs

	< 250 mm *L* (n = 13)		(250-330) mm *L* (n = 9)		> 330 mm *L* (n = 15)	
	% F	% A	% F	% A	% F	% A
Arthropods						
Crustaceans						
Isopodia	20	10	13	5	-	-
Insects						
Diptera	40	38	13	48	-	-
Plecoptera	10	14	-	-	-	-
Trichoptera	10	10	-	-	-	-
Ephemeroptera	10	5	-	-	-	-
Teleosts						
Cyprinids						
Alburnus alburnus	20	10	63	24	67	59
Rutilus rutilus	-	-	13	5	8	5
Abramis brama	-	-	-	-	8	5
Percids						
Perca fluviatilis	10	5	13	5	8	5
Sander lucioperca	20	10	25	10	33	18
Salmonids						
Salmo trutta	-	-	-	-	8	5

Table 5

Index of preponderance for the food items of the three size groups of pikeperch

	Castillon				Treignac			
Prey	Total sample	< 250 mm	(250-330)	> 330 mm	Total sample	< 250 mm	(250-330)	> 330 mm
Arthropods	0.26	0.93	0.17	-	0.55	0.87	0.52	0.07
Percids + Salmonids	0.19	0.04	0.25	0.2	0.43	0.10	0.47	0.86
Cyprinids	0.55	0.04	0.57	0.8	0.03	0.03	0.01	0.07

The small pikeperch (L < 250 mm) simultaneously fed on various types of prey though they seemed to prey preferentially on insects - Trichoptera in Treignac and Diptera in Castillon.

The contribution of fish to the stomach contents increased in the medium-sized class. In this class the proportion containing insects was one-third of the specimens from Treignac compared to 13% from Castillon.

Apart from a single individual in Treignac, all the stomachs of pikeperch over 330 mm in length contained only fish (Tables 5, 6); this corresponds to 3-year-old specimens in Castillon and 4-year-old fish in Treignac. Cannibalism occurred at both sites throughout the length range and increased with individual size (Tables 5, 6). This feeding behavior referred to 56 and 20% of the individuals in Treignac and Castillon, respectively. It reached a level of 88% in the largest size class in Treignac.

Discussion

The allometric equations calculated in this study, whatever the season, were similar to those measured on the Lake Peipsi population (b = 3.11 and b = 3.06

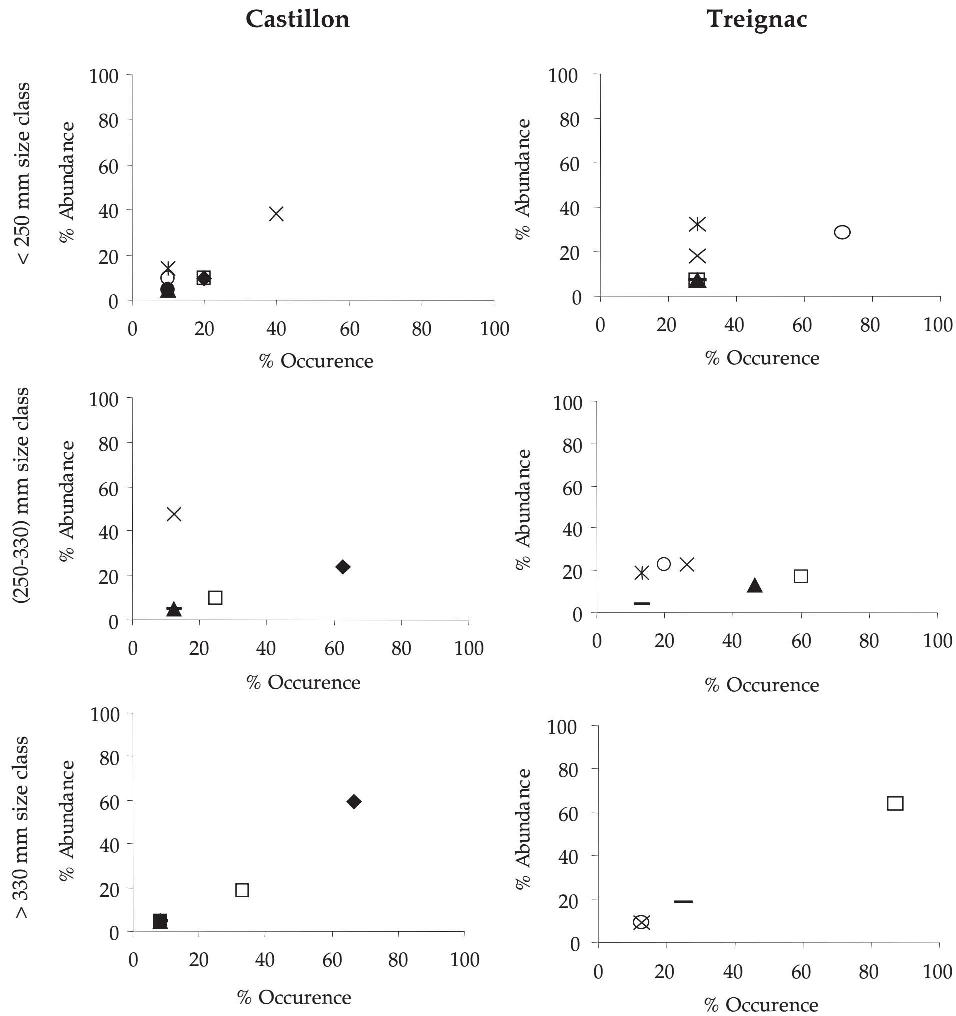

Figure 5. Feeding strategy plots (Costello method) for pikeperch in Castillon and Treignac. ◆ bleak, △ bream, ▲ perch, ▯ pikeperch, – roach, ■ trout, × Diptera, ○ Trichoptera, ● Ephemeroptera, + Isopoda, ✱ Plecoptera Treignac. n is the number of non-empty stomachs.

Table 6

The percentage occurrence (%F) and number proportion (%A) of prey in the diet of the three size groups of pikeperch from Treignac. n is the number of non-empty stomachs

	< 250 mm *L* (n = 7)		(250-330) mm *L* (n = 15)		> 330 mm *L* (n = 8)	
	% F	% A	% F	% A	% F	% A
Arthropods						
Insects						
Diptera	29	18	27	23	13	9
Plecoptera	29	32	13	19	-	-
Trichoptera	71	29	20	23	13	9
Teleosts						
Cyprinids						
Rutilus rutilus	29	7	13	4	25	18
Percids						
Perca fluviatilis	29	7	47	13	-	-
Sander lucioperca	29	7	60	17	88	64

respectively in 1994 and 1995) (Kangur and Kangur 1996) and the Batak Dam population (b = 3.08) (Petrova and Zivkov 1988). The condition factor of the individuals smaller than 600 mm in total length was generally below 1. The values obtained for the whole size range remain below those noted by Goubier (1975) for other French sites.

The late warming of the waters in Castillon due to the spring snow melt, a low surface water temperature (mean annual: 11°C) and the clear, deep and seasonally stratified oligotrophic waters were not favorable for optimal pikeperch growth (Nagiec 1977). Nevertheless, the age – length relationship found in this study site suggests a similar growth pattern to those of other European sites reported in previous literature reviews (Linfield and Rickards 1979, Petrova and Zivkov 1988) and those given in Table 3. Juveniles displayed a good length increment during the first year. The estimated asymptotic length was consistent with Sonesten (1991). Moreover, the presence of every year-class in the absence of stocking proved that reproduction occurred yearly.

The growth observed in Treignac was close to the best reported in other lakes and reservoirs, particularly for individuals of 5 years and over, for which the model was most reliable. Bias was observed at this site as a consequence of the sample structure, and the growth model gave the best results for the oldest individuals, which represented 60% of the sample. The estimated asymptotic length was low for this pikeperch population. The model might have underestimated this parameter, which would be confirmed by the presence in the data set of a 7-year-old fish 770 mm in length. For this species, considered to be better adapted to shallow, productive environments (Nagiec 1977), the warm, eutrophic water of Treignac permits faster growth than that of Castillon. Yearly recruitment was also observed at Treignac.

The shift to piscivory is generally reported to occur during the first summer (Popova and Sytina 1977, Sonesten 1991). Our diet analysis, though limited, suggested that the shift occurred later between years 3 and 4. Similar observations were made by other researchers with piscivory occurring in fish 300 mm (Gerdeaux 1986) and 450 mm in length (Campbell 1992) in environments which lacked forage fish. This hypothesis can be made in the case of Treignac where, despite the use of small mesh sizes in the gillnet series, most of the cyprinids caught were over 200 mm in length - the refuge size for pikeperch predation (Van Densen 1994). Conversely, it is less probable in Castillon where an abundant bleak population is present. Bleak is known to be the ideal shape for pikeperch prey, and it is also easily digestible and has a high nutritive value (Biro and Elek 1969).

Conclusion

These findings suggest that the introduction of pikeperch to these southern French reservoirs is successful. The tolerance of the species appears to allow self-sustaining populations to persist. Nevertheless, the growth rates measured could affect the significance of the species to fishery because the minimum legal size (400 mm) is reached late (5 years for Castillon). Though our observations are limited, they show that in addition to cyprinids, which are not valuable for sport fishing, brown trout and perch, which are in great demand, can be preyed upon by pikeperch. This raises questions about the impact of pikeperch introduction, which is suspected of being significant, on the stocks and exploitation of native species (Smith et al. 1996, Cowx 1997, Smith et al. 1998, Kershner et al. 1999).

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