Available online at www.sciencedirect.com
SCIENCE DIRECT
Food Chemistry 100 (2007) 482–490
Food Chemistry
www.elsevier.com/locate/foodchem

Nutritional quality and safety of European perch (*Perca fluviatilis*) from three lakes of Central Italy

Elena Orban [a,*], Teresina Nevigato [a], Maurizio Masci [a], Gabriella Di Lena [a], Irene Casini [a], Roberto Caproni [a], Loretta Gambelli [a], Paola De Angelis [b], Massimo Rampacci [b]

[a] *National Research Institute for Food and Nutrition, Seafood Study Unit, Via Ardeatina 546, 00178 Rome, Italy*
[b] *A.Ge.I. Agricoltura Gestione Ittica S.c. r. l. Via Carlo Emanuele I, 11 – 00185 Rome, Italy*

Received 27 June 2005; received in revised form 20 September 2005; accepted 20 September 2005

Abstract

European perch (*Perca fluviatilis*) harvested from three lakes of Central Italy were studied in different seasonal periods of a year to evaluate their nutritional quality and some safety aspects related to the pollution of the aquatic environment. The lakes considered, located in the Latium region, differed with respect to their volcanic (Bolsena and Bracciano Lakes) or artificial (Salto Lake) origin. Fillets of fish caught in the three lakes were characterised by good protein (17–19%) and mineral contents and low lipid levels (0.6–1.2%) throughout the year. Total lipids were characterised by low cholesterol levels (41.9–74.7 mg/100 g) and high percentages of total $n-3$ polyunsaturated fatty acids (27.7–33.8% of total fatty acids), in particular docosahexaenoic acid (14.2–25.3% of total fatty acids). The qualitative analysis of the stomach content of perch confirmed their predatory feeding behaviour. The chemical and nutritional profiles of perch from the three lakes were comparable except for rubidium and cesium levels, which were higher in the muscle tissues of perch from the volcanic lakes. These minerals may represent elements of traceability of the origin of fish. Low levels of organochlorine pesticides and polychlorinated biphenyls, well below the Italian and European action limits, were detected in the muscle tissue of perch from all three lakes.

Keywords: Freshwater fish; Perch; *Perca fluviatilis*; Nutritional quality; Safety; Organochlorine pesticides; Polychlorinated biphenyls; Traceability

1. Introduction

The European perch (*Perca fluviatilis* L.), a predatory freshwater fish species feeding on invertebrates and fish, was originally confined to the temperate waters of the northern hemisphere, mainly Europe and North America, although representatives have been introduced to Australia, New Zealand and South Africa.

In Italy, in the North-East sector of the Po basin, the presence of perch has been documented for centuries, while in Central Italy this species is mainly present in the lakes of the Umbria and Latium regions (Bruno & Maugeri, 1992; Gandolfi, Zerunian, Torricelli, & Marconato, 1991). In the Lakes of Latium, perch is one of the fish species more representative of the professional fishery and local gastronomy. Here, special incubators have been established for the artificial reproduction of fry used in the stock enhancement of perch.

Within 2–3 years, when the body length is 15–25 cm, perch reaches sexual maturity. The average length of perch is 20–25 cm but it may vary depending on the environmental conditions: some specimens reach 45 cm, others may show dwarfism signs when living at a high population density.

It is well known that the quality of seafood products is dependent on the genetic basis and on the characteristics of the environment (pH, salinity and temperature of the water, composition of phyto- and zooplankton during the year, presence of other fish species, etc.).

* Corresponding author. Tel.: +39 06 51494452; fax: +39 06 51494550.
E-mail address: orban@inran.it (E. Orban).

0308-8146/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2005.09.069

Seafood safety is strictly dependent on the hygienic quality of the aquatic environment as well as on the different phases of the seafood production chain, from fishing to the treatments on-board and after landing. Fish products, in fact, are particularly susceptible to contamination, especially those from freshwater environments characterised by slow water exchange and high antropic contamination. The presence of organochlorine pesticides and polychlorinated biphenyls (PCBs) in the aquatic environments represents one of the most debated environmental questions due to their ubiquitous presence, accumulation in the food chain and incidence on public health (Smith & Gangolli, 2002). In the environment, they are persistent in soil and water and accumulate in sediments; in living organisms, due to their lipophilic nature, these substances accumulate in lipids. Therefore, the contamination level of a fish species may be affected by its lipid content, age, feeding behaviour and environmental pollution.

In the present work, the chemical and nutritional characteristics of perch caught in three lakes of Latium having volcanic (Bolsena and Bracciano Lakes) or artificial (Salto Lake) origin, were monitored in different months of the year. The feeding behaviour of perch from the three lakes was evaluated by means of the qualitative analysis of their stomach contents. Moreover, in the muscle tissue of fish were determined the levels of mercury, organochlorine pesticides and polychlorinated biphenyls residues. The aims of the study were the evaluation of the nutritional quality and safety of fish and the identification of differentiation elements, if any, among fish from either volcanic or artificial lakes.

2. Materials and methods

2.1. Study design and fish sampling

The study was conducted in collaboration with local fishermen who provided fish samples at seasonal intervals. Perch (*P. fluviatilis*) samples were harvested in December 2001 and in February, June and September 2002 from three lakes of Latium (Central Italy): Bolsena Lake, Bracciano Lake and Salto Lake.

Fish were caught by gillnets. All fish were immediately dipped in a mixture of water and ice to block any digestive system that would potentially hinder the identification in the stomach of the ingested preys. At landing, perch were transferred in polystyrene boxes containing ice and transported under refrigerated conditions (4 °C) to the laboratories for the analysis of the stomach content and for chemical determinations.

Upon arrival at the National Research Institute for Food and Nutrition, fish for nutrient determination were singularly measured for total body weight and total body length and immediately gutted. Perch from the three lakes were spawning in December and in February. Viscera were weighed and their percent of total body weight calculated. Soon after, fish were beheaded, washed, filleted, vacuum-packed, and frozen at −75 °C to be analysed within one week. Fish for organic pollutant determinations were frozen at −75 °C without any prior treatment.

Within each seasonal sampling, 2–3 pools of fish, each composed of 4–6 specimens of comparable body size, were analysed separately in duplicate for nutritional evaluations. The weight of the specimens analysed from the three lakes was 100–120 g, which corresponds to the most marketed size of perch. In one occasion (February 2002) perch from Salto Lake were also analysed at different commercial sizes, 60 and 400 g total body weight, for a comparison of the chemical composition of different fish sizes. Analyses on organochlorinated pollutants were performed on samples (100–120 g body weight) harvested in September 2002.

2.2. Aquatic environments

The Bolsena Lake, with a surface of 114 km^2 and a maximum depth of about 150 m, is the fifth largest lake in Italy and the biggest one among those of volcanic origin. Located at 305 m above the sea level, the lake, characterised by a subcircular shape, receives its main water contribution by rainfall since the hydrographic network of that area is characterised by scanty waterways. Its only effluent is the river Marta. The Bolsena Lake is mesotrophic and rich in solutes. It is rich in phyto- and zooplankton, the basis of the food chain, as well as of algae belonging to the genus *Chara*, that represent a food source for many aquatic organisms. The phytoplankton is mainly represented both quantitatively and qualitatively by Cyanophyceae, Diatoms, Peridiniaceae, Chlorophyceae and Microflagellates. As regards zooplankton, Crustaceans (Copepoda and Cladocera), Rotifera and plenty of benthic taxa belonging to Annelida and to the entomophauna (larval phases) are mainly present. European eel, trout, whitefish, perch and mullet are the species introduced in the lake by stock enhancement, an activity already started by the end of 19th century. The physico-chemical characteristics of the lake water are: pH 8.4, temperature ranging between 9–10 °C in winter and 20–27 °C in summer.

The Bracciano Lake is a typical volcanic lake characterised by a subcircular shape. Located at 164 m above the sea level, the Bracciano Lake is 57.5 km^2 wide, has a diameter of 9 km and reaches a maximum depth of 164 m. Various subterranean springs and thermomineral waters act as tributaries of the lake. The Arrone River and the Paolo aqueduct, bringing water to the city of Rome, are its two effluents. The quality of the Bracciano Lake water is quite high. The lake is an important reservoir of drinkable water for Rome and some minor municipalities in the surroundings. Like the Bolsena Lake, this lake is rich in macroalgae belonging to the genus *Chara*, a species proliferating in aquatic environments with a poor eutrophisation level. The submerged meadows of macroalgae and macrophytes are in a good vegetative state. The lake has also a wide population of phytoplankton (Cyanophyceae, Chlorophyceae, Cryptophyceae, Diatoms, Peridiniaceae). As a consequence

of the richness of the submerged aquatic vegetation, the lake shows a high biodiversity of macrobenthic population. Gasteropod mollusks (*Bithynia tentaculata, Thedoxus fluviatilis*) are prevalent over oligochaeta and Diptera Chironomidae, poorly present. Among crustaceans, *Echinogammarus veneris* and *Palae monetes antennarius* are present while *Musculium* and *Pisidium* are the main bivalve mollusks in the lake. The fish species populating the lake are mostly represented by whitefish, eel and perch. The physico-chemical characteristics of the lake water are the following: pH 8, temperature ranging between 10–12 °C in the winter months and 22–24 °C in summer.

The Salto Lake, 535 m above the sea level, is an artificial basin of about 820 ha. The lake,10 km long, 1 km wide and with a maximum depth of about 90 cm, is rich of creeks and fjords that insinuate in valleys dug in marble-arenaceous rocks. An artificial tunnel connects the lake to the Turano Lake with the purpose to create a big hydroelectric basin.

Like any artificial basin, the Salto Lake is characterised by a limited water exchange and by a sharp thermocline in summer with a superficial layer of warm and well-oxygenated waters and a cooler and less oxygenated layer underneath. In the cold season the whole water column has average values of temperature and oxygen. Moderate seasonal fluctuation is shown by phytoplankton in the Salto Lake, in particular by Cyanobacteria, Chlorophyta, Cryptophyta, while Diatoms are constant during the year. The zooplankton populations, mainly represented by Rotifera, Copepoda (80%) and Cladocera, show very low levels in winter and a marked increment in spring. The physico-chemical characteristics of the lake water are the following: pH 8, temperature ranging between 3.5–7 °C in winter and 24–26 °C in summer.

2.3. Fish stomach content

Perch were analysed singularly for the stomach content. The qualitative identification of the different prey species was accomplished with the use of a stereomicroscope (Carl Zeiss S.p.A., Milan, Italy).

2.4. Chemical composition

On the day of analysis, fillets from four to six fish were rapidly thawed, then skinned, chopped, combined in a pool, and homogenised for 1 min in a Waring blender (model 8010E, Waring® Products Division, New Hartford, CT, USA) at a low speed using a previously cooled stainless steel cup.

Moisture, crude protein, and ash contents of fish fillets were determined by methods described by the Association of Official Analytical Chemists (1990). Nonprotein nitrogen (NPN) was determined by the Kjeldahl method (Association of Official Analytical Chemists, 1990) after protein precipitation with 10% (w/v) trichloroacetic acid. Total lipids were extracted following the method of Bligh and Dyer (1959) slightly modified according to Kinsella, Shimp, Mai, and Weihrauch (1977). All-*trans* retinol, α-tocopherol, squalene, and cholesterol were quantified by HPLC (Orban et al., 2000). The HPLC system used was a Hewlett-Packard (Waldbronn, Germany) 1100 Series liquid chromatograph equipped with an UV/visible photodiode array detector. The analytical separations were performed using a stainless steel (25 cm × 4.6 mm i.d.) 5 μm Ultrasphere C18 column (Beckman, Palo Alto, CA, USA).

Sodium, potassium, calcium and magnesium were analysed in fish fillets homogenates by ion exchange liquid chromatography with suppressed conductivity as already described (Orban et al., 2000). Phosphorus was determined spectrophotometrically according to the AOAC method 965.17 (Association of Official Analytical Chemists, 1990). Zinc, iron, selenium, mercury, rubidium and cesium were analysed by instrumental activation analysis (Orban et al., 2000).

Fatty acid profiles of total lipids were determined after transesterification with a 1:1 (v/v) boron trifluoride in methanol (14%)/methanol solution. Fatty acid methyl esters were extracted with hexane and quantified by gas chromatography using a 6890 Hewlett-Packard gas chromatograph with a flame ionisation detector, equipped with a SPB™ PUFA fused silica capillary column, 30 m × 0.25 mm i.d., 0.20 m film thickness (Supelco Inc., Bellefonte, PA, USA). Operating conditions were as previously described (Orban et al., 2000). Fatty acids were identified by comparison of retention times to authentic standards for percent area normalisation. Relative quantities are expressed as weight percent of total fatty acids.

2.5. Organochlorinated pollutants

On the day of analysis, thawed perch were carefully filleted by means of contamination-free tools. In performing the analyses a number of three individuals was always considered and the edible part of them was selected and combined. Then, homogenisation with a Waring® blender 38BL40 (Waring® Products Division, New Hartford, CT, USA – a few seconds at high speed) and with an Ultra Turrax T25B (IKA, Staufen, Germany – 1.5 min at 11, 000 rpm) was carried out.

Organochlorine pesticides and PCBs were extracted from the muscle tissue together with fat by means of acetone/petroleum ether 1/1 v/v. Sample purification and clean up were accomplished by means of suitable phases, such as diatomaceous earth, Florisil and C18 as described by Di Muccio et al. (1997).

Twenty-six organochlorine pesticides for which action limits have been established by the Italian Health Ministry (Decree dated 19/5/2000) were searched for together with eight more organochlorine pesticides not regulated by the current law but environmentally relevant. The maximum admissible levels set by the Italian regulation vary with the total lipid content of fish (Gazzetta Ufficiale della Repubblica Italiana, 2000).

As regards PCBs the Italian regulation has not yet established limits in seafood. However, action limits have been established at a European level for 7 congeners considered "pollution indicators": PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, PCB 180 (Anon., 1992). Along with these indicators, 26 congeners chosen among those more widespread in the environment, have been studied.

Instrumental analyses were performed with a Varian (Walnut Creek, CA, USA) 3800 gas chromatograph equipped with a Mass Spectrometer Saturn 2000, an EC detector, two injectors and two columns (30 m × 0.25 mm i.d., 0.25 μm film thickness) having different polarities. The first column (CP-SIL 24CB from Chrompack, Middelburg, The Netherlands) was connected to the ECD detector and the second (CP-SIL 8CB, from Chrompack, Middelburg, The Netherlands) was connected to the mass spectrometer. Instrumental conditions were as previously described (Orban et al., 2004a). Qualitative and quantitative analyses were carried out by using a number of standard reference solutions. Each contaminant, with respect to the pure standard, had to meet a series of confirmation criteria for a positive identification: ECD retention time, MS retention time, mass spectrum. When necessary MS/MS determinations were performed.

2.6. Statistical analysis

Chemical evaluations were performed in duplicate on 2–3 pools of fish, each composed of 3–6 specimens of similar body size. Data on the chemical composition are reported as means ± standard deviations and range of values found during the year. Differences between perch of different body size were analysed statistically by the Student's *t*-test.

3. Results and discussion

The study on the seasonal variation of the chemical composition of perch from the three Lakes of Latium was mainly focussed on specimens weighing 100–120 g, which corresponds to the perch size more commercialised. Perch, the object of this study, were all characterised by a very low total lipid content of the muscle, ranging from 0.64 g to 1.20 g/100 g, depending on the season and the place of harvest, and by good protein levels (17.06–18.99 g/100 g, Table 1). The higher lipid contents were attained in summer for perch from Bracciano and Bolsena Lakes and in winter for perch from the Salto Lake.

As a result of the very low lipid content, cholesterol, squalene, and α-tocopherol levels were generally low in perch. In particular, samples from the Salto Lake had levels of α-tocopherol lower than perch from the other two lakes. All-*trans* retinol was always undetectable in perch muscle (Table 2).

The mineral content of perch is reported in Table 3. Low sodium, high potassium and magnesium and levels of calcium variable with time were found in all samples. As regards micro-elements, elevated amounts of zinc and selenium and low levels of iron were detected. Mercury, a heavy metal at risk of bioaccumulation in the aquatic food chain, was present at low levels. Among ultra-trace elements were also determined rubidium and cesium, potentially able to compete with potassium for biochemical and physiological processes in living organisms (Peters, Schultz, & Newman, 1999). These minerals, present in silico-aluminous rocks and vulcanites, were higher in perch from the Bolsena and Bracciano Lakes, basins with a volcanic origin, than in perch from the artificial lake of Salto. Since a similar observation was also made by us on eel (Orban et al., 2004b) and whitefish (unpublished data) from the same sites, rubidium and cesium may be regarded as chemical indicators of the origin of fish.

The fatty acid profile of total lipids extracted from perch harvested in the three lakes are shown in Table 4. Polyunsaturated fatty acids (PUFA), amounting to 37.9–47.0% of total fatty acids were always prevalent over the saturated (29.1–33.7%) and monounsaturated (15.2–27.3%) ones. The variability observed during the year may be the result of reproduction cycle influences as well as of seasonal fluctuations of the natural food resources available in the aquatic environments. It is generally known, in fact, that

Table 1
Biometric measurements of perch (*Perca fluviatilis*) from three lakes of Latium and proximate composition of fish muscle during the year (g 100 g^{-1} wet fillet)

	Bolsena Lake		Bracciano Lake		Salto Lake	
	Mean ± SD	(Range)	Mean ± SD	(Range)	Mean ± SD	(Range)
Length (cm)	21.53 ± 1.24	(20.38–23.30)	21.70 ± 0.44	(21.20–22.20)	21.19 ± 0.93	(20.10–22.40)
Weight (g)	114.15 ± 18.21	(98.02–132.17)	126.23 ± 8.86	(113.40–133.54)	115.77 ± 18.82	(96.67–140.75)
Edible portion (% weight)	59.40 ± 4.58	(55.29–64.33)	63.93 ± 4.52	(59.31–70.14)	59.69 ± 2.21	(57.22–61.48)
Viscera (% weight)	5.26 ± 2.97	(1.92–9.14)	6.73 ± 0.84	(5.79–7.62)	6.45 ± 1.82	(4.47–8.22)
pH	6.78 ± 0.25	(6.53–7.10)	6.81 ± 0.15	(6.66–6.96)	6.78 ± 0.14	(6.58–6.89)
Moisture	80.28 ± 1.30	(78.47–81.53)	79.71 ± 0.49	(79.01–80.07)	79.45 ± 0.38	(79.06–79.93)
Protein	17.89 ± 0.72	(17.29–18.93)	18.43 ± 0.39	(18.14–18.99)	18.10 ± 0.76	(17.06–18.87)
Lipid	0.90 ± 0.28	(0.64–1.15)	0.86 ± 0.13	(0.76–1.01)	0.99 ± 0.20	(0.78–1.20)
Nonprotein nitrogen	0.32 ± 0.01	(0.31–0.33)	0.33 ± 0.02	(0.31–0.35)	0.33 ± 0.01	(0.32–0.34)
Ash	1.21 ± 0.17	(1.03–1.42)	1.15 ± 0.03	(1.13–1.19)	1.29 ± 0.17	(1.18–1.53)

Table 2
Unsaponifiable lipid components of perch (*Perca fluviatilis*) muscle from three Lakes of Latium during the year

	Bolsena Lake		Bracciano Lake		Salto Lake	
	Mean ± SD	(Range)	Mean ± SD	(Range)	Mean ± SD	(Range)
mg 100 g^{-1} wet fillet						
Cholesterol	64.7 ± 11.2	(53.8–74.7)	60.4 ± 9.6	(51.4–73.2)	60.7 ± 12.6	(41.9–68.0)
α-Tocopherol	0.89 ± 0.27	(0.64–1.26)	0.94 ± 0.14	(0.76–1.09)	0.42 ± 0.10	(0.32–0.51)
Squalene	0.21 ± 0.05	(0.15–0.25)	0.21 ± 0.04	(0.15–0.24)	0.20 ± 0.08	(0.11–0.28)
All-*trans* retinol	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
mg g^{-1} lipid						
Cholesterol	74.1 ± 10.2	(64.9–84.1)	68.0 ± 5.4	(61.2–72.4)	61.8 ± 11.2	(53.7–78.3)
α-Tocopherol	1.00 ± 0.17	(0.80–1.16)	1.08 ± 0.23	(0.81–1.30)	0.42 ± 0.02	(0.41–0.45)
Squalene	0.23 ± 0.02	(0.22–0.27)	0.23 ± 0.03	(0.20–0.27)	0.19 ± 0.05	(0.14–0.25)
All-*trans* retinol	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d., not detectable.

Table 3
Mineral elements in perch (*Perca fluviatilis*) muscle from three Lakes of Latium during the year

	Bolsena Lake		Bracciano Lake		Salto Lake	
	Mean ± SD	(Range)	Mean ± SD	(Range)	Mean ± SD	(Range)
mg 100 g^{-1} wet fillet						
Na	33.2 ± 12.6	(21.6–50.5)	25.1 ± 3.6	(21.4–29.2)	31.4 ± 10.4	(25.1–46.9)
K	378 ± 26.7	(343–407)	325 ± 110	(161–394)	395 ± 8.7	(383–404)
Mg	26.3 ± 1.5	(25.4–28.6)	21.8 ± 7.8	(10.6–27.2)	27.1 ± 3.6	(21.8–30.1)
Ca	85.4 ± 46.7	(51.9–153)	46.3 ± 22.3	(15.6–68.5)	62.4 ± 38.8	(28.6–118)
P	223 ± 2.1	(221–225)	231 ± 2.9	(229–235)	215 ± 4.0	(211–220)
μg 100 g^{-1} wet fillet						
Se	27.3 ± 3.0	(25.6–31.6)	35.3 ± 6.9	(28.8–42.4)	43.9 ± 3.3	(40.6–48.0)
Zn	584 ± 52	(535–650)	737 ± 45	(680–787)	693 ± 50	(660–760)
Fe	160 ± 19	(140–181)	235 ± 30	(208–260)	195 ± 13	(180–210)
Hg	13.6 ± 0.9	(12.6–14.7)	14.7 ± 8.8	(7.3–22.7)	6.8 ± 0.7	(6.0–7.7)
Rb	2572 ± 252	(2230–2810)	3450 ± 370	(3000–3900)	848 ± 17	(850–870)
Cs	68.2 ± 2.4	(68.0–70.0)	99.0 ± 37.5	(46.0–130)	1.2 ± 0.5	(0.8–1.0)

the lipid profile of fish is markedly influenced by the fatty acid composition of their natural food (Henderson & Tocher, 1987).

Palmitic (C16:0, 20.0–23.5% of total fatty acids) and stearic (C18:0, 4.7–8.0%) acids were the prevalent saturated fatty acids in perch from all provenances. As regards monounsaturated fatty acids, 18:1 $n-9$ was predominant (7.7–13.0%) over 16:1 $n-7$ (3.1–9.9%) and 18:1 $n-7$ (2.58–5.0%).

Docosahexaenoic acid (C22:6, 14.2–25.3% of total fatty acids) was the predominant polyunsaturated fatty acid in perch regardless of their origin, followed by C20:4 $n-6$ (5.0–10.6%) and C20:5 $n-3$ (3.3–8.6%). Most of the PUFA underwent a fluctuation during the period under study.

In consideration of the very low lipid content of perch fillets, it may be assumed that the high percentage levels of PUFA found in total lipids, in particular C22:6, reflect their preferential association with phospholipids in cell membranes.

High levels of total $n-3$ PUFA (27.7–33.8% of total fatty acids), important for their platelet anti-aggregating and blood pressure-reducing properties, considerable levels of total $n-6$ PUFA (8.69–14.38) and $n-3/n-6$ ratio values ranging between 2.0 and 3.9 characterised perch from any lake studied.

High percentages of $n-3$ PUFA, in particular C22:6, were also observed by other authors in wild and reared perch from different sites (Blanchard, Druart, & Kestemont, 2005; Xu, Fontaine, Melard, & Kestemont, 2001; Xu & Kestemont, 2002). This observation has been related to the high inherent capability of perch to desaturate and elongate enzymatically dietary precursors into long chain highly unsaturated fatty acids.

The lipid profile of perch reflects also its particular dietary habit, based mainly on fish and aquatic invertebrates. The qualitative analysis of the stomach contents of perch from the three lakes evidenced an opportunistic feeding behaviour, strongly influenced by the natural diet resources available in the aquatic environment (Dorner et al., 2003; Persson & Greenberg, 1990). In particular, a dietary pattern mainly based on fish and benthos has emerged from the analysis of the gut content. Cyprinids were prevalent in the stomach of perch from the Salto Lake while *Atherina boyeri* and the gobidae *Knipowitschia panizzae* were the prevalent species in perch from Bracciano and Bolsena

Table 4
Fatty acid profiles of total lipids in perch (*Perca fluviatilis*) muscle from three Lakes of Latium during the year (% of total fatty acids)

	Bolsena Lake		Bracciano Lake		Salto Lake	
	Mean ± SD	(Range)	Mean ± SD	(Range)	Mean ± SD	(Range)
C12:0	0.08 ± 0.03	(0.04–0.12)	0.11 ± 0.04	(0.07–0.14)	0.10 ± 0.04	(0.07–0.15)
C13:0	0.02 ± 0.01	(0.02–0.03)	0.02 ± 0.00	(0.02–0.02)	0.03 ± 0.01	(0.02–0.04)
C14:0	1.75 ± 0.74	(0.94–2.47)	1.67 ± 0.23	(1.43–1.95)	2.03 ± 0.40	(1.46–2.39)
C15:0	0.52 ± 0.08	(0.46–0.64)	0.52 ± 0.06	(0.45–0.60)	0.47 ± 0.03	(0.44–0.51)
C16:0	21.85 ± 1.60	(19.97–23.50)	21.32 ± 0.86	(20.41–22.32)	21.24 ± 0.85	(20.27–22.08)
C17:0	0.58 ± 0.05	(0.55–0.65)	0.63 ± 0.02	(0.61–0.66)	0.65 ± 0.23	(0.50–0.99)
C18:0	6.25 ± 1.14	(4.73–7.34)	6.16 ± 0.41	(5.72–6.69)	6.53 ± 1.50	(5.04–8.01)
C20:0	0.17 ± 0.04	(0.13–0.23)	0.17 ± 0.03	(0.14–0.21)	0.17 ± 0.04	(0.13–0.22)
C21:0	0.15 ± 0.04	(0.11– 0.20)	0.18 ± 0.03	(0.16–0.23)	0.45 ± 0.13	(0.34–0.63)
Total saturated	31.38 ± 1.73	(29.75–32.90)	30.76 ± 0.91	(29.75–31.58)	31.64 ± 1.93	(29.08–33.68)
C14:1 $n-5$	0.12 ± 0.08	(0.02–0.19)	0.15 ± 0.04	(0.10–0.20)	0.13 ± 0.05	(0.07–0.18)
C16:1 $n-7$	6.59 ± 3.00	(3.14–9.90)	6.98 ± 1.12	(5.37–7.75)	6.33 ± 1.45	(4.79–8.28)
C18:1 $n-9$	10.33 ± 2.48	(7.67–12.98)	10.16 ± 1.33	(8.23–11.21)	11.89 ± 0.70	(11.04–12.65)
C18:1 $n-7$	4.25 ± 0.50	(3.90–4.99)	4.36 ± 0.28	(3.95–4.58)	2.90 ± 0.23	(2.58–3.13)
C20:1 $n-9$	0.40 ± 0.23	(0.20–0.72)	0.43 ± 0.05	(0.36–0.47)	0.59 ± 0.19	(0.41–0.85)
C22:1 $n-9$	0.04 ± 0.03	(0.04–0.08)	0.04 ± 0.03	(0.04–0.06)	0.07 ± 0.02	(0.05–0.09)
Total monounsaturated	21.73 ± 5.93	(15.18–27.3)	22.10 ± 2.55	(18.56–24.10)	21.91 ± 1.40	(20.18–23.56)
C18:2 $n-6$	2.50 ± 0.35	(2.05–2.89)	3.46 ± 0.55	(2.71–4.02)	3.29 ± 0.73	(2.63–4.21)
C18:3 $n-6$	0.31 ± 0.15	(0.15–0.50)	0.27 ± 0.06	(0.23–0.36)	0.20 ± 0.03	(0.17–0.23)
C18:3 $n-3$	1.08 ± 0.47	(0.54–1.62)	1.24 ± 0.61	(0.90 –2.15)	2.10 ± 0.92	(1.42–3.44)
C18:4 $n-3$	0.54 ± 0.33	(0.14–0.82)	0.49 ± 0.23	(0.30–0.82)	0.63 ± 0.10	(0.52–0.72)
C20:2 $n-6$	0.31 ± 0.09	(0.25–0.44)	0.51 ± 0.14	(0.31–0.63)	0.32 ± 0.06	(0.24–0.38)
C20:4 $n-6$	7.95 ± 2.46	(5.20–10.58)	7.84 ± 1.14	(6.43–9.03)	5.52 ± 0.51	(5.05–6.24)
C20:5 $n-3$	6.78 ± 1.25	(5.93–8.58)	6.46 ± 0.62	(5.89–7.34)	4.31 ± 0.65	(3.34–4.64)
C22:4 $n-6$	0.77 ± 0.08	(0.70–0.89)	0.91 ± 0.20	(0.62–1.07)	0.42 ± 0.10	(0.30–0.52)
C22:5 $n-3$	2.82 ± 0.28	(2.52–3.18)	2.91 ± 0.62	(2.38–3.56)	1.66 ± 0.25	(1.50–2.02)
C22:6 $n-3$	18.83 ± 4.30	(14.19–23.91)	18.03 ± 1.50	(16.22–19.83)	23.00 ± 2.01	(20.46–25.31)
Total polyunsaturated	41.89 ± 4.26	(37.93–46.97)	42.13 ± 1.86	(40.66–44.86)	41.45 ± 1.97	(39.66–43.68)
Total $n-3$ fatty acids	30.05 ± 2.31	(28.07–33.04)	29.13 ± 1.15	(27.70–30.48)	31.70 ± 1.73	(29.78–33.82)
Total $n-6$ fatty acids	11.83 ± 2.04	(9.54–13.93)	13.00 ± 1.33	(11.74–14.38)	9.75 ± 1.27	(8.69–11.48)
Ratio $n-3/n-6$	2.58 ± 0.29	(2.34–2.98)	2.26 ± 0.24	(1.99–2.46)	3.29 ± 0.48	(2.81–3.89)

Lakes. Macrobenthonic invertebrates like the Decapoda *Palaemotenes antennarius* in perch from the Lakes of Bracciano and Bolsena and *Orconectes limosus* in perch from the Salto Lake were also found.

The average weight of perch commercialised may range between 150 and 500 g, but in the lakes of Latium smaller fish (60–70 g) are also caught since, due to the presence of spines, perch is preferably consumed after filleting. To evaluate any size-effect on the chemical composition of perch, in February we analysed also perch of smaller (60 g) and larger (400 g) size. As regards the levels of nutrients, perch of about 60 g weight were characterised by a significantly higher water content ($P \leqslant 0.001$) and lower protein ($P \leqslant 0.001$), lipid ($P \leqslant 0.01$), nonprotein nitrogen ($P \leqslant 0.05$), cholesterol ($P \leqslant 0.05$) and α-tocopherol ($P \leqslant 0.01$) levels if compared with perch weighing 400 g (Tables 5, 6). The fatty acid profile of perch of different size harvested from the Salto Lake in the month of February is reported in Table 7. While small perch (60 g) showed a profile similar to that of fish weighing about 120 g, perch of large size (400 g) were characterised by even higher total PUFA ($P \leqslant 0.05$), $n-3$ PUFA ($P \leqslant 0.01$) and $n-3/n-6$ PUFA ratio values ($P \leqslant 0.001$), and lower MUFA ($P \leqslant 0.05$) and $n-6$ PUFA ($P \leqslant 0.001$). As regards single fatty acids, C22:6 appears to be highly affected by fish size (18.6% in small perch vs. 27.3% in large perch, $P \leqslant 0.001$). It is evident that the different feeding behaviour of perch during its lifetime, ranging from planktivorous to piscivorous, affects the lipid profile of fish muscle.

Table 5
Biometric measurements of perch (*Perca fluviatilis*) of different size harvested in February from the Salto Lake and proximate composition of the muscle tissue (g 100 g^{-1} wet fillet)

	60 g	400 g	*t*-Test
Length (cm)	17.2 ± 0.6	31.0 ± 2.8	*
Weight (g)	58.73 ± 8.59	415.14 ± 41.86	**
Viscera (% weight)	6.29 ± 2.65	8.64 ± 0.65	NS
Edible portion (% weight)	58.04 ± 1.94	59.06 ± 6.63	NS
pH	6.69 ± 0.01	6.53 ± 0.02	**
Moisture	81.58 ± 0.08	78.68 ± 0.13	***
Protein	16.22 ± 0.09	18.45 ± 0.07	***
Total lipid	1.01 ± 0.01	1.16 ± 0.01	**
Non protein N	0.29 ± 0.01	0.34 ± 0.01	*
Ash	1.01 ± 0.10	1.22 ± 0.09	NS

NS, not significant.
* $P \leqslant 0.05$.
** $P \leqslant 0.01$.
*** $P \leqslant 0.001$.

Table 6
Unsaponifiable lipid components of the muscle of perch (*Perca fluviatilis*) of different size harvested in February from the Salto Lake

	60 g	400 g	*t*-Test
mg 100 g^{-1} wet fillet			
Cholesterol	64.7 ± 0.2	65.9 ± 0.09	*
α-Tocopherol	0.66 ± 0.01	1.01 ± 0.02	**
Squalene	0.26 ± 0.01	0.32 ± 0.03	NS
All-*trans* retinol	n.d.	n.d.	
mg g^{-1} lipid			
Cholesterol	64.1 ± 0.2	56.8 ± 0.08	***
α-Tocopherol	0.65 ± 0.01	0.87 ± 0.02	**
Squalene	0.25 ± 0.01	0.28 ± 0.03	NS
All-*trans* retinol	n.d.	n.d.	

n.d., not detectable; NS, not significant.
* $P \leqslant 0.05$.
** $P \leqslant 0.01$.
*** $P \leqslant 0.001$.

Table 7
Fatty acid profiles of total lipids of the muscle of perch (*Perca fluviatilis*) of different size harvested in February from the Salto Lake (% of total fatty acids)

	60 g	400 g	*t*-Test
C12:0	0.10 ± 0.00	0.09 ± 0.00	***
C13:0	0.03 ± 0.00	0.03 ± 0.00	***
C14:0	2.60 ± 0.01	2.33 ± 0.06	*
C15:0	0.54 ± 0.01	0.43 ± 0.01	**
C16:0	20.24 ± 0.07	20.77 ± 0.07	*
C17.0	0.65 ± 0.00	0.48 ± 0.00	***
C18:0	5.72 ± 0.09	4.43 ± 0.02	**
C20:0	0.23 ± 0.01	0.11 ± 0.00	**
C21:0	0.29 ± 0.00	0.48 ± 0.01	***
Total saturated	30.41 ± 0.18	29.16 ± 0.01	**
C14:1 $n-5$	0.15 ± 0.01	0.27 ± 0.03	*
C16:1 $n-7$	6.89 ± 0.08	7.10 ± 0.04	NS
C18:1 $n-9$	13.23 ± 0.17	11.39 ± 0.01	**
C18:1 $n-7$	3.53 ± 0.15	2.80 ± 0.04	*
C20:1 $n-9$	0.70 ± 0.01	0.57 ± 0.01	**
C22.-1 $n-9$	0.06 ± 0.01	0.04 ± 0.00	NS
Total monounsaturated	24.57 ± 0.41	22.16 ± 0.04	*
C18:2 $n-6$	3.42 ± 0.01	2.95 ± 0.08	*
C18:3 $n-6$	0.21 ± 0.02	0.13 ± 0.01	*
C18:3 $n-3$	2.00 ± 0.03	1.93 ± 0.00	NS
C18:4 $n-3$	0.90 ± 0.03	0.74 ± 0.05	NS
C20:2 $n-6$	0.30 ± 0.00	0.40 ± 0.01	**
C20:4 $n-6$	6.22 ± 0.05	4.26 ± 0.01	***
C20:5 $n-3$	6.03 ± 0.07	4.26 ± 0.02	***
C22:4 $n-6$	0.46 ± 0.01	0.25 ± 0.00	***
C22:5 $n-3$	1.84 ± 0.01	1.50 ± 0.07	*
C22:6 $n-3$	18.63 ± 0.43	27.26 ± 0.10	***
Total polyunsaturated	40.03 ± 0.59	43.68 ± 0.05	*
Total $n-3$ fatty acids	29.42 ± 0.51	35.69 ± 0.14	**
Total $n-6$ fatty acids	10.61 ± 0.07	7.99 ± 0.10	***
Ratio $n-3/n-6$	2.77 ± 0.03	4.47 ± 0.07	***

NS, not significant.
* $P \leqslant 0.05$.
** $P \leqslant 0.01$.
*** $P \leqslant 0.001$.

Table 8
Organochlorine pesticides residues in muscle tissue of perch (*Perca fluviatilis*) from three Lakes of Latium (μg kg^{-1} wet fillet)[a]

	Bolsena Lake	Bracciano Lake	Salto Lake
Total lipids (g kg^{-1})	5.1	6.4	6.0
Aldrin	n.d.	n.d.	n.d.
Dieldrin	0.04	0.03	0.02
Sum[b]	*0.04*	*0.03*	*0.02*
4,4′-DDT	0.17	0.08	0.01
4,4′-DDD	0.38	0.04	0.08
4,4′-DDE	1.71	0.26	0.52
2,2′-DDE	n.d.	n.d.	n.d.
4,4′-DDM	n.d.	n.d.	n.d.
4,4′-DDMU	n.d.	n.d.	0.03
2,4′-DDT	0.01	n.d.	n.d.
2,4′-DDD	0.04	n.d.	0.01
2,4′-DDD olefin	n.d.	n.d.	n.d.
2,4′-DDE	0.01	n.d.	n.d.
Sum[c]	*2.32*	*0.38*	*0.65*
α-Chlordane	0.02	0.01	0.01
γ-Chlordane	<0.01	<0.01	<0.01
Oxychlordane	0.01	n.d.	n.d.
cis-Nonachlor	0.01	0.01	0.01
trans-Nonachlor	0.03	0.01	0.03
Sum[d]	*0.07*	*0.03*	*0.05*
Endrin[e]	n.d.	n.d.	n.d.
α-HCH	0.01	0.01	0.01
β-HCH	n.d.	0.06	n.d.
δ-HCH	n.d.	n.d.	n.d.
Sum[f]	*0.01*	*0.07*	*0.01*
γ-HCH (Lindane)[g]	0.01	0.02	0.02
HCB[f]	0.08	0.04	0.34
Heptachlor	n.d.	n.d.	n.d.
Heptachlor endo ep.	n.d.	n.d.	n.d.
Heptachlor exo ep.	0.01	0.01	0.01
Sum[d]	*0.01*	*0.01*	*0.01*
Octachlorostyrene	n.d.	n.d.	0.03
α-Endosulfan	n.d.	n.d.	n.d.
α-Chlordene	n.d.	n.d.	n.d.
γ-Chlordene	n.d.	n.d.	n.d.
Mirex	n.d.	n.d.	n.d.
Quintozen	n.d.	n.d.	n.d.
Methyl-chlorpyriphos	n.d.	n.d.	n.d.
Chlorpyriphos	n.d.	n.d.	n.d.

n.d., not detected.
[a] When not specified, action limit is not established.
[b] Action limit established by the Italian Government (=5 μg kg^{-1}) and by OSPAR countries (=100 μg kg^{-1}).
[c] Action limit established by the Italian Government (=50 μg kg^{-1}) and by OSPAR countries (DDT + DDE + DDD = 500 μg kg^{-1}).
[d] Action limit established by the Italian Government (=5 μg kg^{-1}).
[e] Action limit established by the Italian Government (=1 μg kg^{-1}).
[f] Action limit established by the Italian Government (=10μg kg^{-1}) and by OSPAR countries (HCB = 50 μg kg^{-1}; α-HCH + β-HCH = 50 μg kg^{-1}).
[g] Action limit established by the Italian Government (=25 μg kg^{-1}) and by OSPAR countries (=100 μg kg^{-1}).

The levels, expressed on a fresh weight basis, of organochlorine pesticides and PCBs residues detected in the muscle tissue of perch from the lakes of Bracciano, Bolsena and Salto are shown in Tables 8 and 9, respectively. All samples showed a low contamination level, well below the Italian and European action limits. When values are reported on a lipid g basis (Table 10) it is possible to observe a higher presence of DDT and its metabolites in the lipid fraction of perch from Bolsena than in that of perch from Bracciano and Salto Lakes (453 ng/lipid g vs. 59.3 and 109 ng/lipid g, respectively). Similarly, PCB contamination of perch fillets on a lipid g basis was relatively higher in the lipid fraction of perch from the Bracciano Lake (507 ng/lipid g vs. 340 and 402 ng/lipid g). This observation may be an indirect information on the different contamination of the aquatic environments.

In spite of the low contamination levels detected in all samples analysed, in consideration of the known increasing bioaccumulation of organochlorine substances with the age of fish, any evaluation on the safety of perch from the lakes of Latium should require a higher number of analyses extended also to specimens of larger size.

Table 9
Polychlorinated biphenyl residues in muscle tissue of perch (*Perca fluviatilis*) from three Lakes of Latium (μg kg^{-1} wet fillet)[a]

	Bolsena Lake	Bracciano Lake	Salto Lake
Total lipids (g kg^{-1})	5.1	6.4	6.0
PCB 151	n.d.	0.02	0.05
PCB 74	0.01	0.04	0.02
PCB 49	0.02	0.02	0.03
PCB 206	0.03	n.d.	n.d.
PCB 119	n.d.	n.d.	n.d.
PCB 136	n.d.	n.d.	n.d.
PCB 47	0.01	0.01	0.01
PCB 97	0.03	0.06	0.05
PCB 188	0.05	0.08	n.d.
PCB 185	n.d.	n.d.	n.d.
PCB 155	n.d.	n.d.	n.d.
PCB 198	n.d.	n.d.	n.d.
PCB 194	0.01	n.d.	n.d.
PCB 183	0.04	0.04	0.04
PCB 87	0.03	0.07	0.06
PCB 110	0.08	0.19	0.18
PCB 104	n.d.	n.d.	n.d.
PCB 28[b]	0.03	0.02	0.03
PCB 52[c]	0.03	0.04	0.05
PCB 101[b]	0.15	0.26	0.24
PCB 118[b]	0.29	0.65	0.38
PCB 138[d]	0.19	0.47	0.30
PCB 153[d]	0.37	0.63	0.42
PCB 180[b]	0.15	0.21	0.17
PCB 44	0.01	0.04	0.02
PCB 132	0.03	0.05	0.04
PCB 70	0.01	0.02	0.05
PCB 128	0.06	0.13	0.06
PCB 31	0.01	<0.01	0.02
PCB 187	n.d.	0.06	0.08
PCB 170	0.07	0.09	0.07
PCB 5	n.d.	n.d.	n.d.
PCB 66	0.03	0.05	0.03
Sum	*1.74*	*3.25*	*2.40*

n.d., not detected.
[a] When not specified, action limit is not established.
[b] Action limit established by OSPAR countries (=80 μg kg^{-1}).
[c] Action limit established by OSPAR countries (=40μg kg^{-1}).
[d] Action limit established by OSPAR countries (=100 μg kg^{-1}).

Table 10
Sum of DDT and related metabolites and sum of PCBs in perch (*Perca fluviatilis*) muscle from three Lakes of Latium (ng g^{-1} lipid)

	Bolsena Lake	Bracciano Lake	Salto Lake
Σ DDT and metabolites	453	59.3	109
Σ PCBs	340	507	402

4. Conclusions

The results of this study enable a positive evaluation of the nutritional quality and safety of European perch (*P. fluviatilis*) living in the lakes of Latium. Perch from the three lakes under study were characterised by a comparable nutritional quality, mainly characterised by good protein and mineral contents and low lipid levels throughout the year. The lipid fraction was characterised by a high proportion of $n-3$ PUFA, ascribable to the predatory feeding habit of perch and by a good $n-3/n-6$ ratio value, an important parameter considering that generally freshwater fish has a higher amount of $n-6$ PUFA in comparison with marine fish. Rubidium and cesium, minerals higher in perch from the volcanic lakes of Bracciano and Bolsena, resulted to be good indicators of the origin of fish. As regards organic contaminants, all samples were characterised by low residues of organochlorine pesticides and PCBs level, well below the Italian and European action limits.

Acknowledgement

Work supported by Regione Lazio (Programma Triennale di Ricerca Agricola, Agroambientale ed Agroindustriale 1999–2001).

References

Anon. (1992). *Monitoring Manual – Principles and Methodology of the Joint Monitoring Programme*. A compilation of standards and guidance values for contaminants in fish, crustaceans and molluscs for the assessment of possible hazards to human health. Oslo and Paris Commissions. Update 1992 – A7.2/92-E.

Association of Official Analytical Chemists (1990). *Official methods of analysis* (15th ed.). Arlington, VA: Association of Official Analytical Chemists.

Blanchard, G., Druart, X., & Kestemont, P. (2005). Lipid content and fatty acid composition of target tissues in wild *Perca fluviatilis* females in relation to hepatic status and gonad maturation. *Journal of Fish Biology, 66*, 73–85.

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction. *Canadian Journal Biochemistry and Physiology, 37*, 911–917.

Bruno, S., & Maugeri, S. (1992). *Pesci d'acqua dolce: atlante d'Europa*. Milano: Mondadori.

Di Muccio, A., Generali, T., Attard Barbini, D., Pelosi, P., Ausili, A., Vergori, F., et al. (1997). Single-step separation of organochlorine pesticide residues from fatty materials by combined use of solid-matrix

partition and C18 cartridges. *Journal of Chromatography A, 765*, 61–68.

Dorner, H., Berg, S., Jacobsen, L., Hulsmann, S., Brojerg, M., & Wagner, A. (2003). The feeding behaviour of large perch *Perca fluviatilis* (L.) in relation to food availability: a comparative study. *Hydrobiologia, 506–509*, 427–434.

Gandolfi, G., Zerunian, S., Torricelli, P., & Marconato, A. (1991). *I pesci delle acque interne italiane*. Roma: Istituto Poligrafico e Zecca dello Stato.

Gazzetta Ufficiale della Repubblica Italiana, Number 207, 5-Sept-2000 (suppl. ord.). Ministero dell'Economia e delle Finanze. Istituto Poligrafico e Zecca dello Stato, Roma.

Henderson, R. J., & Tocher, D. R. (1987). The lipid composition and biochemistry of freshwater fish. *Progress in Lipid Research, 26*, 281–347.

Kinsella, J. E., Shimp, J. L., Mai, J., & Weihrauch, J. (1977). Fatty acid content and composition of freshwater finfish. *Journal of the American Oil Chemists' Society, 54*, 424–429.

Orban, E., Di Lena, G., Masci, M., Nevigato, T., Casini, I., Caproni, R., et al. (2004a). Growth, nutritional quality and safety of oysters (*Crassostrea gigas*) cultured in the lagoon of Venice (Italy). *Journal of the Science of Food and Agriculture, 84*, 1929–1938.

Orban, E., Di Lena, G., Ricelli, A., Paoletti, F., Casini, I., Gambelli, L., et al. (2000). Quality characteristics of sharpsnout sea bream (*Diplodus puntazzo)* from different intensive rearing systems. *Food Chemistry, 70*, 27–32.

Orban, E., Masci, M., Di Lena, G., Nevigato, T., Casini, I., Caproni, R., et al. (2004b). Qualità alimentare e sicurezza d'uso in funzione dell'ambiente e della stagione dell'anguilla (*Anguilla anguilla*) oggetto di pesca nei principali bacini lacustri della regione Lazio. *Industrie Alimentari, 43*, 760–767.

Persson, L., & Greenberg, L. A. (1990). Optimal foraging and habitat shift in perch (*Perca fluviatilis*) in a resource gradient. *Ecology, 71*, 1699–1713.

Peters, E. L., Schultz, I. R., & Newman, M. C. (1999). Rubidium and cesium kinetics and tissue distributions in channel catfish (*Ictalurus punctatus*). *Ecotoxicology, 8*, 287–300.

Smith, A. G., & Gangolli, S. D. (2002). Organochlorine chemicals in seafood: occurrence and health concerns. *Food and Chemical Toxicology, 40*, 767–779.

Xu, X. L., Fontaine, P., Melard, C., & Kestemont, P. (2001). Effects of dietary fat levels on growth, feed efficiency and biochemical compositions of Eurasian perch *Perca fluviatilis*. *Aquaculture International, 9*, 437–449.

Xu, X. L., & Kestemont, P. (2002). Lipid metabolism and fatty acid composition in tissues of Eurasian perch *Perca fluviatilis* as influenced by dietary fats. *Lipids, 37*, 297–304.