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Morphological screening of carp *Cyprinus carpio*: relationship between morphology and fillet yield

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Abstract – We propose a simple method to quantify the morphology of 2–3-year-old carps (*Cyprinus carpio*) which is related to their fillet yield. This method is based on the automated image analysis of the lateral projection of the fish (mask). Seven morphological measurements specifically related to fillet yield of carps were defined. The comparison between this method and the conventional quantification of fish shape, based on measurements of skeletal landmarks, increases the significance of this fitting. From the analysis of the morphometric data, we propose a profitable carp morphotype which is defined by four angles and two distances which quantify the shape of the head and the position of the caudal peduncle, respectively. The main characteristic of this morphotype is the absence of a large dorsal development, and the ventral position of the caudal peduncle. © Ifremer/Elsevier, Paris

Automation / image analysis / morphology / morphotype / multivariate analysis / fillet yield / carp / *Cyprinus carpio*

Résumé – Tri morphologique des carpes, *Cyprinus carpio* : relation entre la morphologie et le rendement du filetage. Nous proposons une méthode simple pour quantifier la morphologie des carpes (*Cyprinus carpio*) âgées de 2 à 3 ans et prédire leur rendement au filetage. Cette méthode est fondée sur une analyse automatique de l'image de leur profil (masque). Un total de sept mesures morphologiques directement liées au rendement du filetage des carpes a été défini. La comparaison de la présente méthode avec celles, plus conventionnelles, fondées sur les mesures d'intervalles entre points remarquables associés au squelette des animaux, renforce ce lien. À partir de l'analyse des données morphométriques obtenues, nous proposons un morphotype de carpes économiquement rentables, en aquaculture, à partir de la connaissance de quatre angles et deux distances qui définissent la forme de la tête et la position du pédoncule caudal. Les caractéristiques principales de ce morphotype sont un faible développement dorsal et une position ventrale du pédoncule caudal. © Ifremer/Elsevier, Paris

Automatisation / analyse d'image / morphologie / morphotype / analyse multivariée / rendement au filetage / carpe / *Cyprinus carpio*

1. INTRODUCTION

Commercial fish farming in intensive systems has been developed for few fish species, for example salmonids like *Salmo trutta*, *S. salar* or *Oncorhynchus mykiss* [6, 34] in European countries. But, this aquaculture production requires the use of artificial food, specific installations, high investments and especially selected breeders. In contrast, extensive aquaculture systems (i.e. with natural food and less expensive substructures but with environmental constraints) are more widespread in Europe [6]. Extensive aquaculture is used for several species and traditionally for the production of carps in the Rhône-Alps [4]. This region

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produces annually about 400 t carp for filleting (the production in France is about 8 000 t carp per year, about 60 % of which are used for restocking [19, 31]). In the eighties, this activity tended to disappear because of both economical and ecological difficulties [19, 31] as well as an unjustified bad image of the cooking of carps [29, 35]. Nevertheless, there are objective reasons for favouring new developments [26] and consequently, for maintaining and increasing this activity in the Rhône-Alps region, via the development of aquaculture in natural ponds or in fishfarms [4, 23, 36]. To be profitable, these developments must take into account consumer desires, who appreciate new products such as ready-cooked dishes or fillets [3, 4]. They require the standardisation of fish size, the increase of fillet yield and the mechanisation of filleting, even if it is still not at all settled yet for carps [3].

In this study, we show that carp fillet yield may be estimated from the analysis of the shape of their lateral surfaces obtained directly from pictures. We propose a profitable morphotype deduced from our measurements.

2. MATERIALS AND METHODS

All abreviations of terms used are defined in *table I*.

2.1. Fishes

Sixty-two carps (0.9–2.2 kg) were captured in winter time from ponds and stored in small basins for 10 d without any food, before processing. They were killed by electrocution when entering the plant. Filleting was done manually without gutting the fish. Carps coming from five regions of France were studied: Allier, Brenne, Dombes, Forez and Poitou-Charentes. Three groups were considered. The first one was constituted by 42 animals which came from Allier, Brenne, Dombes, Forez and Poitou-Charentes and allowed us to define the method. The second and the third one, were constituted by the animals which came from Dombes and Forez, respectively, and were used to validate the method.

2.2. Photos

The fish photos were either black and white prints or numerical files. Black and white prints were provided by B. Fauconneau (Inra, Rennes, France) [12, 31]. These prints were scanned with an Arcus II color scanner (Agfa) (300 ppi, 8 bits) and treated with Adobe

Table I. Abbreviations used.

Symbol	Unit	Signification
C	–	circle that overlaps M, G and T
C_c	–	centre of the circle C
$D-_i$	%	$Y-_i$ minus the mean of Y–
$D+_i$	%	$Y+_i$ minus the mean of Y+
d_0, d_1	pixel	partitions of the height of the skull which corresponds to the 17th angular sector by the circular projection of the upper point of pc
F+	g	weight of the fillet with skin
F–	g	weight of the fillet without skin
G	–	centroid of the binary mask of the fish
H_6	pixel	mean height of the skull for the 3 angular partitions R_5, R_6 and R_7
H_{17}	pixel	height of the skull for the 17th angular partition
L	pixel	longitudinal axis of the animal defined as the line which overlaps M, G and Q_i when Q_i corresponds to the maximum height of the caudal peduncle
L_1	pixel	length of L
M_i	%	$D-_i$ ($Y-_i$ minus the mean of $Y-_i$) minus $D+_i$ ($Y+_i$ minus the mean of $Y+_i$)
M	–	mouth
pc	–	caudal peduncle
PCA	–	principal components analysis
P_1	–	$(H_6 + \Delta_6)/H_6$
P_2	–	d_0/d_1
P_3	–	L_1/pc
P_4	–	$(H_{17} - H_6)$/pc
P_5	–	$(H_{17} - H_6)/H_{17}$
P_6	–	$H_6 \times 17/H_{17} \times 6$
pixels	–	picture elements
Q_1, Q_2, Q_3	pixel	pc heights at 79, 84 and 89 % of the total length of the binary mask of the fish, respectively
R0	–	boundary of 41 % of the total length of the binary mask of the fish
R_5, R_6, R_7, R_{17}	–	partition at 5/20, 6/20, 7/20 and 17/20 of R0, respectively
T	–	notch of the caudal fin
Y+	%	fillet yield with skin
Y–	%	fillet yield without skin
Δ_6	pixel	mean height of the ventral side of the head for the 3 angular partitions which correspond to R_5, R_6 and R_7

Photoshop software. Numerical pictures came from the 'Association pour le développement de la pêche en Rhône-Alpes' (ADAPRA).

2.3. Fillet yield measurements

Each animal was weighed fresh. The fillets were weighed with (F+) and without (F–) the skin. The fillet yields (Y+) and (Y–) of individuals were defined as the ratio of the weight of the fillets (F+) and (F–) versus the total weight of the fish, respectively.

2.4. Image analysis system and principle

The images were analysed on an Undigo R-4000 Work Station (SiliconGraphic, USA) with Visilog 4.1.1 (Noesis, France) under the C-interpreter with which the dedicated software was written. Image analysis was realised in two steps. First, 7 basic parameters were measured from the binary masks of the lateral surface flanks of the animals. Second, 6 ratios were calculated from the data and used to determine how the morphology of the animals was related to their fillet yield.

The analysis of the mask was based on the calculation of its axis (L), which allows a logical partition. The outlines of the mask were obtained directly from the pictures of the fish (*figure 1*a and b). The bounding box and the coordinates of the centre of mass (G) of the mask were calculated (*figure 1*a). The abscissa of the mouth (M) is one of the first vertical boundary of the bounding box; its ordinate is calculated as the mass centre of the intersection between 4 vertical lines (the first of which is the first vertical boundary of the bounding box) and the boundary of the mask (*figure 1*a). The coordinates of the notch of the caudal fin were calculated as follows. We selected the tail as the intersection between the binary mask of the fish and a rectangle defined as the area of the rear 16 % of the area of the bounding box. The coordinates of the notch (T) are the ones of the centroid of the major concavity of the outline of the tail [16]. The arc of the fish was defined as the intersection between the binary mask of the fish and the circle (C) defined by M, T and G; C_c is the centre of this circle. A chord is defined between M and the intersection between C and the radius, which defines a sector equal to 41 % of the angle MC_cT (R0) (*figure 1*b). L (MGT) corresponds to the chord (MG) in its proximal part, and to the arc (GT) in its rear one.

The aim of the logical partition of the mask is the calculation of sectors on C. C_cM is considered as the origin of the angles. The position of the caudal peduncle corresponds to one of the 3 radii C_cQ_1, C_cQ_2 and C_cQ_3 defined by the angles MC_cQ_1, MC_cQ_2 and MC_cQ_3, respectively (*figure 1*b). These three angles were equal to 79, 84 and 89 % of the angle MC_cT, respectively. The segment Q_i is selected when the area of its overlap with the binary mask is minimum. The skull corresponds to the first quadrant of the binary mask defined by L and R0. Twenty angles were calculated in the skull between C_cM and R0. Four radii were considered as morphologically significant: R_5, R_6, R_7 and R_{17} (*figure 1*b); the indices correspond to the ranks of angular partition of the leading part of the mask.

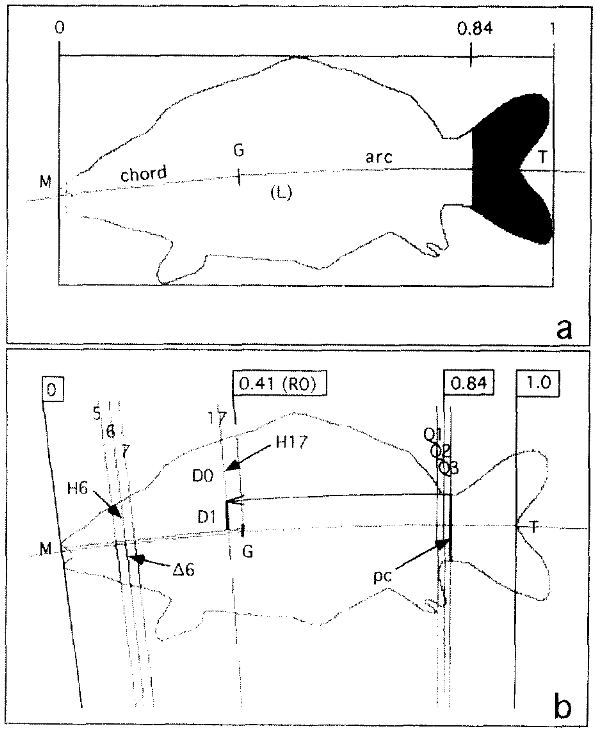

Figure 1. (a) Partition of the lateral projection of the fish (mask). The tail (grey area) of the fish was defined as the most posterior 16 % of the distal region of the bounding box. T: Centroid of the main notch of the tail; M: mouth; L: axis of the fish. (b) Angular partition of the fish mask. The skull is the first quadrant of the mask. H_6 is equal to the mean of the heights of the three segments 5, 6 and 7 of the skull, and $\Delta 6$ equals the mean of the heights of the three homologous segments in the ventral part of the head. H_{17} is the height of the 17th segment of the skull. The caudal peduncle (pc) is defined as the minimum height of three crossings of the mask by three radii Q_1, Q_2 and Q_3. d_1 is the projection of the highest point of pc on the 17th segment of the skull.

2.5. Calculation of morphological parameters

Seven morphological parameters were used (*figure 1*b): (i) length of the arc MGQ_i (defined as L_l); (ii) height of the caudal peduncle (defined as pc); (iii) mean height of the skull for the 3 angular partitions numbered 5, 6 and 7 (defined as H_6); (iv) mean height of the ventral side of the head for the same angular partitions (defined as Δ_6); (v) distance between C_c and the upper point of pc; (vi) d_0 and d_1, which are the partitions of the 17th angular sector height of the skull by the circular projection of the upper point of pc; and (vii) the height of the 17th segment of the skull (defined as H_{17}). From these measurements six ratios were calculated: $P_1 = (H_6 + \Delta_6)/H_6$, $P_2 = d_0/d_1$, $P_3 = L_l/pc$, $P_4 = (H_{17} - H_6)/pc$, $P_5 = (H_{17} - H_6)/H_{17}$ and $P_6 = H_6 \times 17/H_{17} \times 6$. They do not depend on the magnification of the pictures. From these ratios, 6 parameters were calculated when L_l equals 10 cm: a_1, a_2, a_3, a_4, d_1 and pc (*figure 5*), which were used to define the morphotype of each of the animals (a_2 and a_3 correspond to the angle MH_6H_{17} for the lower and the upper values of a_1, respectively).

2.6. Classical morphometric measurements

This analysis was performed on 30 carps coming from Dombes. Because of the difficulty of determining precisely landmarks on fish photos, we decided not to perform a geometric analysis [7, 8, 32, 33]. In our case of dealing with one population of individuals of the same age, classical multivariate analyses are sufficient to show the general tendency of shape variation, including allometry. A log-shape ratio or Mosimman approach was used [22, 23, 37, 38]. The main purpose of this analysis is to perform a double-centred principal component analysis (PCA) (centred by line and column) on the log-transformed data [24] using ADE software [10]. This method is efficient to remove isometric size effect. As shown in *figure 2* and *table II*, the coordinates of 10 points were measured on each of the numerical fish photos [13, 14, 31]. To reduce measurement errors, the coordinates of each landmark of each fish were taken five times. Then, we used the mean of each of them, excluding aberrant values. They were measured with NIH Image 5.9 software. The 19 distances between all point pairs were considered as the morphometric parameters. The data were log-transformed according to the general formula for allometry [21]. Then, we computed the double centred PCA on the transformed data. To check if there was a significant difference between fish with good and bad fillet yield, we performed ANOVA with the JMP software (SAS Institute Inc., © 1989–1994, USA).

2.7. Multivariate analysis of the image analysis data

We have done a centred principal component analysis (PCA) on the values of H_6, H_{17}, D_6, d_1 and pc,

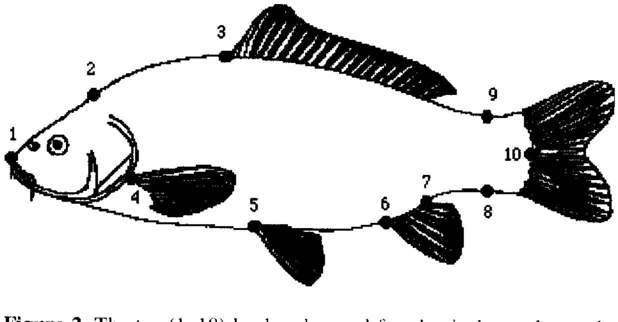

Figure 2. The ten (1–10) landmarks used for classical morphometric data.

Table II. Classical morphometric variables used as described in *figure 2*.

Variables	Landmarks
Length between the mouth and the upper limit of the opercle	1–2
Predorsal fin length	1–3
Prepectoral fin length	1–4
Preventral fin length	1–5
Preanal fin length	1–6
Standard length	1–10
Length between the upper limit of the opercle and the anterior limit of the dorsal fin	2–3
Length between the upper limit of the opercle and the anterior limit of the pectoral fin	2–4
Length between the upper limit of the opercle and the anterior limit of the ventral fin	2–5
Distance between the dorsal fin (anterior) and the pectoral fin	3–4
Distance between the dorsal fin (anterior) and the ventral fin	3–5
Distance between the dorsal fin (anterior) and the anal fin (anterior)	3–6
Distance between the dorsal fin (anterior) and the anal fin (posterior)	3–10
Distance between the ventral fin and the anal fin (anterior)	5–6
Distance between the ventral fin and the anal fin (posterior)	5–7
Distance between the ventral fin and the caudal fin (anterior)	5–10
Anal fin length	6–7
Distance between the anal fin (posterior) and the caudal fin (anterior)	7–10
Caudal peduncle depth	8–9

which were calculated when the length of L_l equalled 10 cm. To check the differences between fish with good and bad fillet yield, we performed ANOVA as described previously.

2.8. Individual aging

We have studied the carp's dorsal spiny rays with skeletochronological techniques [9, 27, 28, 30] to compare the real growth performance of fish between the five regions and to estimate their age at commercial length. The dorsal spiny ray of ten carps per pond were sampled. They were dried, demineralised and sliced with a Cryomat apparatus (Leica). The sections (about 15–20 µm thick) were stained with Ehrlich's hematoxylin [28]. The annuli (winter slow-growing marks) look like thin hematoxylinophilic concentric lines, and they are separated by unstained (or weakly stained) fast growing zones. Annual marks were counted and the widths of growth spaces between annuli (i.e. the zones) were compared.

3. RESULTS

In a given pond, the number of annuli and the spatial organisation of growth marks, especially fast-growing zones, are homogeneous. But when comparing the results between the ponds, carps show a variety of annuli numbers (i.e. different ages). Moreover, even if the fish coming from the different ponds have similar lengths and weights, the growth intervals' widths on spiny rays are different. The best growth (wide, fast-growth space) was obtained in Forez' pond; the spiny rays of the carps of this region show only one annulus that is distant from the margin of the bone. The slower growth is observed in carps of Brenne and Allier. They have three annuli and the fast growing zones are less wide, i.e. less than half the growth intervals of Forez carps. In the two other geographical regions, the commercial length is reached only after two winters.

The variability in fillet yields of animals that we have processed in this study was very low, and equalled published values [31]. In the first tested population, the mean of Y+ and Y− equal 34.6 ± 2.7 and 28.9 ± 2.6 %, respectively (*table III*). These fillet yields did not depend on the sex of animals. For each animals, we considered $D+_i$ and $D-_i$, defined as $Y+_i$ minus the mean of $Y+_i$, and $Y-_i$ minus the mean of $Y-_i$ (i corresponds to fish rank), respectively; m_i was the mean of $D+_i$ and $D-_i$ of a given animal.

As shown in *figure 3*, the segregation of fish with and without a good fillet yield is not clearly realised when we take into account the classical morphometric

Table III. R: Rank of the animal in the first test population. Y: Rank of the animals when the m value is over 1.4 %. M: Rank of the animal which have profitable morphotype according to the morphometric screening. W: Weight of the animals. The other abbreviations are defined in the text.

R	W (g)	F+ (g)	F− (g)	Y+ (%)	D+ (%)	Y− (g)	D− (g)	m_i (%)	m_i (%)	Y	M
1	1 360	480	395	35.29	0.67	29.04	0.15	0.41			
2	1 410	440	370	31.21	−3.42	26.24	−2.65	−3.04			
3	1 190	445	380	37.39	2.77	31.93	3.04	2.91	2.91	3	3
4	1 340	465	395	34.70	0.08	29.48	0.58	0.33			
5	1 560	550	460	35.26	0.63	29.49	0.59	0.61			
6	1 090	380	320	34.86	0.24	29.36	0.46	0.35			
7	1 270	430	335	33.86	−0.77	26.38	−2.52	−1.64			
8	1 070	395	335	36.92	2.29	31.31	2.41	2.35	2.25	8	8
9	1 350	435	350	32.22	−2.40	25.93	−2.97	−2.68			
10	1 240	440	375	35.48	0.86	30.24	1.35	1.10			
11	1 120	390	320	34.82	0.20	28.57	−0.32	−0.06			
12	1 340	465	385	34.70	0.08	28.73	−0.16	−0.04			12
13	1 160	395	335	34.05	−0.57	28.88	−0.01	−0.29			
14	940	325	275	34.57	−0.05	29.26	0.36	0.16			
15	870	290	240	33.33	−1.29	27.59	−1.31	−1.30			
16	790	285	240	36.08	1.45	30.38	1.49	1.47	1.47	16	16
17	1 570	480	390	30.57	−4.05	24.84	−4.05	−4.05			
18	1 260	455	380	36.11	1.49	30.16	1.27	1.38			
19	1 020	355	290	34.80	0.18	28.43	−0.46	−0.14			
20	1 140	355	280	31.14	−3.48	24.56	−4.33	−3.91			
21	1 460	510	415	34.93	0.31	28.42	−0.47	−0.08			
22	1 730	585	480	33.82	−0.81	27.75	−1.15	−0.98			22
23	1 140	415	340	36.40	1.78	29.82	0.93	1.36			
24	1 170	445	375	38.03	3.41	32.05	3.16	3.28	3.28	24	24
25	1 350	500	410	37.04	2.41	30.37	1.48	1.94	1.94	25	25
26	1 350	495	405	36.67	2.04	30.00	1.11	1.57	1.57	26	26
27	910	300	250	32.97	−1.66	27.47	−1.42	−1.54			
28	880	280	225	31.82	−2.81	25.57	−3.33	−3.07			
29	1 020	350	290	34.31	−0.31	28.43	−0.46	−0.39			
30	970	340	285	35.05	0.43	29.38	0.49	0.46			30
31	1 540	595	490	38.64	4.01	31.82	2.92	3.47	3.47	31	31
32	1 420	500	430	35.21	0.59	30.28	1.39	0.99			
33	2 040	610	530	29.90	−4.72	25.98	−2.91	−3.82			
34	2 310	800	680	34.63	0.01	29.44	0.54	0.28			
35	1 950	760	660	38.97	4.35	33.85	4.95	4.65	4.65	35	35
36	2 040	610	530	29.90	−4.72	25.98	−2.91	−3.82			
37	1 240	520	445	41.94	7.31	35.89	6.99	7.15	7.15	37	37
38	1 270	435	365	34.25	−0.37	28.74	−0.15	−0.26			
39	1 280	500	425	39.06	4.44	33.20	4.31	4.37	4.37	39	39
40	1 060	330	275	31.13	−3.49	25.94	−2.95	−3.22			
41	1 060	295	245	27.83	−6.79	23.11	−5.78	−6.29			
42	1 180	405	345	34.32	−0.30	29.24	0.34	0.02			
Mean				34.62		28.89					
SD				2.74		2.55					
SE				2.77		2.58					

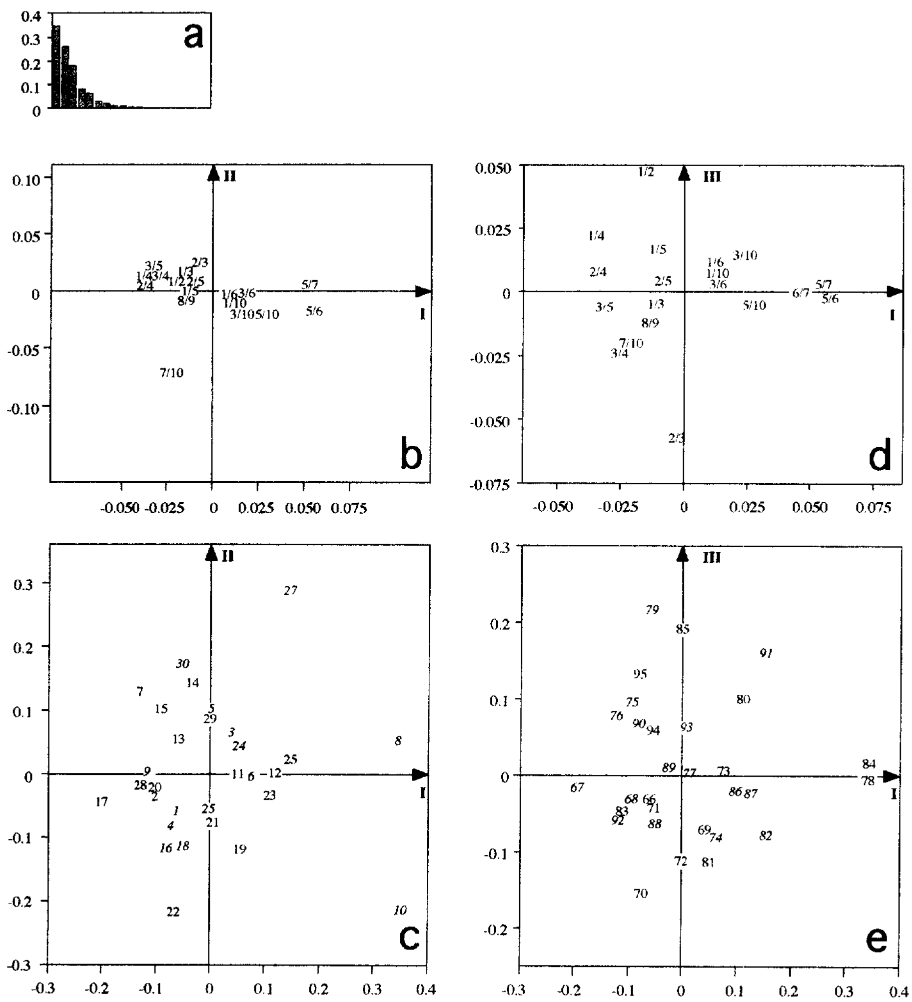

Figure 3. (a) Relative inertia of the axes of the double centred PCA on classical morphometric data. The (I, II) projection planes of the spatial distribution of the variables and the fish are presented in (b), and (c), respectively. Homologous (I, III) projection planes are presented in (d) and (e), respectively. The fish with a good fillet yield (defined in terms of weight) are indicated in italics.

approach. From this figure, only individuals #8 and #10 may be isolated from the first population (*table III*). The ANOVA analysis of coordinates of individuals in the projection plane (I, II) shows that the two samples are not significantly different ($P = 0.2264$).

To characterise the most significant morphometric parameters in terms of fillet yield, we proceeded as follows. We considered fish which were characterised by a value of m_i over a given threshold, and we retained those morphometric parameters which allowed us to define a frame of references that characterised the same fish (males and females) with the lower percentage of false positive and false negative answers. This enabled us to define the 7 basic parameters and the 6 ratios (P_1, P_2, P_3, P_4, P_5, P_6) which were deduced from them. For example, in the first sample, when the lower limit of m_i equalled 1.4 %, the image analysis characterised 13 animals (*table III*). The individuals #12, #22 and #30 should be considered as false positive as shown by m_{12}, m_{22} and m_{30} which were lower than 1.4 %. However, the measured ($Y+_i$, $Y-_i$) equalled (34.7, 28.7 %), (33.8, 27.8 %) and (35.1, 29.4 %), respectively. The differences between these values and the homologous mean are around 1 %, rendering the error acceptable. The multivariate analysis of these data reinforced this conclusion (*figure 4*).

As described in the Materials and Methods section, the standardised values of the elementary parameters H_6, H_{17}, Δ_6, d_l and pc of the individuals were calculated when L_l equals 10 cm. The centred PCA analysis on these values for the first 30 individuals of the first population, is shown in *figure 4*. The ANOVA analysis of the coordinates of the projections of individuals in the plane (I, II) shows that fish with a low and a high fillet yield may be discriminated by the method that we propose ($P = 0.006$). In *figure 4*d, (α) and (β) indicate the convex hulls of the positions of the individuals with a low (full circles) and a high (open circles) fillet yield, respectively; (γ) corresponds to the convex hull of the individuals which are considered to have a profitable morphology as determined by the confidence intervals

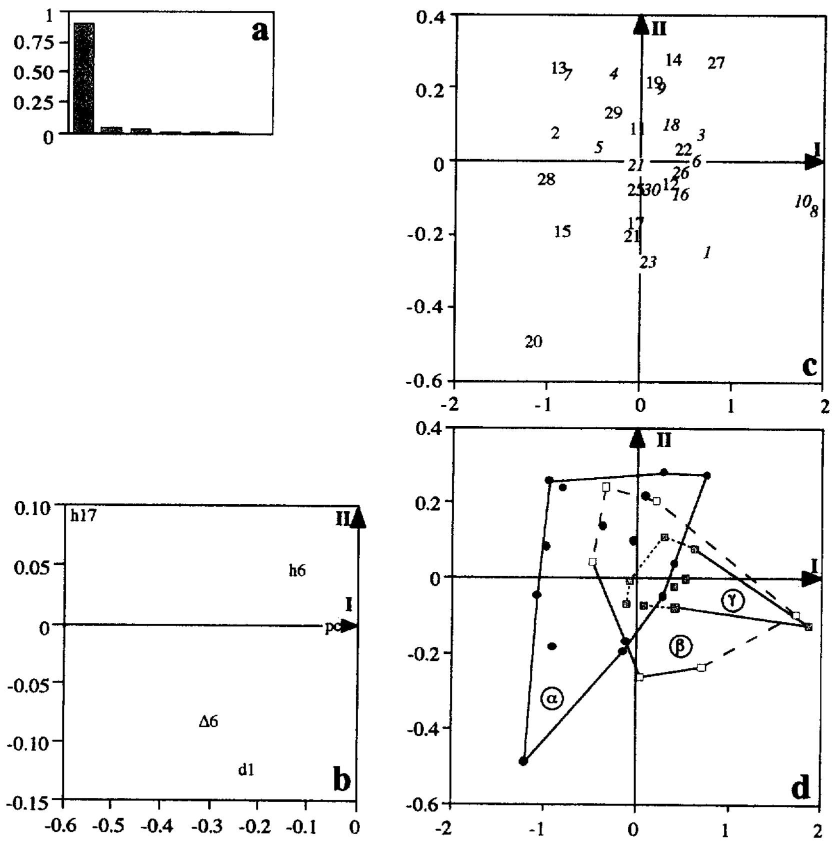

Figure 4. (a) Relative inertia of the axes of the centred PCA of the data obtained from the classic morphometric measurements. (b) and (c) are the (I, II) projection planes of the spatial distribution of the variables and the fish, respectively. Fish with a good fillet yield (defined in terms of weight) are in italics. (d) The low and high fillet yield individuals are represented with full and open circles, respectively, and (α) and (β) are the convex hulls of these two populations. (γ) is the convex hull of the individuals which are considered as profitable according to the image analysis data.

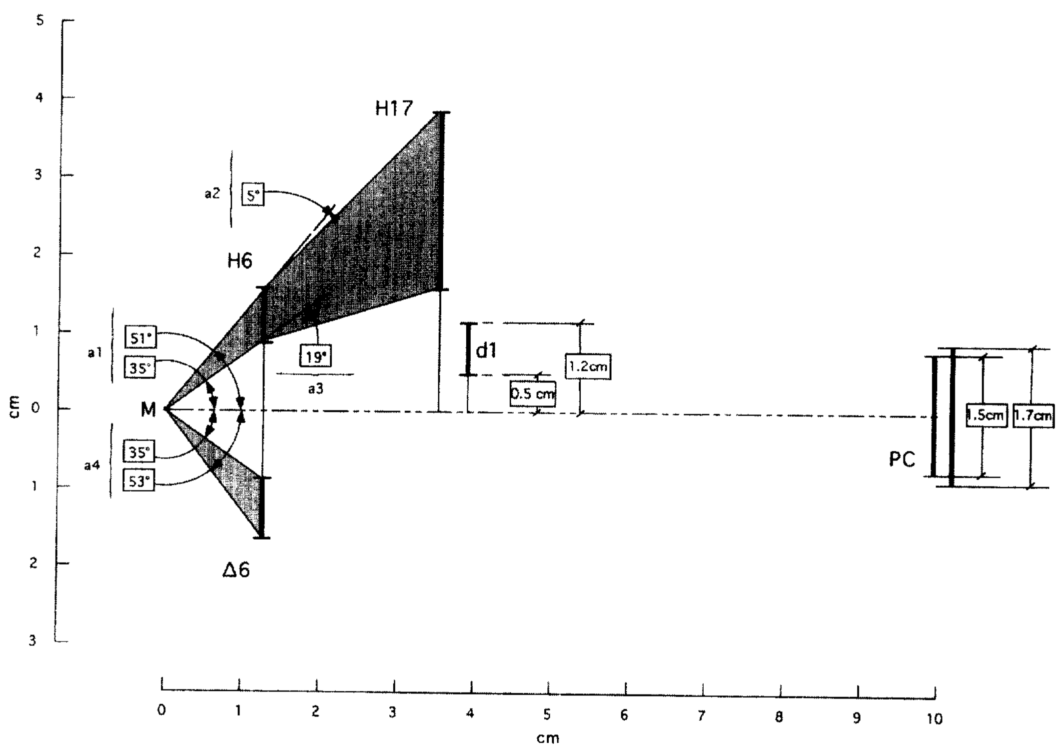

Figure 5. Profitable morphotype of the carps at 'commercial size' (mean weight = 1.3 kg). All the parameters were calculated when L_l equals 10 cm. The angle MH_6H_{17} defines the outline of the skull of the animals. The angles a_2 and a_3 are associated with the highest and the lowest values of a_1, respectively.

of the ratios already defined. It must be noted that the positions of the two false positive individuals (#12 and #22) (*table III*) are included in the region relative to the high fillet yield individuals.

From the standardised values of H_6, H_{17}, Δ_6, d_1 and pc calculated from the high fillet yield individuals defined by morphometric measurements, the most probable profitable morphotype may be proposed (*figures 5, 6*). The main morphological characteristics of the anterior part of the fish is a general convex shape of the upper part of the head ($35° \leq a_1 \leq 51°$, $a_2 \geq 5°$, $a_3 \leq 19°$ and $35° \leq a_4 \leq 53°$). The angle MH_6H_{17} is never concave. The lower values of a_2 are excluded from the profitable morphotype when a_1 is high (*figure 6*). The sum $(a_1 + a_4)$ equals 70° and 104° for the lower and the upper values of a_1, respectively. The other main characteristics of this morphotype correspond to the dorsal location of a high caudal peduncle (d_1 and pc ranged between 0.5–1.2 cm and 1.5–1.7 cm, respectively) (*figure 5*). It must be noted that the angles are not equivalent in terms of fillet yield prediction. The angles a_1 and a_2 are the most significant. It must be noted that the angle a_4 of the profitable fillet yield fish that weigh about 2.0 kg may be lower than 60° (*figure 6*).

4. DISCUSSION

The proposal of this study is to define a profitable carp morphotype to develop aquaculture in the Rhône-Alps region of France. The fillet yield of the 2–3-year-old carp and its standard deviation are low: ~31 ± 2.4 % [11, 31]. This yield does not directly depend on the weight and the sex of the animals. One of the most important limitation of this study is the quality of filleting. If we assume that the mean weight of the carps at 'commercial size' is about 1.3 kg, the filleting error may be about 31 g. This weight must be correlated to the flesh weight which remains on the bone after filleting, whatever the expertise of the person who fillets the fish.

This homogeneity is correlated with a high degree of consanguinity among the animals [31], which may be related to the large fertility of carps (90 000–300 000 eggs per female [20]), and the commercial relationships between different countries and regions. *Cyprinus carpio* wild-type has nearly disappeared in natural ponds and in farms of western European countries [1, 2]. In France, the number of carps is low, and the differences in their growth mainly depend on breeding conditions [11, 12, 25]. This apparent homogeneity may limit increasing fillet yield through selective breeding.

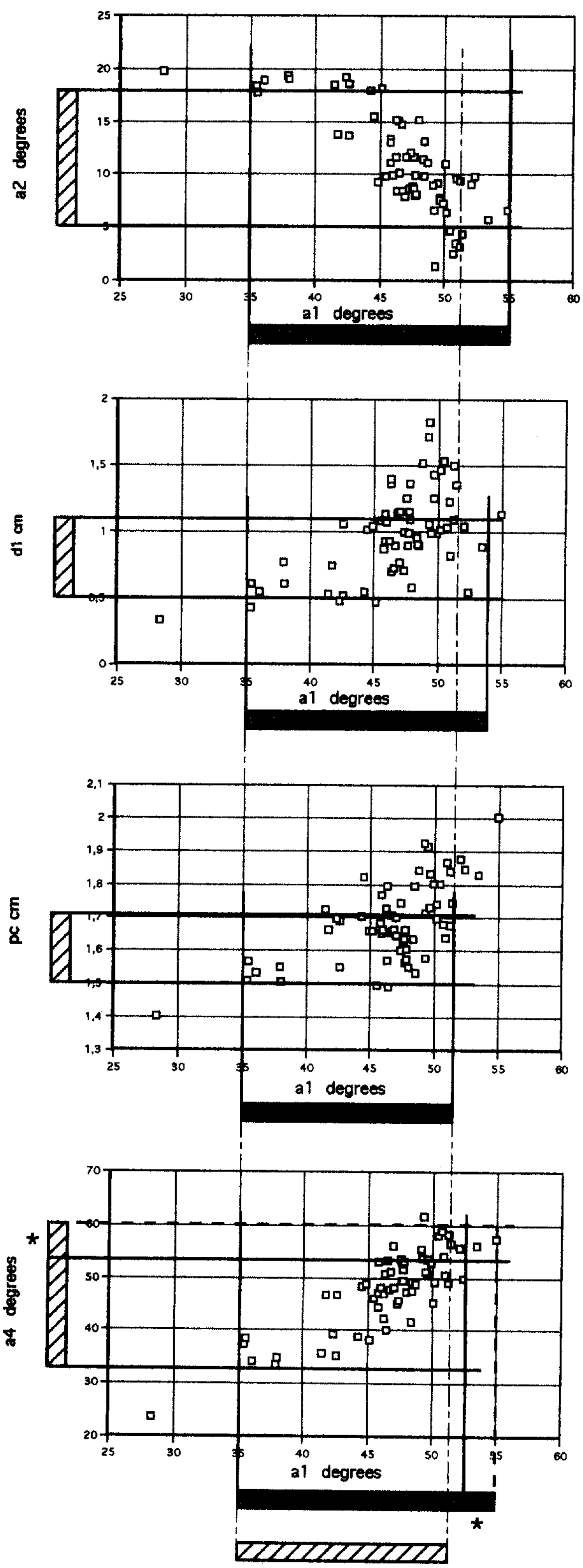

Figure 6. Variations of a_2, d_1, pc and a_4 in function of a_1. The vertical hatched bars indicate the confidence intervals of a_2, d_1, pc and a_4 that characterise the high fillet yield animals. The horizontal hatched bars indicate the overlap of the confidence intervals of a_1 that are defined on all the graphs. The horizontal grey bar corresponds to confidence intervals of a_1 deduced from the ones of a_2, d_1, pc and a_4 on each of the graphs. The stars indicate the increase of the limits of the confidence intervals of a_1 and a_4 which characterise the fish which weigh more than the mean commercial sized animals.

However, it was reported that the most streamlined fish are characterised by the highest fillet yields [31]. This first observation leads us to propose that carps may be selected by their morphology, providing that morphology and fillet yields are quantified correctly.

Many parameters may be measured to quantify the morphology of a fish. The conventional method consists of measuring the intervals between remarkable landmarks defined from the animal's skeletal organisation. According to this approach, the morphology of carps from the Danube was characterised by 37 distances [2], and French carps by 23 [12], 17 [31] or 15 distances [25]. The exact location of the landmarks is the main limiting factor in this quantification. It implies that the animals have to be manipulated for a long time out of water, and limits the use of photos. They increase animal stress, and consequently may have unknown physiological effects. It was reported that the standard ichthyological measures do not truly capture the shape of the fish but, rather redundantly and unevenly, sample only one aspect of it [15]. Moreover, in the present study, the multivariate analysis of the data obtained from classical morphometric measurements of carps shows that this method was not powerful enough to characterise the fillet yield of the animals in the same population and at the same age.

The method that we have defined is specifically committed to a morphometric approach for carp fillet yield. From our data, it must be noted that the values of a_1, a_2, a_3, a_4, d_1 and pc are linked because of the link between their relative variations. We have determined the most profitable morphotype in the considered carp populations, whose mean weight equals 1.3 kg. It mainly corresponds to the lower dorsal development of the anterior part of the animals (*figure 5*), as defined by the ranges of the angles and the distances that we have considered (*figure 6*). As indicated by the low values of d_1, the upper fillet yields are associated with a ventral position of the caudal peduncle. This corresponds to the increase of the area of the dorsal part of the lateral surface projection. As mentioned above, some individuals, that are heavier than 1.3 kg with a high fillet yield, may be characterised by a higher value of a_4 ranging between 50° and 60°. In these cases, the morphometric characteristics of the animals skull are similar to the one that we have described. However, the sums ($a_1 + a_4$) of these animals ranged between 90° and 110°. This shows that the heaviest animals are characterised by a more important ventral development which is not related to the increase of their fillet yield.

This last finding suggests that the current European principles of carp selection are not optimal. In the past (and still today) in Europe, large selection programmes of carp breeders were founded on the capability of the individual to increase rapidly their muscular mass in their anterodorsal region [2]. However, these selected individuals rapidly present a large quantity of fat in the connective tissue of their intestine [2].

To develop a carp breeding programme, and to control the animals'growth through the quantification of their shape, the best breeding conditions must be defined in controlled ponds [23]. If maintaining carps in natural ponds remains the main option to ensure the development of carp aquaculture in Rhône-Alps, it is futile to plan for animal selection. This problem must be settled by the producers themselves in function of both their economical options and the capability of carps to breed under either intensive or extensive conditions [5]. But this is also needed to improve breeder stocks [17, 18].

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REFERENCES

[1] Balon E., Domestication of the Carp *Cyprinus carpio*, R. Ont. Mus. Life Sci. Misc. Publ., 1974.

[2] Balon E., Origin and domestication of the wild carp, *Cyprinus carpio*: from roman gourmet to the swimming flowers, Aquaculture 129 (1995) 3–48.

[3] Berka R., Fauconneau B., La transformation, in: Billard R. (Ed.), Les carpes, biologie et élevage, coll. Hydrobiologie et aquaculture, Inra, Paris, 1995, pp. 303–310.

[4] Billard R. (Ed.), Les carpes, biologie et élevage, coll. Hydrobiologie et aquaculture, Inra, Paris 1995, 388 p.

[5] Billard R., Le grossissement en étang, in: Billard R. (Ed.), Les carpes, biologie et élevage, coll. Hydrobiologie et aquaculture, Inra, Paris 1995, pp. 183–247.

[6] Billard R., Les systèmes de production aquacole : un continuum de l'exploitation en milieu ouvert aux élevages hors environnement, in: Hussenot J., Buchet V. (Eds.), Marais maritimes et aquaculture, Ifremer, Brest, 1998, pp. 40–52.

[7] Bookstein F., Morphometric tools for landmark data: geometry and biology, NY Cambridge University Press, 1991.

[8] Bookstein F., Chernoff B., Elder R., Humphries J., Smith G., Strauss R., Morphometrics in Evolutionary Biology, Acad. Nat. Sci. Philadelphia, 1985.
[9] Castanet J., Francillon-Vieillot H., Meunier F.J., Ricqlès A., Bone and individual aging, in: Hall B.K. (Ed.), Bone, CRC Press, Boca Baton, 1993, pp. 245–283.
[10] Chessel D., Dolodec S., Thioulouse J., ADE: HyperCard© Lyon: Stacks and Programme Library for the Analysis of Environmental Data, URA CNRS 1451, Université Lyon-1, France, 1995.
[11] Dubost N., Masson G., Moreteau J.-C., Gonad development and filleting yield of common carp *Cyprinus carpio* L. reared in ponds in eastern France, J. Appl. Ichthyol. 13 (1997) 15–20.
[12] Fauconneau B., Faure A., Haffray P., Médale F., Vallet J., Amélioration des rendements de carcasse et maîtrise de l'état d'engraissement des poissons d'élevage, Piscic. Fr. 124 (1995) 25–29.
[13] Fermon Y., Les *Haplochromis* spp. (Teleostei, Cichlidae) des zones rocheuses du Mwanza Gulf, lac Victoria : structure des communautés et écomorphologie, Trav. Doc. Orstom n° 157, 1997, 270 p.
[14] Fermon Y., Cibert C., Ecomorphological individual variation in a population of *Haplochromis nyererei* (Teleostei: Cichlidae) from the Tanzanian part of Lake Victoria, J. Fish Biol. 53 (1998) 66–83.
[15] Fink L., Data acquisition for morphometric analysis in systematic biology, in: Rohlf Y., Bookstein F. (Eds.), Michigan Morphometrics Workshop, Univ. Michigan, Museum of Zoology Spec. Publ., 1990, pp. 9–19.
[16] Haenlin M., McDonald W., Cibert C., Mohier E., The angle of the dorsal axis with respect to the anterior axis in the *Drosophila* embryo is controlled by the distribution of gurken mRNA in the oocyte, Mech. Develop. 49 (1995) 97–106.
[17] Hollebecq M.G., Haffray P., L'amélioration génétique, in: Billard R. (Ed.), Les carpes, biologie et élevage, coll. Hydrobiologie et aquaculture, Inra, Paris 1995, pp. 125–148.
[18] Hulata G., A review of genetic improvement of the common carp (*Cyprinus carpio* L.) and other cyprinids by crossbreeding, hybridization and selection, Aquaculture 129 (1995) 143–155.
[19] Jacquinot M., Le marché de la carpe. L'exemple français, in: Billard R. (Ed.), Les carpes, biologie et élevage, coll. Hydrobiologie et aquaculture, Inra, Paris, 1995, pp. 310–315.
[20] Jhingran V., Pullin R., A hatchery manual for the common, Chinese and Indian major carps: Metro Manila, Southeast Asian Fisheries Development Center, 1985.
[21] Jolicoeur P., The multivariate generalization of the allometry equation, Biometrics (1963) 497–499.
[22] Jolicoeur P., Mosimann J., Size and shape variation in the painted turtle, A principal component analysis, Growth 24 (1960) 339–354.
[23] Kestemont P., Different systems of carp production and their impacts on the environment, Aquaculture 129 (1995) 347–372.
[24] Klingenberg C., Multivariate allometry, in: Marcus L.F., Corti M., Loy A., Naylor G.J.P., Slice D. (Eds.), Advances in Morphometrics, Proc. 1993 NATO-ASI, NY Plenum Publ. NATO ASI, ser. A Life Sciences, 1996, pp. 23–49.
[25] Loy A., Ciccotti E., Ferrucci L., Cataudella S., An application of automated feature extraction and geometric morphometrics: temperature-related changes in body from *Cyprinus carpio* juveniles, Aquac. Eng. 15 (1996) 301–311.
[26] Mariojouls C., Approche de l'économie de la production piscicole en étang, in: Billard R. (Ed.), Les carpes, biologie et élevage, coll. Hydrobiologie et aquaculture, Inra, Paris, 1995, pp. 317–331.
[27] Meunier F.J., Détermination de l'âge individuel chez les Ostéichthyens à l'aide de la squelettochronologie : historique et méthodologie, Acta Ecol. Ecol. Gen. 9 (1988) 299–329.
[28] Meunier F.J., Pascal M., Étude expérimentale de la croissance cyclique des rayons de nageoire de la carpe (*Cyprinus carpio* L.), Résultats préliminaires, Aquaculture 26 (1982) 23–40.
[29] Moav R., Finkel A., Wohlfarth G., Variability of intermuscular bones, vertebrae, ribs, dorsal fin rays and skeletal disorders in the common carp, Theor. Appl. Genet. 46 (1975) 33–43.
[30] Pascal M., Castanet J., Méthodes de détermination de l'âge chez le chat haret des îles Kerguelen, Terre Vie 32 (1978) 529–255.
[31] Pereira V., Comparaison, à taille commerciale, de populations de carpe commune (*Cyprinus carpio*) issues de différentes régions d'élevage, Variabilité morphologique et rendement de filetage, Université de Franche-Comté, France, 1996.
[32] Rohlf F.J., Bookstein F., Proc. Michigan Morphometric Workshop, Ann Arbor, Michigan, University of Michigan, Mus. Zool., Spec. Publ., 1990.
[33] Rohlf F.J., Marcus L., A revolution in morphometrics, Trends Ecol. Evol. 8 (1993) 129–132.
[34] Shearer W.M., The Atlantic Salmon, Natural History, Exploitation and Future Management, Fishing News Books, Oxford, 1992, 244 p.
[35] Vallod D., Carp processing and market analysis: a case study in France, Aquaculture 129 (1995) 475–478.
[36] Varadi L., Equipment for the production and processing of carp, Aquaculture 129 (1995) 443–466.
[37] Yoccoz N., Le rôle du modèle euclidien d'analyse des données en biologie évolutive, Université Lyon-1, France, 1988.
[38] Yoccoz N., Morphométrie et analyses multidimensionnelles, Une revue des méthodes séparant taille et forme, in: Lebreton J.D., Asselain B. (Eds.), Biométrie et environnement, Masson, Paris, 1993, pp. 73–99.