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Abstract

Gilthead seabream (*Sparus aurata* L.) and European seabass (*Dicentrarchus labrax* L.) are important commercial marine fish species both for aquaculture and fisheries in the Mediterranean. It is known that farmed individuals escape from farm facilities, but the extent of escape events is not easy to report and estimate because of the difficulty to distinguish between wild and farmed individuals. In this study, significant differences evidence that the cranial and body regions of seabream and seabass are different regarding their farm or wild origin at a different scales are provided through morphometry. Morphological variations have been shown to be a valuable tool for describing changes in shape features. Therefore, the biomass contribution of escapees to local habitats could be determined by identifying escaped individuals from fisheries landings as a first step to assess the potential negative effects of fish farm escapees on the environment, and their influence on wild stocks and local fisheries.

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PRIMARY RESEARCH PAPER

Morphological differences between wild and farmed Mediterranean fish

P. Arechavala-Lopez · P. Sanchez-Jerez · J. T. Bayle-Sempere · D. G. Sfakianakis · S. Somarakis

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Abstract Gilthead seabream (*Sparus aurata* L.) and European seabass (*Dicentrarchus labrax* L.) are important commercial marine fish species both for aquaculture and fisheries in the Mediterranean. It is known that farmed individuals escape from farm facilities, but the extent of escape events is not easy to report and estimate because of the difficulty to distinguish between wild and farmed individuals. In this study, significant differences evidence that the cranial and body regions of seabream and seabass are different regarding their farm or wild origin at a different scales are provided through morphometry. Morphological variations have been shown to be a valuable tool for describing changes in shape features. Therefore, the biomass contribution of escapees to local habitats could be determined by identifying escaped individuals from fisheries landings as a first step to assess the potential negative effects of fish farm escapees on the environment, and their influence on wild stocks and local fisheries.

Keywords Seabream · Seabass · Morphometry · Escapees · Aquaculture · Fisheries landings

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Introduction

Gilthead seabream (*Sparus aurata* L., Fam. Sparidae) and European seabass (*Dicentrarchus labrax* L., Fam. Moronidae) are the important commercial marine fish species along the Mediterranean and Eastern Atlantic coastline both for aquaculture and fisheries. In 2008, the total aquaculture production of seabream and seabass in Europe were 89,354 and 58,467 t, respectively, and total landings reached 7,812 and 8,528 t, respectively (FAO, 2011). It is well known that reared individuals escape from farm facilities due to technical and operational failures (Dempster et al., 2007), but the knowledge concerning ecological and genetic impacts of these escapees on the Mediterranean ecosystem is still sparse. Escaped fish could be present on spawning areas and could interbreed with native populations as was found for salmonids (Naylor et al., 2005) and for cod (Uglem et al., 2008; Meager et al., 2009). Furthermore, it has been reported that escaped seabream and seabass were able to swim away from farm facilities to nearby farms, local fishing grounds and coastal habitats (González-Lorenzo et al., 2005; Toledo-Guedes et al., 2009; Arechavala-Lopez et al., 2011a, b). Thus, the potential for negative ecological consequences to occur through predation, competition or transmitting pathogens to closely reared and wild populations is significant (Dempster et al., 2007). For a better understanding of these potential negative effects, it is important to quantify the number of individuals that escape from sea-cages, and to analyse their mobility, spatial distribution and survival. Because of the difficulty in surveying directly the escapes events, it is imperative to distinguish escapees from native individuals in the natural habitats as a first step to assess their contribution to fisheries landings, for instance examining captured individuals from local fisheries after an escape event.

In hatcheries, fish grow faster and frequently with different patterns and environment than in the wild and this phenomenon has been mainly utilized to distinguish between wild and reared salmonids with a relatively high degree of certainty (Swaine et al., 1991; Fleming et al., 1994; Hard et al., 2000; Fiske et al., 2005). Differential relative growth of body parts conditioned by environmental factors is a common feature of fish development (Osse, 1990; Osse & van den Boogaart, 1995, 1999; Gisbert, 1999; Loy et al., 2001). In several species, developmental modifications may be closely linked also to ontogenetic changes in resource use (Webb & Weihs, 1986; Hernandez & Motta, 1997; Sagnes et al., 1997; Ward-Campbell & Beamish, 2005). Such different developmental modifications may exist between wild and farmed fish given that they experience large differences in feeding regimen and environment. Moreover, in reared seabream and seabass, the presence of malformations or morphoanatomical anomalies has been widely documented (Paperna, 1978; Francescon et al., 1988; Balebona et al., 1993; Boglione et al., 1993, 2001; Marino et al., 1993; Chatain, 1994; Koumoundourous et al., 1997; Loy et al., 1999, 2000; Afonso et al., 2000; Sfakianakis et al., 2006). The objective of this study is to assess the body measures which can discriminate between farmed or wild origin of seabream and seabass in the Mediterranean Sea, and therefore, if the existence of some specific measurements could be applied to study the contribution on wild populations and fisheries landings.

Materials and methods

Sampling and morphometric measurements

A total of 200 wild seabream and 200 farmed seabream individuals, as well as 200 wild seabass and 200 farmed seabass individuals, from Spain and Greece, were used in this study (Table 1). Wild and farmed fish from Spain were obtained during the period of July 2009–June 2010, from two different localities and farms, respectively (Fig. 1). Fish from Greece were obtained in October 2009, from a single locality and a single farm (Fig. 1). Each seabream or seabass was photographed with a digital camera (Canon® Powershot-G10) mounted on tripod with a light source. A ruler was used on each photograph to ensure correct calibration in the following image processing. Morphological landmarks were selected to give a precise definition of the fish morphology (Humphries et al., 1981; Strauss & Bookstein, 1982). Altogether 16 morphological landmarks on seabream (Fig. 2; Table 2) and 17

Table 1 Characteristics of seabream and seabass specimens used in this study

Species	Locality	Origin	*n*	Ls (cm)		Wt (g)	
				Range	Mean ± SD	Range	Mean ± SD
Sparus aurata	Spain	Wild	100	25.3–47.9	34.6 ± 4.8	393–2628	1077 ± 445
		Farmed	100	28.6–39.4	30.7 ± 1.2	796–1105	906 ± 53
	Greece	Wild	100	13.1–17.5	15.3 ± 1.1	47–103	71 ± 1
		Farmed	100	13.0–18.7	15.6 ± 1.1	40–132	79 ± 1
Dicentrarchus labrax	Spain	Wild	100	17.3–54.7	31.1 ± 10.1	84–2920	671 ± 676
		Farmed	100	32.7–38.6	35.6 ± 1.1	821–1075	918 ± 48
	Greece	Wild	100	18.1–27.8	23.6 ± 1.9	80–280	152 ± 37
		Farmed	100	19.0–25.0	21.4 ± 1.2	91–197	128 ± 22

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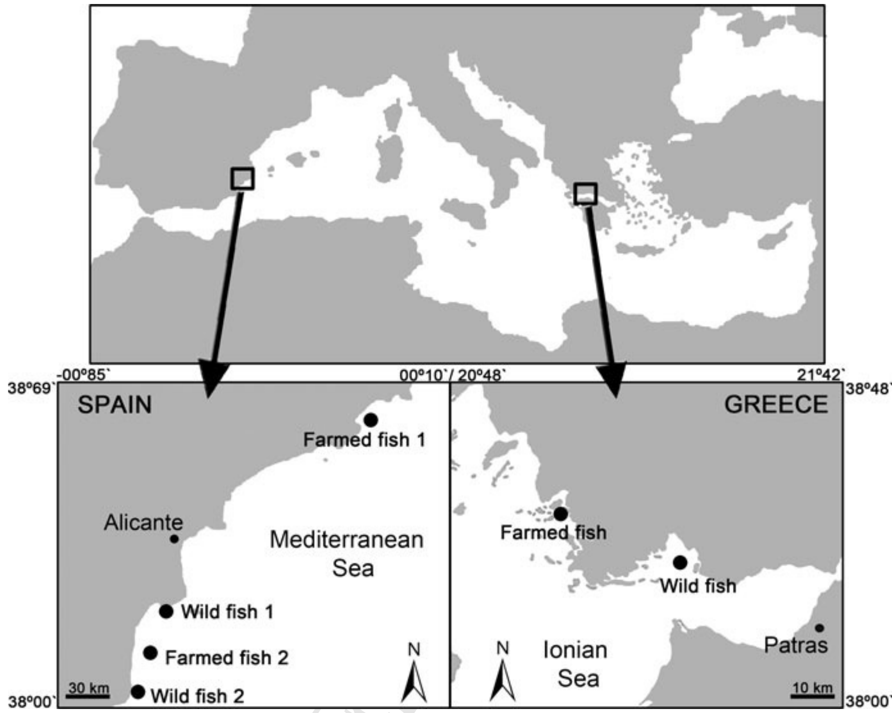

Fig. 1 Maps of the study areas in Spain and Greece, showing the wild and farmed fish sampling localities

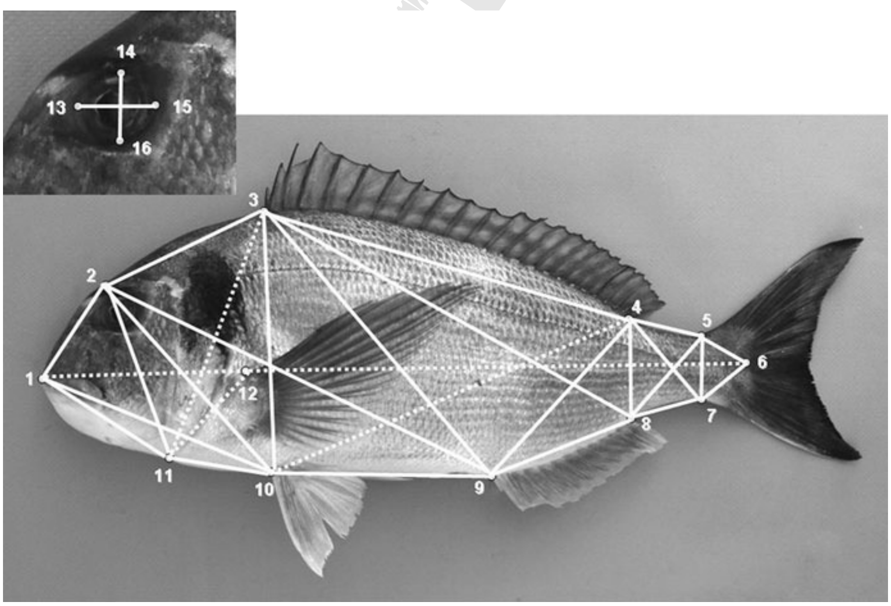

Fig. 2 The 16 landmarks and the distances measured which were used for the morphological analysis on seabream. The morphometric traits described from the landmarks are shown in Table 2. *Solid lines* TNS; *dotted line* additional measurements. *1* tip of the premaxillary; *2* point of maximum curvature in the head profile curve; *3* anterior insertion of dorsal fin; *4* posterior insertion of dorsal fin; *5* dorsal point at least depth of caudal peduncle; *6* posterior extremity of the lateral line; *7* ventral point at least depth of caudal peduncle; *8* posterior insertion of anal fin; *9* anterior insertion of anal fin; *10* anterior insertion of pelvic fin; *11* insertion of the operculum on the profile; *12* dorsal insertion of pectoral fin; *13* most anterior point of the eye; *14* most dorsal point of the eye; *15* most posterior point of the eye; *16* most ventral point of the eye

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morphological landmarks on seabass were used (Fig. 3; Table 2), and they were placed using the image processing programme ImageJ (Abramoff et al., 2004), in which the morphological landmarks are given as x and y co-ordinates. This tool is called Truss Network System (TNS) and covers the entire fish in a uniform network which should theoretically increase the likelihood of extracting morphometric differences within and between species. A regionally unbiased network of morphometric measurements over the two-dimensional outline of a fish should give more information about local body differences than a conventional set of measurements (Bookstein, 1982; Strauss & Bookstein, 1982). A total of 31 morphological vectors were selected among the landmarks on seabream and 30 morphological vectors on seabass (Table 2). The distances between the landmarks were determined from their co-ordinates. The repeatability of all measurements was determined by measuring 20 seabream and 20 seabass from each group three different times. The coefficient of variation ranged from 0.5 to 2%, which indicates a high accuracy and repeatability of this method. Moreover, morphometric indices such as Fulton's Condition Index [$K = 100 \times$ total weight/(total length)^3], Cephalic Index [CI = (head length/total length)] and Relative Profile Index [RP = (maximum body height/total length)] were computed from linear and weight measurements.

Table 2 Morphological traits of seabream and seabass measured from the landmarks in Figs. 2 and 3

Sparus aurata		*Dicentrarchus labrax*	
Code	Landmark	Code	Landmark
A1	1–2	A1	1–2
A2	2–10	A2	2–12
A3	10–11	A3	1–12
A4	1–11	B1	2–3
A5	1–10	B2	3–11
A6	2–11	B3	11–12
B1	2–3	B4	2–11
B2	3–9	B5	3–12
B3	9–10	C1	3–4
B4	2–9	C2	4–10
B5	3–10	C3	10–11
B6	3–11	C4	3–10
C1	3–4	C5	4–11
C2	4–8	D1	4–5
C3	8–9	D2	5–9
C4	3–8	D3	9–10
C5	4–9	D4	4–9
C6	4–10	D5	5–10
D1	4–5	E1	5–6
D2	5–7	E2	6–8
D3	7–8	E3	8–9
D4	4–7	E4	5–8
D5	5–8	E5	6–9
E1	5–6	F1	6–7
E2	6–7	F2	7–8
F1	1–12	F3	1–13
F2	11–12	F4	7–13
F3	6–12	Eye L	14–16
Eye L	13–15	Eye H	15–17
Eye H	14–16	SL	1–7
SL	1–6		

Statistical analysis

In order to avoid the effect of the different specimen's lengths in the study, all morphological traits were size adjusted using the method described by Reist (1985), because heterogeneity in size among samples produces heterogeneity in measurements. These transformations were done separately for the different group analysis (Spain, Greece and both together Spain–Greece) to avoid interference from the other groups. All the size-correlated traits were standardized to a mean of zero and a standard deviation of 1. Multivariate statistics (SPSS, version 15.0 for Windows) were used to test for intra- and inter-groups variation. Statistical differences for size and all the morphometric indices among groups was tested by ANOVA at $P < 0.05$. A principal component analysis (PCA), with varimax rotation was selected because the rotation minimizes the number of variables that have high loadings on a factor. All PCAs with eigenvalue >1.00 were considered as important (Chatfield & Collins, 1983) and variables were tested by ANOVA at $P < 0.05$. Discriminant analyses were then used to test for group membership. The different discriminant functions are hereafter described as DC1, DC2, etc. ANOVA was used to test if there were differences in morphological traits between the wild and the farmed seabream and seabass, respectively.

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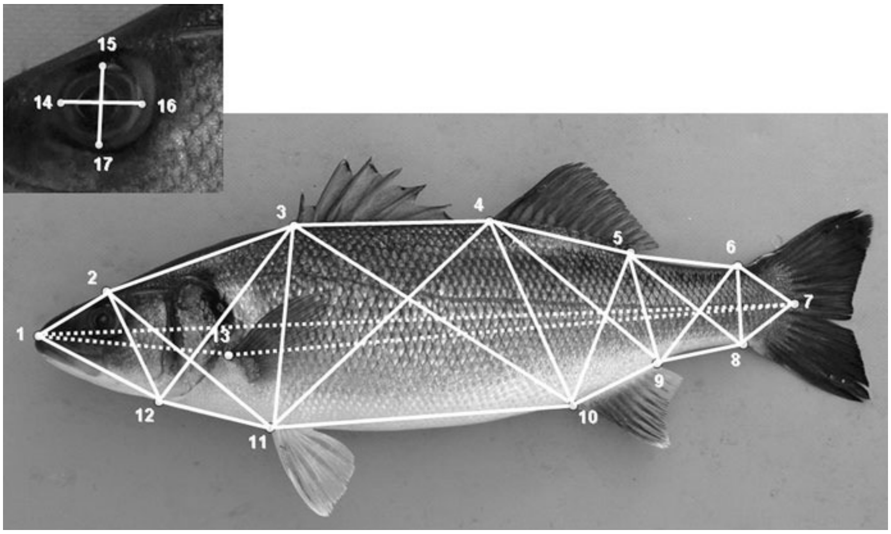

Fig. 3 The 17 landmarks and the distance measured which were used for morphological measurement on seabass. The morphological traits described from the landmarks are shown in Table 2. *Solid lines* TNS; *dotted line* additional length measures. *1* tip of the premaxillary; *2* point of maximum curvature in the head profile curve; *3* anterior insertion of the first dorsal fin; *4* anterior insertion of the second dorsal fin; *5* posterior insertion of the second dorsal fin; *6* dorsal point at least depth of caudal peduncle; *7* posterior extremity of the lateral line; *8* ventral point at least depth of caudal peduncle; *9* posterior insertion of anal fin; *10* anterior insertion of anal fin; *11* anterior insertion of pelvic fin; *12* insertion of the operculum on the profile; *13* dorsal insertion of pectoral fin; *14* most anterior point of the eye; *15* most dorsal point of the eye; *16* most posterior point of the eye; *17* most ventral point of the eye

Results

Results evidenced clear differences between wild and farmed fish, mainly on the cranial and body regions, for both seabass and seabream. It should be noted that seabream from Spain and Greece were of different sizes (ANOVA, $P \leq 0.05$), while sizes of seabass were similar in the two countries (ANOVA, $P > 0.05$; Table 1). Fulton's Condition Index (K) revealed significant differences between wild and farmed individuals of both studied species (ANOVA; $P \leq 0.01$) with the farmed fish exhibiting the highest values (Fig. 4a, b). Cephalic Index (CI) values were significantly different in seabass (ANOVA; $P \leq 0.05$), where wild fish showed the highest values in both countries (Fig. 4c); but there were no significant differences between wild and farmed seabream specimens (ANOVA; $P > 0.05$; Fig. 4d). However, values of Relative Profile Index (RP) were significantly different among seabream from different origins (ANOVA; $P \leq 0.05$), where farmed fish showed higher values than wild fish (Fig. 4e), while there were no differences for seabass in both countries (ANOVA; $P > 0.05$; Fig. 4f).

A combination of five principal components explained as much as 87.03% of the variation of size-adjusted body morphology variables for Spanish seabream (ANOVA, $P \leq 0.01$; Table 3). In case of Greece, eight principal components explained as much as 85.69% of this variation in seabream, but only four with significant differences (ANOVA, $P \leq 0.01$; Table 3). In both countries, the most important differences were located in the anterior body portion, principally in head measurements and body height. Discriminant analysis presented four differentiated groups in Spain, belonging to the two fish farms and two control localities (Fig. 5). Two percent of wild fish were not adequately assigned, which may indicate a cultivated origin, while 100% of the farmed fish were correctly classified. Since there were only two groups from Greece, the discriminant analysis gave only one function and it was therefore not possible to plot the relationship between components. However, classification score for the discriminant analysis resulted in 98% of wild fish and 99% of farmed fish from Greece being correctly classified. Comparisons between wild and farmed seabream according to their Spanish or Greek origin showed clear differences for almost all of

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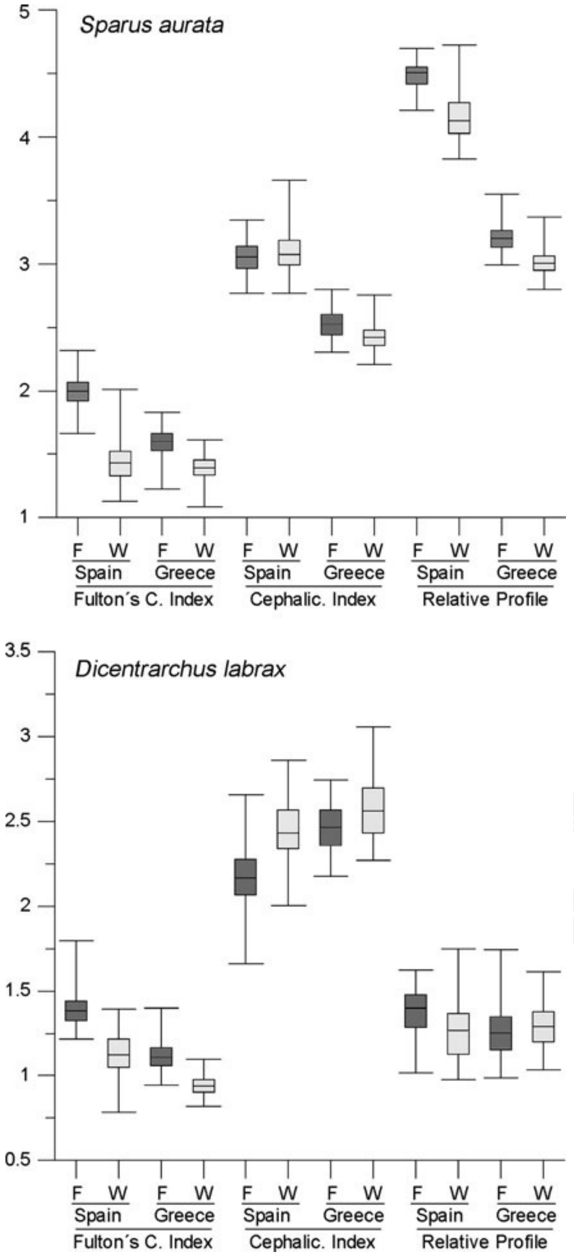

Fig. 4 Morphometric indices of wild and farmed seabream and seabass from Spain and Greece. *Bars* show mean values ± standard deviation

the taken measurements (Fig. 6). Nonetheless, discriminant analysis exhibited that around 3% of wild individuals, both from Greece and Spain, could be of cultivated origin (Table 4). It is remarkable that these individuals presented high indices values. The differences in morphological traits were significant (ANOVA, $P \leq 0.05$) for all discriminant functions for all groups, and could be explained by the group origin (Wilks' λ, ANOVA, $P \leq 0.01$; Table 5).

Significant differences in morphological traits between wild and farmed seabass in Spain were described by two components in the PCA analysis which explained 86.47% of the variation (ANOVA, $P \leq 0.01$; Table 6). First component principally correlated with longitudinal and transversal body measurements, while head and eye measurements were most representative for the second component. Variation in morphological traits between farmed and wild seabass from Greece was explained by five principal components (80.12%) but only three of them presented significant differences (ANOVA, $P \leq 0.05$; Table 6). These differences were mainly due to eye and head measurements (PC1) and some transversal body measurements (PC2). Discriminant analysis plot for Spanish seabass groups illustrated a pronounced variation in the morphological traits between wild and farmed fish, where the two locations of farmed fish were more similar between them, and the two wild groups were considerably more heterogeneous (Fig. 7). However, the 2% of wild fish from Spain were not correctly classified, whereas 100% of the farmed fish were correctly assigned. Since there were only two groups of seabass from Greece, the discriminant analysis gave only one function and it was therefore not possible to plot the relationship between components. However, discriminant analysis correctly grouped the 100% of individuals within their respective group.

When comparing morphological traits for seabass from Spain and Greece together, significant differences were explained by two principal components (93.52%; ANOVA, $P \leq 0.01$). Body measurements were mainly located on the first component (PC1: 56.2%), while head and eyes measurements were more important in the second one (PC2: 37.2%). The first two resulting functions from discriminant analysis explained 70.4 and 23.1% of the variation, respectively (Table 8); and the differences in morphological traits were significant (Wilks' λ, ANOVA, $P \leq 0.01$; Table 8). Plotting these two functions, the first one grouped the seabass according to their geographical origin, while the second function grouped the samples according to their wild or farm origin (Fig. 8). Moreover, 98 and 99% of reared seabass from Spain and Greece, respectively, were correctly grouped (Table 7). Furthermore, 88% of wild seabass from

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Table 3 Component loadings, percent of variance (% V) and eigenvalues (Eigen.) for the principal components (with varimax rotation) in the Spain and Greece groups analyses for seabream

Spain	PC1	PC2	PC3	PC4	PC5
Eye H	**0.954**				
B2	**0.920**				
B5	**0.920**				
A6	**0.907**				
C4	**0.879**				
A5	**0.869**				
A4	**0.866**				
B6	**0.866**				
B4	**0.855**				
C6	**0.850**				
B3	**0.827**				
B1	**0.818**				
A2	**0.808**				
C5	**0.802**				
F1	**0.795**				
C2	**0.767**				
D4	**0.756**				
E2	0.754				
D2	0.752				
D5	0.750				
C3	**0.729**				
D3	**0.725**				
D1		**−0.661**			
F2		**0.477**			
C1			**0.628**		
A1			**0.430**		
F3			**0.484**		
A3			**0.463**		
E1				0.517	
Eye L					**0.594**
% V	30.03	20.52	16.51	14.81	5.17
Eigenv.	9.01	6.15	4.95	4.44	1.55
ANOVA	<0.01	<0.01	<0.01	<0.01	<0.01

Greece	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
A5	**0.859**							
A3	**0.849**							
A2	**0.848**							
B5	**0.823**							
B6	**0.708**							
D2	**0.661**							
F1	**0.660**							
F2	0.652							
B4	0.639							
A6	0.524							
B3	**0.516**							
C1		**0.878**						
C4		**0.853**						
B2		0.739						
B1		**−0.557**						
C3			**0.897**					
C5			**0.830**					
F3			0.614					
C6			0.574					
D3				**0.868**				
D5				0.844				
C2				0.525				
E2					0.831			
E1					**0.813**			
Eye L						0.850		
Eye H						0.723		
A4						**0.596**		
D4							0.746	
D1							**0.832**	
A1								0.861
% V	24.18	11.12	10.93	10.07	8.93	8.56	6.67	5.22
Eigenv.	7.25	3.34	3.28	3.02	2.68	2.57	2.01	1.59
ANOVA	<0.01	<0.01	<0.01	0.61	0.16	0.92	<0.01	0.82

Components with significant differences (ANOVA; $P \leq 0.05$) in morphological traits between farmed and wild seabream are marked in bold (see Table 2 for definition of characters)

Spain were correctly assigned, but 5 and 7% were assigned to Greek and Spanish farm origin. Only 1% of wild seabass from Greece were not correctly grouped (Table 7).

Discussion

Body morphology was clearly different between wild and farmed fish for both species. The spatial consistency of these results indicate the usefulness of these indices in discriminating the origin of the studied species, such as the CI for seabass, the RP for seabream or Fulton's Condition Index for both species. In addition, morphometric analyses suggest that most differences are located primarily in the head and anterior region of the body of the fish. Specifically, these differences on seabream were focused either on the head height (B5) or the distances from the base of the pectoral fin to the edges of the mouth (A5) and to

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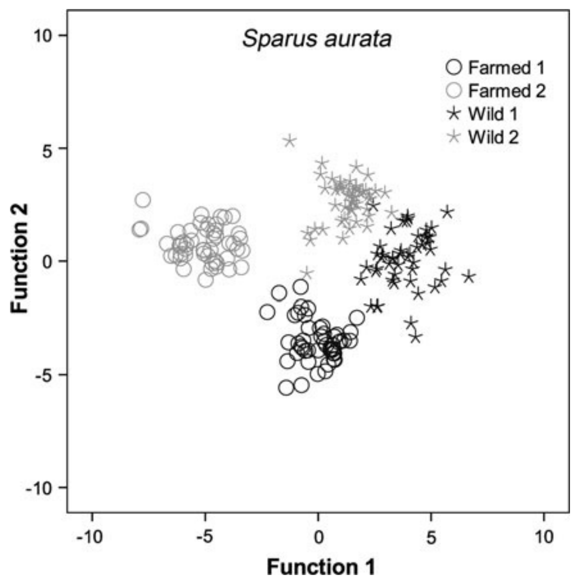

Fig. 5 Scatterplot of functions 1 and 2 for the discriminant analysis at Spain group including the two locations of farmed seabream and the two localities of wild seabream

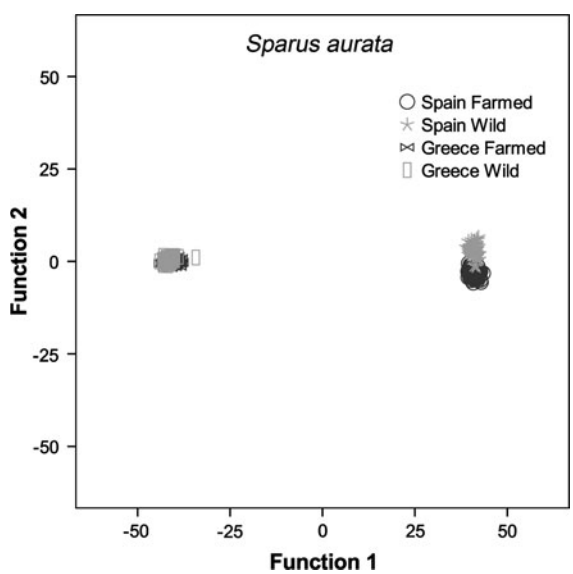

Fig. 6 Scatterplot of functions 1 and 2 for the discriminant analysis including the groups of farmed and wild seabream from Spain and Greece

forehead (A2), (see Table 2; Fig. 2); while for seabass they were on head and body length (F3 and F4, respectively), proportions of the eye and the distances from the base of the operculum to the edge of the mouth (A2) and to the forehead (A3), (see Table 2; Fig. 3).

These morphological differentiations could be due to either the selective breeding programmes applied in aquaculture, genetic drift following founding generations, or the different origin of fish used as broodstocks (Karaiskou et al., 2009). Although the accidental escapes of fish from farms have certainly contributed to a mix of all gilthead seabream genetic stocks (Sola et al., 2006), a high genetic differentiation between cultivated and wild populations from the same area has been reported, which might indicate no evidence for significant genetic flow between them (Alarcón et al., 2004). The first genetics studies carried out on gilthead seabream populations reported conflicting data concerning the existence of panmictic (Cervelli et al., 1985) or subdivided populations (Funkenstein et al., 1990). More recent studies have depicted a picture of species subdivision that still needs to be clarified. The results of Arabaci et al. (2010) suggest a slight but significant population structure for the Mediterranean Sea and Atlantic Ocean, but not apparently associated with geographic or oceanographic factors (Alarcón et al., 2004; Ben-Slimen et al., 2004; De Innocentiis et al., 2004; Karaiskou et al., 2005; Rossi et al., 2006). In addition to fish origin, it should be noted that the mean sizes among Spanish and Greek seabream in this study were significantly different. Mean size (both length and weight) of Spanish seabream proved to be higher than the group from Greece. Thus, some morphological variations between regions may be the result of differences in individual's age, and hence body size. Gilthead seabream are characterized by remarkable anatomical changes throughout their life history (Cataldi et al., 1987), and this species is known to undergo ontogenetic shifts in feeding habits (Mariani et al., 2002; Tancioni et al., 2003). Furthermore, a pattern of allometric growth on different body regions was characterized for each age-stage (Russo et al., 2007). Further studies will be necessary to compare different sizes of farmed and wild seabream from different geographical regions.

In the case of European seabass, numerous genetic population differentiation studies at different geographic scales have led to the identification of three genetically distinct zones: the northeastern Atlantic Ocean, the western Mediterranean and the eastern Mediterranean (Patarnello et al., 1993; Allegrucci et al., 1997; García de León et al., 1997; Castilho & McAndrew, 1998; Sola et al., 1998; Bahri-Sfar et al.,

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Table 4 Inter-group classification score result (in %) for the discriminant analysis of the four groups of seabream

Sparus aurata	Group	Spain		Greece		Total
		Farmed	Wild	Farmed	Wild	
Origin group (%)	Spain farmed	100	0	0	0	100
	Spain wild	3	97	0	0	100
	Greece farmed	0	0	98	2	100
	Greece wild	0	0	3	97	100

Table 5 Data from the intra- and inter-groups discrimination analyses

	F	Eigenvalue	Percent variance	Cumulative variance	Canonical correlation	Wilks' λ	χ^2	*df*	*P*
Spain	1	10.849	65.6	65.6	0.957	0.009	884.059	60	<0.001
Spain	2	5.132	31.0	96.6	0.915	0.105	421.750	38	<0.001
Spain	3	0.555	3.4	100.0	0.598	0.643	82.608	18	<0.001
Greece	1	4.975	100.0	100.0	0.912	0.167	327.129	30	<0.001
Spain–Greece	1	1695.914	99.5	99.5	1.000	0.000	4073.060	90	<0.001
Spain–Greece	2	5.206	0.3	99.8	0.916	0.040	1232.292	58	<0.001
Spain–Greece	3	3.057	0.2	100.0	0.868	0.247	534.946	28	<0.001

The groups of seabream were classified from these functions (*F*) in the discriminant analysis

2000; Castilho & Ciftci, 2005; Ergüden & Turan, 2005; Katsares et al., 2005; Lemaire et al., 2005). In this study, through discriminate analysis, some wild seabass from Spain (7%) were grouped along with farmed fish from Spain, which probably belong to an escapee group; but some others (5%) were grouped with seabass from Greek farms. Cases in which individuals do not cluster with other samples belonging to the same geographical origin are not surprising, since eggs or fingerlings originating from the western basin were most likely used to seed many hatcheries around the Mediterranean when seabass aquaculture, and therefore, escapes into the wild, began in the early 1980s (Haffray et al., 2006).

On the other hand, phenotypic differences are not necessarily indicative of genetic differentiation between populations (Ihssen et al., 1981; Allendorf, 1988), and thus the detection of morphological differences among populations cannot usually be taken as evidence of genetic differentiation (Turan, 1999). Phenotypic plasticity of fish allows them to respond adaptively to environmental change by modification to their physiology and behaviour which leads to changes in their morphology, reproduction or survival that mitigate the effects of environmental variation (Stearns, 1983; Meyer, 1987). Unlike wild populations, farmed fish live inside the cages with a periodic feeding rate and easily available food, suggesting that foraging is different from wild fish (Arabaci et al., 2010). Therefore, the morphological differences found in this study between wild and farmed seabream agree with those differences found by Grigorakis et al. (2002) where wild seabream presented lower body height, sharper snout and more spindle-shaped body than cultured seabream. Moreover, such differences could be partly explained by dietary shifts, which induce changes on the body shape (Keast, 1978), influencing prey selection and catch efficiency (Mérigoux & Ponton, 1998). Furthermore, as they have been widely reported for farmed seabream and seabass, all fish species may develop shape abnormalities under farming conditions (Divanach et al., 1996). Some of such anomalies are observable in the cranial and ventral region (Loy et al., 2000; Tulli et al., 2009), fin erosion by erodibility (Arechavala-Lopez et al., unpublished data), otoliths

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Table 6 Component loadings, percent of variance (% V) and eigenvalues for the principal components (with varimax rotation) in the Spain and Greece groups analyses for seabass

Spain			Greece					
	PC1	PC2		PC1	PC2	PC3	PC4	PC5
F4	**0.945**		F3	**0.904**				
E4	**0.905**		Eye L	**0.805**				
D2	**0.890**		A3	**0.801**				
C2	**0.887**		A2	**0.729**				
C5	**0.885**		Eye H	**0.725**				
E3	**0.884**		B4	**0.692**				
C4	**0.875**		D5	**0.543**				
D4	**0.872**		B3	**0.419**				
E5	**0.867**		F2		**0.724**			
D5	**0.859**		F4		**0.675**			
C3	**0.855**		F1		**0.671**			
B2	**0.851**		C1		**0.664**			
E1	**0.847**		A1		**−0.655**			
E2	**0.839**		D3		**0.583**			
C1	**0.835**		C5		**0.554**			
B5	**0.815**		E2		**0.491**			
D1	**0.812**		D1			**0.780**		
B1	**0.787**		C2			0.748		
B3	**0.771**		D4			**0.712**		
D3	**0.756**		C4			**0.627**		
B4	**0.697**		B2			0.597		
F3		**0.919**	C3			**0.581**		
A3		**0.914**	E4				0.907	
A1		**0.853**	E1				0.885	
Eye L		**0.830**	E3				0.659	
A2		**0.800**	D2				**0.626**	
F2		**0.695**	E5				**0.516**	
Eye H		**0.685**	B1					**0.758**
F1		**0.632**	B5					**0.687**
% V	57.72	33.75		22.64	18.01	16.01	14.98	8.48
Eigenv.	16.74	9.79		6.56	5.22	4.64	4.34	2.46
ANOVA	<0.01	<0.01		<0.01	<0.01	0.24	0.11	0.03

Components with significant differences (ANOVA; $P \leq 0.05$) in morphological traits between farmed and wild seabass are marked in bold (see Table 2 for definition of characters)

and scale modifications (Carrillo et al., 2001; Arechavala-Lopez et al., 2011c), and also bent body shape by skeletal anomalies, mainly in the haemal and caudal body regions (Paperna, 1978; Francescon et al., 1988; Balebona et al., 1993; Boglione et al., 1993, 2001; Marino et al., 1993; Chatain, 1994; Koumoundourous et al., 1997; Loy et al., 1999, 2000; Afonso et al., 2000; Sfakianakis et al., 2006). However, wild-caught seabream and seabass present a low number of malformations and are scarcely affected by any severe anomalies (Boglione et al., 2001; Loy et al., 2000). In this study, farmed fish were carefully selected from the captures looking for streamlined wild-like profiles, associated with absence or light anomalies cadres (Loy et al., 2000), to avoid these morphoanatomical differences cited above. Despite this, significant

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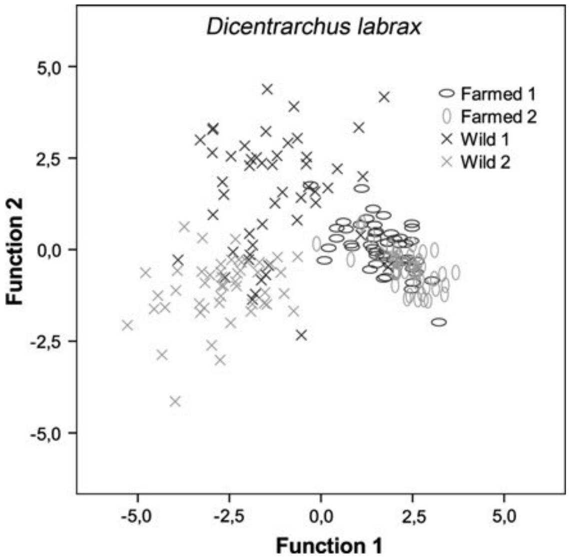

Fig. 7 Scatterplot of functions 1 and 2 for the discriminant analysis at Spain-group including the two locations of farmed seabass and the two localities of wild seabass

differences have been detected mainly in the anterior region for both species, resulting from neither malformations nor abnormalities.

In conclusion, this study provides evidences that body morphology of seabream and seabass are different according to their origin at different scales, which could be attributed to both rearing environment and genetic differentiation. Even more, the use of morphoanatomical indices (K, CI and RP) seems to have wider applicability than image processing (TNS) in the identification of wild and farmed fish. Such indices entail no great scientific expertise and they have been shown to be a valuable tool for describing changes in shape features, and could be used as a useful technique in the field to identify escapees within the wild stocks, and therefore, to monitor their potential negative effects on the environment and their influence on local fisheries landings. However, it must be taken into account that an escapee that survives over time may resemble a wild individual due to the changes on habitat and food. The use of the combined approach, such as morphometry, genetic and other biological indicators (e.g. growth pattern of scales and otoliths, fatty acids and trace elements), should be considered for the more precise quantification of escapes within natural populations, fisheries landing or for evaluation of re-stocking programs. This will not only contribute greatly to biological and ecological clarification of the species but will also help to the development of a strategy for natural stocks conservation and improving the aquaculture sustainability.

Table 7 Inter-group classification score result (in %) for the discriminant analysis of the four groups of seabass

Dicentrarchus labrax	Group	Spain		Greece		Total
		Farmed	Wild	Farmed	Wild	
Origin group (%)	Spain farmed	98	2	0	0	100
	Spain wild	7	88	5	0	100
	Greece farmed	0	0	99	1	100
	Greece wild	0	1	0	99	100

Table 8 Data from the intra- and inter-groups discrimination analyses

Group	F	Eigenvalue	Percent variance	Cumulative variance	Canonical correlation	Wilks' λ	χ^2	df	P
Spain	1	4.405	77.5	77.5	0.903	0.071	485.064	81	<0.001
Spain	2	0.930	16.4	93.9	0.694	0.384	175.457	52	<0.001
Spain	3	0.348	6.1	100.0	0.508	0.742	54.848	25	<0.001
Greece	1	7.596	100.0	100.0	0.940	0.116	394.768	29	<0.001
Spain–Greece	1	9.818	70.4	70.4	0.953	0.011	1709.278	87	<0.001
Spain–Greece	2	3.227	23.1	93.5	0.874	0.124	798.482	56	<0.001
Spain–Greece	3	0.908	6.5	100.0	0.690	0.524	247.106	27	<0.001

The groups of seabass were classified from these functions (F) in the discriminant analysis

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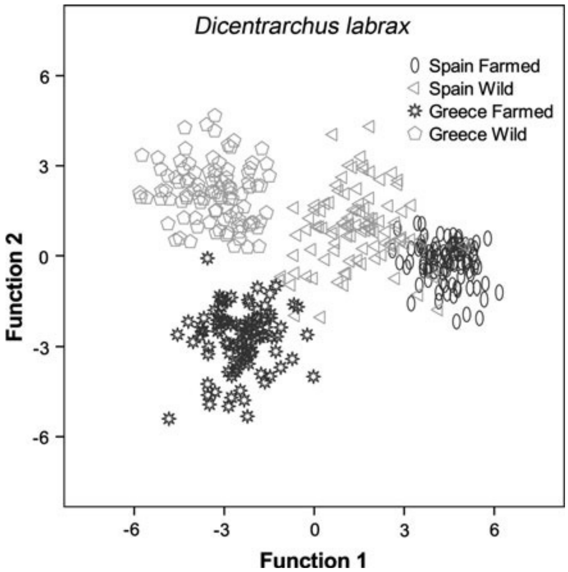

Fig. 8 Scatterplot of functions 1 and 2 for the discriminant analysis including the groups of farmed and wild seabass from Spain and Greece: *white circle* Spain Farmed; *white triangle* Spain Wild; *black star* Greece Farmed; *grey pentagon* Greece Wild

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References

Abramoff, M. D., P. J. Magelhaes & S. J. Ram, 2004. Image processing with ImageJ. Biophotonics International 11: 36–42.

Afonso, J. M., D. Montero, L. Robaina, N. Astorga, M. S. Izquierdo & R. Gines, 2000. Association of a lordosis–scoliosis–kyphosis deformity in gilthead sea bream. Fish Physiology and Biochemistry 22: 159–163.

Alarcón, J. A., A. Magoulas, T. Georgakopoulos, E. Zouros & M. C. Alvarez, 2004. Genetic comparison of wild and cultivated European populations of the gilthead sea bream (*Sparus aurata*). Aquaculture 230: 65–80.

Allegrucci, G., C. Fortunato & V. Sbordoni, 1997. Genetic structure and allozyme variation of sea bass (*Dicentrarchus labrax* and *D. punctatus*) in the Mediterranean Sea. Marine Biology 128: 347–358.

Allendorf, F. W., 1988. Conservation biology of fishes. Conservation Biology 2: 145–148.

Arabaci, M., Y. Yilmaz, S. B. Ceyhun, O. Erdogan, H. G. Dorlay, I. Diler, S. Akhan, M. Kocabas, K. Ozdemir, H. Koyun & S. Koncagul, 2010. A review on population characteristics of gilthead seabream (*Sparus aurata*). Journal of Animal and Veterinary Advances 9(6): 976–981.

Arechavala-Lopez, P., I. Uglem, D. Fernandez-Jover, J. T. Bayle-Sempere & P. Sanchez-Jerez, 2011a. Immediate behaviour of escaped seabass (*Dicentrarchus labrax* L.) from sea-cages in the Mediterranean. Journal of Applied Ichthyology (online): 1–14.

Arechavala-Lopez, P., I. Uglem, D. Fernandez-Jover, J. T. Bayle-Sempere & P. Sanchez-Jerez, 2011b. Post-escape behaviour of farmed seabream (*Sparus aurata* L.) and their influence on local fisheries. Fisheries Research (submitted).

Arechavala-Lopez, P., P. Sanchez-Jerez, J. T. Bayle-Sempere, D. G. Sfakianakis & S. Somarakis, 2011c. Discriminating farmed fish from wild Mediterranean stocks through scales and otoliths. Journal of Fish Biology (submitted).

Bahri-Sfar, L., C. Lemaire, O. Kalthoum Ben Hassine & F. Bonhomme, 2000. Fragmentation of sea bass populations in the western and eastern Mediterranean as revealed by microsatellite polymorphism. Proceedings of the Royal Society B 267: 929–935.

Balebona, M. C., M. A. Morinigo, J. A. Andrades, J. A. Santamaria, J. Becerra & J. J. Borrego, 1993. Microbiological study of gilthead sea bream *S. aurata* L. affected by lordosis a skeletal deformity. Bulletin of the European Association of Fish Pathologist 13: 33–36.

Ben-Slimen, H., H. Guerbej, A. Ben Othmen, I. Ould Brahim, H. Blel, N. Chatti, A. El Abed & K. Said, 2004. Genetic differentiation between populations of gilthead seabream (*Sparus aurata*) along the Tunisian coast. Cybium 28: 45–50.

Boglione, C., G. Marino, B. Bertolini, A. Rossi, F. Ferreri & S. Cataudella, 1993. Larval and postlarval monitoring in sea bass: morphological approach to evaluate finfish seed quality. In Barnabé, G. & P. Kestemont (eds), Production, Environment and Quality. Bordeaux Aquaculture'92, Vol. 18. European Aquaculture Society, Gent: 189–204.

Boglione, C., F. Gagliardi, M. Scardi & S. Cataudella, 2001. Skeletal descriptors, quality assessment in larvae, post-larvae of wild-caught, hatchery-reared gilthead sea bream (*Sparus aurata* L. 1758). Aquaculture 192: 1–22.

Bookstein, F. L., 1982. Foundations of morphometrics. Annual Review of Ecology, Evolution and Systematic 13: 451–470.

Carrillo, J., G. Koumoundouros, P. Divanach & J. Martinez, 2001. Morphological malformations of the lateral line in reared gilthead sea bream (*Sparus aurata* L. 1758). Aquaculture 192: 281–290.

Castilho, R. & Y. Ciftci, 2005. Genetic differentiation between close eastern Mediterranean *Dicentrarchus labrax* (L.) populations. Journal of Fish Biology 67: 1746–1752.

Castilho, R. & B. J. McAndrew, 1998. Population structure of seabass in Portugal: evidence from allozymes. Journal of Fish Biology 53: 1038–1049.

Cataldi, E., S. Cataudella, G. Monaco, L. Rossi & L. Tancioni, 1987. A study of the histology and morphology of the digestive tract of the sea-bream, *Sparus aurata*. Journal of Fish Biology 30: 135–145.

Cervelli, M., A. Comparini, G. Fava & E. Rodinò, 1985. Prime ricerche di genetica biochimica applicate all'acquacoltura di orata (*Sparus auratus* L.). Oebalia 9: 49–58.

Chatain, B., 1994. Abnormal swimbladder development and lordosis in sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*). Aquaculture 119: 371–379.

Chatfield, C. & A. J. Collins, 1983. Introduction to Multivariate Analysis. Chapman & Hall, London.

De Innocentiis, S., A. Lesti, S. Livi, A. R. Rossi, D. Crosetti & L. Sola, 2004. Microsatellite markers reveal population structure in gilthead sea bream *Sparus auratus* from the Atlantic Ocean and Mediterranean Sea. Fisheries Science 70: 852–859.

Dempster, T., H. Moe, A. Fredheim, Ø. Jensen & P. Sanchez-Jerez, 2007. Escapes of marine fish from sea-cage aquaculture in the Mediterranean Sea: status and prevention. CIESM Workshop Monographics 32: 55–60.

Divanach, P., C. Boglione, B. Menu, G. Koumoundouros, M. Kentouri & S. Cataudella, 1996. Abnormalities in finfish mariculture: an overview of the problem, causes and solutions. In Chatain, B., M. Saroglia, J. Sweetman & P. Lavens (eds), Seabass and Seabream Culture: Problems and Prospects. European Aquaculture Society, Oostende: 45–66.

Ergüden, D. & C. Turan, 2005. Examination of genetic, morphologic structure of sea-bass (*Dicentrarchus labrax* L., 1758) populations in Turkish coastal waters. Turkish Journal of Veterinary and Animal Sciences 29: 727–733.

FAO, 2011. The State of World Fisheries and Aquaculture (SOFIA), 2010. Departamento de Pesca, Roma.

Fiske, P., R. A. Lund & L. P. Hansen, 2005. Identifying fish farm escapees. In Cadrin, S. X., K. D. Friedland & J. R. Waldman (eds), Stock Identification Methods: Applications in Fishery Science. Elsevier, Amsterdam: 659–680.

Fleming, I. A., B. Jonsson & M. R. Gross, 1994. Phenotypic divergence of sea-ranched, farmed, and wild salmon. Canadian Journal of Fisheries and Aquatic Sciences 51: 808–2824.

Francescon, A., A. Freddi, A. Barbaro & R. Giavenni, 1988. Daurade *S. aurata* L. reproduite artificiellement et daurade sauvage. Expériences paralleles en diverses conditions d'elevage. Aquaculture 72: 273–285.

Funkenstein, B., B. Cavari, T. Stadie & E. Davidovtch, 1990. Restriction site polymorphism of mitochondrial DNA of the gilthead sea bream (*Sparus auratus*) broodstock in Eilat, Israel. Aquaculture 89: 217–223.

García de León, F. J., L. Chikhi & F. Bonhomme, 1997. Microsatellite polymorphism and population subdivision in natural populations of European sea bass *Dicentrarchus labrax* (Linnaeus, 1758). Molecular Ecology 6: 51–62.

Gisbert, E., 1999. Early development and allometric growth patterns in *Siberian sturgeon* and their ecological significance. Journal of Fish Biology 54: 852–862.

González-Lorenzo, G., A. Brito & J. Barquín, 2005. Impactos provocados por los escapes de peces de las jaulas de cultivos marinos en Canarias. Vieraea 33: 449–454.

Grigorakis, K., M. N. Alexis, K. D. A. Taylor & M. Hole, 2002. Comparison of wild and cultured gilthead sea bream (*Sparus aurata*): composition, appearance and seasonal variations. International Journal of Food Science & Technology 37: 477–484.

Haffray, P., C. S. Tsigenopoulos, F. Bonhomme, B. Chatain, A. Magoulas, M. Rye, A. Triantafyllidis & C. Triantaphyllidis, 2006. European sea bass—*Dicentrarchus labrax*. In Crosetti, D., S. Lapègue, I. Olesen & T. Svaasand (eds), Genetic Effects of Domestication, Culture and Breeding of Fish and Shellfish, and Their Impacts on Wild Populations. GENIMPACT Project: Evaluation of Genetic Impact of Aquaculture Activities on Native Populations. A European Network. WP1 Workshop "Genetics of Domestication, Breeding and Enhancement of Performance of Fish and Shellfish", Viterbo, Italy, 12–17th June, 2006: 6 pp. http://genimpact.imr.no/.

Hard, J. J., B. A. Berejiikian, E. P. Tezak, S. L. Schroder, C. M. Knudsen & L. T. Parker, 2000. Evidence for morphometric differentiation of wild and captively reared adult coho salmon: a geometric analysis. Environmental Biology of Fishes 58: 61–73.

Hernandez, L. P. & P. J. Motta, 1997. Trophic consequences of differential performance: ontogeny of oral jaw-crushing performance in the sheepshead, *Archosargus probatocephalus* (Teleostei, Sparidae). Journal of Zoology 243: 737–756.

Humphries, J. M., F. L. Bookstein, B. Chernoff, G. R. Smith, R. L. Elder & S. G. Poss, 1981. Multivariate discrimination by shape in relation to size. Systematic Zoology 30: 291–308.

Ihssen, P. E., H. E. Booke, J. M. McGlade, N. R. Payne & F. M. Utter, 1981. Stock identification: materials and methods. Canadian Journal of Fisheries and Aquatic Sciences 38: 1838–1855.

Karaiskou, N., A. Triantafyllidis, V. Katsares, T. Abatzopoulos & C. Triantaphyllidis, 2005. Genetic structure of wild and cultured Greek populations of the European sea bream (*Sparus aurata*, Linnaeus 1758). Panhellenic Congress of Ichthyologists, October 13–16, Drama, Greece, Book of Abstracts: 354–357.

Karaiskou, N., A. Triantafyllidis, V. Katsares, T. J. Abatzopoulos & C. Triantaphyllidis, 2009. Microsatellite variability of wild and farmed populations of *Sparus aurata*. Journal of Fish Biology 74: 1816–1825.

Katsares, V., A. Triantafyllidis, N. Karaiskou, T. Abatzopoulos & C. Triantaphyllidis, 2005. Genetic structure and discrimination of wild and cultured Greek populations of the European sea bass (*Dicentrarchus labrax*, Linnaeus 1758). 12th Panhellenic Congress of Ichthyologists, October 13–16, Drama, Greece, Book of Abstracts: 350–353.

Keast, A., 1978. Trophic and spatial interrelationships in the fish species of Ontario temperate lake. Environmental Biology of Fishes 13: 211–224.

Koumoundourous, G., F. Gagliardi, P. Divanach, C. Boglione, S. Cataudella & M. Kentouri, 1997. Normal and abnormal osteological development of caudal fin in *Sparus aurata* L. fry. Aquaculture 149: 215–226.

Lemaire, C., J. J. Versini & F. Bonhomme, 2005. Maintenance of genetic differentiation across a transition zone in the sea: discordance between nuclear and cytoplasmic markers. Journal of Evolutionary Biology 18: 70–80.

Loy, A., C. Boglione & S. Cataudella, 1999. Geometric morphometrics and morpho-anatomy: a combined tool in the study of sea bream (*Sparus aurata*, Sparidae) shape. Journal of Applied Ichthyology 15: 104–110.

Loy, A., C. Boglione, F. Gagliardi, L. Ferrucci & S. Cataudella, 2000. Geometric morphometrics and internal anatomy in sea bass shape analysis (*Dicentrarchus labrax* L., Moronidae). Aquaculture 186: 33–44.

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Loy, A., M. Bertelletti, C. Costa, L. Ferlin & S. Cataudella, 2001. Shape changes and growth trajectories in the early stages of three species of the genus *Diplodus* (Perciformes, Sparidae). Journal of Morphology 250: 24–33.

Mariani, S., A. Maccaroni, F. Massa, M. Rampacci & L. Pancioni, 2002. Lack of consistency between the trophic interrelationships of five sparid species in two adjacent central Mediterranean coastal lagoons. Journal of Fish Biology 61(A): 138–147.

Marino, G., C. Boglione, B. Bertolini, A. Rossi, F. Ferreri & S. Cataudella, 1993. Observations on the development, anomalies in the appendicular skeleton of sea bass, *D. labrax* L. 1758, larvae and juveniles. Aquaculture and Fisheries Management 24: 445–456.

Meager, J. J., J. E. Skjæraasen, A. Fernö, Ø. Karlsen, S. Løkkeborg, K. Michalsen & S. O. Utskot, 2009. Vertical dynamics and reproductive behaviour of farmed and wild Atlantic cod *Gadus morhua*. Marine Ecological Progress Series 389: 233–243.

Mérigoux, S. & D. Ponton, 1998. Body shape, diet and ontogenetic diet shifts in young fish of the Sinnamary River, French Guiana, South America. Journal of Fish Biology 52: 556–569.

Meyer, A., 1987. Phenotypic plasticity and heterochrony in *Cichlasoma managuense* (Piscles, Ciclidae) and their implication for speciation in cichlid fishes. Evolution 41: 1357–1369.

Naylor, R., K. Hindar, I. A. Fleming, R. Goldburg, S. Williams, J. Volpe, F. Whoriskey, J. Eagle, D. Kelso & M. Mangel, 2005. Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. BioScience 55(5): 427–437.

Osse, J. W. M., 1990. Form changes in fish larvae in relation to changing demands of function. Netherlands Journal of Zoology 40: 362–385.

Osse, J. W. M. & J. G. M. van den Boogaart, 1995. Fish larvae, development, allometric growth, and the aquatic environment. ICES Marine Sciences Symposium 201: 21–34.

Osse, J. W. M. & J. G. M. van den Boogaart, 1999. Dynamic morphology of fish larvae, structural implications of friction forces in swimming, feeding and ventilation. Journal of Fish Biology 55(A): 156–174.

Paperna, I., 1978. Swimbladder and skeletal deformations in hatchery bred *S. aurata*. Journal of Fish Biology 12: 109–114.

Patarnello, T., L. Bargelloni, F. Caldara & L. Coombo, 1993. Mitochondrial DNA sequence variation in the European sea bass, *Dicentrarchus labrax* L.: evidence of differential haplotype distribution in natural and farm populations. Molecular Marine Biology and Biotechnology 2: 333–337.

Reist, J. D., 1985. An empirical evaluation of several univariate methods that adjust for size variation in morphometric data. Canadian Journal of Zoology 63: 1429–1439.

Rossi, R., E. Perrone & L. Sola, 2006. Genetic structure of gilthead seabream, *Sparus aurata*, in the Central Mediterranean Sea. Central European Journal of Biology 1(4): 636–647.

Russo, T., C. Cota & S. Cataudella, 2007. Correspondence between shape and feeding habit changes throughout ontogeny of gilthead sea bream *Sparus aurata* L., 1758. Journal of Fish Biology 71: 629–656.

Sagnes, P., P. Gaudin & B. Statzner, 1997. Shifts in morphometry and their relation to hydrodynamic potential and habitat use during grayling ontogenesis. Journal of Fish Biology 50: 846–858.

Sfakianakis, D. G., E. Georgakopoulou, M. Kentouri & G. Koumoundouros, 2006. Geometric quantification of lordosis effects on body shape in European sea bass, *Dicentrarchus labrax*, (Linnaeus, 1758). Aquaculture 256: 27–33.

Sola, L., S. De Innocentiis, A. R. Rossi, D. Crosetti, M. Scardi, C. Boglione & S. Cataudella, 1998. Genetic variability and fingerling quality in wild and reared stocks of European sea bass. In Bartley, D. & B. Basurco (eds), Cahiers Options Méditerranéennes, Vol. 34: 273–280.

Sola, L., A. Moretti, D. Crosetti, N. Karaiskou, A. Magoulas, A. R. Rossi, M. Rye, A. Triantafyllidis & C. S. Tsigenopoulos, 2006. Gilthead seabream—*Sparus aurata*. In Crosetti, D., S. Lapègue, I. Olesen & T. Svaasand (eds), Genetic Effects of Domestication, Culture and Breeding of Fish and Shellfish, and Their Impacts on Wild Populations. GENIMPACT Project: Evaluation of Genetic Impact of Aquaculture Activities on Native Populations. A European Network. WP1 Workshop "Genetics of Domestication, Breeding and Enhancement of Performance of Fish and Shellfish", Viterbo, Italy, 12th–17th June, 2006: 6 pp. http://genimpact.imr.no/.

Stearns, S. C., 1983. A natural experiment in life-history evolution: field data on the introduction of mosquitofish (*Gambusia affinis*) to Hawaii. Evolution 37: 601–617.

Strauss, R. E. & F. L. Bookstein, 1982. The truss: body form reconstruction in morphometrics. Systematic Zoology 31: 113–135.

Swaine, D. P., B. E. Ridell & C. B. Murray, 1991. Morphological differences between hatchery and wild populations of coho salmon (*Oncorhynchus kisutch*): environmental versus genetic origin. Canadian Journal of Fisheries and Aquatic Sciences 48: 1783–1791.

Tancioni, L., S. Mariani, A. Maccaroni, A. Mariani, F. Massa, M. Scardi & S. Cataudella, 2003. Locality-specific variation in the feeding of *Sparus aurata* L.: evidence from two Mediterranean lagoon systems. Estuarine, Coastal and Shelf Science 57: 469–474.

Toledo-Guedes, K., P. Sanchez-Jerez, G. González-Lorenzo & A. Brito, 2009. Detecting the degree of establishment of a non-indigenous species in coastal ecosystems: sea bass *Dicentrarchus labrax* escapes from sea cages in Canary Islands (Northeastern Central Atlantic). Hydrobiologia 623(1): 203–212.

Tulli, F., I. Balenovic, M. Messina & E. Tibaldi, 2009. Biometry traits and geometric morphometrics in sea bass (*Dicentrarchus labrax*) from different farming systems. Italian Journal of Animal Science 8(2): 881–883.

Turan, C., 1999. A note on the examination of morphometric differentiation among fish populations: the truss system. Turkish Journal of Zoology 23: 259–263.

Uglem, I., P. A. Bjørn, T. Dale, S. Kerwath, F. Økland, R. Nilsen, K. Aas, I. Fleming & R. S. McKinley, 2008. Movements and spatiotemporal distribution of escaped farmed and local wild Atlantic cod (*Gadus morhua* L.). Aquaculture Research 39: 158–170.

Journal : Medium 10750 | Dispatch : 13-9-2011 | Pages : 15
Article No. : 886 | ☐ LE | ☐ TYPESET
MS Code : HYDR6416 | ☑ CP | ☑ DISK

Ward-Campbell, B. M. S. & W. H. Beamish, 2005. Ontogenetic changes in morphology and diet in the snakehead, *Channa limbata*, a predatory fish in western Thailand. Environmental Biology of Fishes 72: 251–257.

Webb, P. W. & D. Weihs, 1986. Functional locomotor morphology of early life history stages of fishes. Transaction of the American Fisheries Society 115: 115–127.

Journal : **Medium 10750** Dispatch : **13-9-2011** Pages : **15**
Article No. : **886** ☐ LE ☐ TYPESET
MS Code : **HYDR6416** ☑ CP ☑ DISK