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## Morphometrics and Allometry in Fishes

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### 1. Introduction

Fish morphometrics has been in the hot-spot of ichthyological studies for many decades, but the initial steps date back to the time of Galileo Galilei (Froese 2006). Yet, the scientific basis for morphometry in fishes, and especially the mathematical way that weight relates to length, was set by Fulton, in 1906, who for the first time introduced fisheries science into 'allometry' (Froese 2006).

Nowadays, the most commonly used relationships, that have been established for the majority of fishes (Binohlan & Pauly 2000, FishBase: [www.fishbase.org](http://www.fishbase.org): Froese & Pauly 2011), are those relating weight to body length (in the majority of cases, total body length (TL)), and different types of length (i.e., standard (SL) and fork (FL) length) to TL. Weight (W)-length (TL) relationships are of power type, i.e.,  $W=a TL^b$ . In this equation, a is the coefficient of body shape (Lleonart et al. 2000, Froese 2006, [www.fishbase.org](http://www.fishbase.org)), and it gets values around 0.1 for fishes which are small sized and with a rounded body shape, 0.01 for streamlined-shaped fishes and 0.001 for eel-like shaped fishes. In contrast, b is the coefficient balancing the dimensions of the equation and its values can be smaller, larger or equal to 3 (Lleonart et al. 2000, Froese 2006, [www.fishbase.org](http://www.fishbase.org)). In the first two cases (i.e.,  $b<3$  and  $b>3$ ) fish growth is allometric (i.e., when  $b<3$  the fish grows faster in length than in weight, and when  $b>3$  the fish grows faster in weight than in length), whereas when  $b=3$  growth is isometric. Froese (2006) analyze 3929 weight-length relationships for 1773 species, and reports that b ranges between 1.96 and 3.94, with 90% of the cases falling inside the 2.7-3.4 range. The lowest values have been recorded for *Cepola macrophthalma*, whereas the highest for *Chaenocephalus aceratus*. In principle, these types of relationships are allometric (82%), with a trend towards positive allometry (Froese 2006). Weight-length relationships are of high importance for fisheries science and can be used in a wide range of applications, such as: (a) estimation of biomass from length data; (b) estimation of a species condition factor; and (c) comparisons among life history and morphologic differentiations of the same species in different areas (e.g., Pauly 1993, Petrakis & Stergiou 1995, Binohlan & Pauly 2000).

In recent years, attempts have been made to relate other morphological characteristics of fishes, such as mouth (e.g., Karpouzi & Stergiou 2003, Chalkia & Bobori 2006, Karachle & Stergiou 2011a), intestine (e.g., Kramer & Bryant 1995a, b, Karachle & Stergiou 2010) and tail (Karachle & Stergiou 2004), to TL, and as well as to feeding habits and fractional trophic

levels ( $\tau$ ). In general, eco-morphological studies focus on the patterns that relate morphology and the use of available resources (e.g., Motta et al. 1995, Wainwright & Richard 1995), and consider morphology as a key factor for the determination of a species' feeding habits. Hence, variations in morphology are due to differences in the ability of different fish species to catch and consume their food, affecting the overall diet composition (e.g., Wainwright & Richard 1995, Wootton 1998).

Mouth gape has long been considered as the most important, yet restraining, factor affecting food consumption mainly in: (a) defining the size range of prey items a consumer can catch/consume and (b) affecting the efficiency of a predator to catch and consume its food (Wainwright & Richard 1995). More specifically, mouth gape can be used for the evaluation of the relationship between prey and predator size (e.g., Keast & Webb 1966, Wainwright & Richard 1995), whereas mouth shape and position, teeth, structure and number of gill rakers seem to be related to the type of food being consumed (e.g., Al-Hussaini 1947, Kapoor et al. 1975, Verigina 1991). The size spectrum of prey items for fishes increases as they grow, which is more evident in apex predators (Karpouzi & Stergiou 2003), and this fact has been mainly attributed to ontogenetic changes related to mouth morphology, visual acuity, more efficient digestion and better swimming ability of large fish (e.g., Keast & Webb 1966, Kaiser & Hughes 1993, Juanes 1994, Juanes & Conover 1994, Hart 1997, Wootton 1998, Fordham & Trippel 1999). Hence, mouth morphometry is generally related to  $\tau$  (Karpouzi & Stergiou 2003).

Intestine (or gut) length (GL) is considered to be an indicator of diet (Kramer & Bryant 1995a) and, particularly in fishes, can be used for interspecific dietary comparisons (e.g., Al-Hussaini 1947, Karachle & Stergiou 2010a). For a given body length, intestine in herbivorous species is longer than in omnivorous ones, and in omnivorous species longer than in carnivorous ones (e.g., Kapoor et al. 1975, Kramer & Bryant 1995b, Karachle & Stergiou 2010a, b). Hence, the widely accepted pattern of fish GL variation in relation to species feeding habits is:

Carnivores < omnivores < herbivores < detritus feeders

(e.g., Kapoor et al. 1975, Ribble & Smith 1983, Kramer & Bryant 1995b, Karachle & Stergiou 2010a, b). The same pattern is also true in other vertebrate classes (e.g., reptiles: O'Grady et al. 2005, birds: Ricklefs 1996, and mammals: Chivers & Hladik 1980).

Recent research has shown that there is a strong relationship between GL and body length (BL), that can be best described by the power type equation, i.e.,  $GL = a BL^b$  (Kramer & Bryant 1995a, b, Karachle & Stergiou 2010a, b). The significance of this allometry in GL could be related to the effect of the increasing body length to the relative efficiency of intestine to absorb nutrients from the digested food (e.g., Ribble & Smith 1983, Kramer & Bryant 1995a). Since growing organisms require more energy and nutrients, changes of the structural capacity, i.e. lengthier intestine, must be performed in order for those needs to be met. Those structural changes of intestine will ensure that food will be retained longer in the tract and more nutrients will be adsorbed, and more receptors for the absorption of energy and nutrients will be available.

Tail, the one characteristic that in the eyes of everyday people is what defines a fish, is the least examined of all feeding-related morphologic characteristics in fishes. Its relationship

with feeding was established in a model of the estimation of annual food consumption per unit biomass, i.e.,  $Q/B$  (Palomares & Pauly 1989). In this model, the tail aspect ratio ( $A$ ; i.e., the ratio of squared tail height per tail area) is a key variable:

$$Q/B = \frac{T^{0.61} \times A^{0.52}}{1.2 \times W^{0.2}}$$

where  $T$  is the mean water temperature ( $^{\circ}\text{C}$ ) and  $W$  is the asymptotic (or maximum) live weight of the fish (g) in the population (Pauly 1989a).

Despite the importance of tail characteristics, such as height, area and aspect ratio, little effort has been put into their study and thus available information is limited (Karachle & Stergiou 2004, 2005, 2008a). Moreover, even in research focusing on  $Q/B$  estimation,  $A$  has been estimated mainly from fish photos or drawings (e.g., García & Duarte 2002), or from measurements derived from a small number of individuals (e.g., 3-4 individuals; Angelini & Agostinho 2005).

In this chapter, we explore the effects of feeding habits, environment and/or habitat type on weight-length relationships and the morphometrics of feeding-related characteristics of fishes, namely mouth, intestine and tail. For weight-length relationships, mouth and intestine, we expanded on previously published information and relationships. For tail allometry we estimated tail area (TA), height (TH) and tail aspect ratio ( $A$ ) for 61 species from the North Aegean Sea, Greece, using imprints of tails, for a large number of individuals per species. Based on these estimates, we established the within-species relationships between TA, TH and  $A$  with TL. We also explored the relationships of the above mentioned tail characteristics with species' feeding habits and habitat type (i.e., pelagic, benthopelagic, demersal, and reef-associated; the ecological niche concept being also included). Finally, the relationship between the mean  $A$  values ( $A_m$ ) and mean TL ( $TL_m$ ) per species was explored.

## 2. Materials and methods

We used prior published information on morphology and morphometrics of fishes, and especially mathematical expressions, which were transformed into allometric regressions and grouped based on species' feeding habits and environment/habitat. The use of the allometric model, instead of other types of models (i.e., linear, exponential, and logarithmic), in the description of relationships between morphological characteristics, such as those presented here, and body length, was better for the following reasons:

1. it allows the detection of morphologic changes in shape, which is the basic hypothesis in the study of morphometrics (Leonart et al. 2002)
2. in contrast with the other types of models, the allometric one is the only one for which when  $X=0$ , then  $Y=0$ , a fact that is meaningful in morphometrics (Leonart et al. 2002), and
3. especially in the case of feeding related characteristics, it is the only one that can explain changes in the morphology such as required for a growing fish to meet its increasing energetic demands, while the energy spent for the acquisition of food is minimized (Karachle & Stergiou 2010b, 2011a).

## 2.1 Weight-length relationships

In order to examine the effect of feeding habits and habitat type on the weight-length relationships, we used the data of Karachle & Stergiou (2008b) for 60 species from the North Aegean Sea. The individual data of all 60 species were plotted together in order to examine whether there is any pattern in the way that  $W$  changes with  $TL$  across species. Consequently, the weight-length data of the different species were grouped according to:

1. species' feeding habits, using their  $\tau$  as given in FishBase ([www.fishbase.org](http://www.fishbase.org)). Based on  $\tau$  values, fishes were grouped into five different functional trophic groups (FTGs), using the classification of Stergiou & Karpouzi (2002):
  - a. pure herbivores ( $2.0 < \tau < 2.1$ ) (H);
  - b. omnivores with preference for plants ( $2.1 < \tau < 2.9$ ) (OV);
  - c. omnivores with preference for animals ( $2.9 < \tau < 3.7$ ) (OA);
  - d. carnivores with preference for decapods/fish ( $3.7 < \tau < 4.0$ ) (CD); and
  - e. carnivores with preference for fish/cephalopods ( $4.0 < \tau < 4.5$ ) (CC).
2. habitat type (i.e., pelagic, benthopelagic, demersal, and reef-associated; information from FishBase ([www.fishbase.org](http://www.fishbase.org))).

Next, the combined regression lines of species per FTG and habitat type were plotted on the same graph and patterns were identified. Finally, the combined general regression lines of  $W$ - $TL$  relationships of each of the above mentioned groupings were compared, using the log-transformed data, with Analysis of Covariance (ANCOVA; Zar 1999).

## 2.2 Mouth characteristics

The relationships of mouth area (MA) with total body length (TL), which are given in Karpouzi & Stergiou (2003) and Karachle & Stergiou (2011a), were used. They were again grouped according to FTGs and habitat type (see section 2.1). Based on the original MA- $TL$  equations for 68 species, general regression lines were constructed.

## 2.3 Intestine morphometrics

The relationships of fish gut length (GL) with body length (BL), presented in Karachle & Stergiou (2010a) and Karachle & Stergiou (2010b), were used in order to check for GL changes in relation to feeding habits and habitat. Overall, relationships of GL-BL were used for 99 species, and the individual data for these species were grouped according to the FTGs of the species and habitat (see section 2.1).

## 2.4 Tail

Samples were collected in the North Aegean Sea, on a seasonal basis, from June 2001 to January 2006, using commercial fishing vessels (i.e., trawlers, purse-seiners, and gill-netters) and preserved in 10% formalin (for details see Karachle & Stergiou 2008c). In the laboratory,  $TL$  was measured and tail was imprinted (for at least 30 individuals per species, when possible). Based on these imprints, tail height (TH) and area (TA) were estimated, using UTHSCSA IMAGETOOL Ver. 3.0 (Wilcox et al. 1997) software. Based on TH and TA measurements,  $A$  was estimated, as follows (Pauly 1989a):

$$A = \frac{TH^2}{TA}$$

The relationships between TA-TL and TH-TL were established using power regression ( $Y=aX^b$ ; Lleonart et al. 2000) and consequently  $b$  (given the mathematical traits of  $b$  as explained in the introduction) was tested for difference from 2, in the case of TA (since the measurement unit of TA is  $\text{cm}^2$ ), and difference from 1, in the case of TH (since the measurement unit of TH is cm), using t-test (Zar 1999). Additionally, all TA-TL regressions were plotted together for the detection of possible groupings of species.

In order to identify patterns of changes of TA with TL, the data for the different species were compiled together based on FTGs and habitat type (see section 2.1). In order to identify possible patterns, the regressions per group in each of the above mentioned compilations were plotted together. Comparisons of the slopes of the general regression lines were performed on the log-transformed data using ANCOVA (Zar 1999).

The relationships between  $A$  and TL were estimated for all species (they are not presented here) and the type of the relationship was defined based on the  $R^2$  values. Finally, the across-species relationship between the mean  $A$  values ( $A_m$ ) and mean TL ( $TL_m$ ) per species was also explored.

### 3. Results

#### 3.1 Weight-length relationships

When all data for the 60 species were plotted together, three major groups were identified (Fig. 1a, b): group (I) included *C. macrophthalma* and *Belone belone*, group (II) *Scyliorhinus canicula* and *Sphyraena sphyraena*, and group (III) the remaining species. The slopes of the regressions of the three groups differed significantly (for all combinations:  $p < 0.05$ ). The graphs of the combined regression lines per FTG and habitat type (number of species per FTG and habitat type are given in Table 1) did not reveal any clear grouping of weight-length relationships (Fig. 1c and d). Nevertheless, in the case of FTGs, based on the results of ANCOVA, there was a significant difference in the slopes of the regression lines between omnivores with preference to animal material, carnivores with preference to fish and decapods and carnivores with preference to fish and cephalopods (for all combinations:  $p < 0.05$ ), whereas there was no difference between those of the regressions for herbivorous species with those of the species of all other FTGs (for all combinations:  $p > 0.10$ ). Accordingly, in the case of habitat type, there was not any significant difference in the slopes of the relationships between pelagic and benthopelagic species (ANCOVA:  $p = 0.569$ ,  $F\text{-ratio} = 9026.64$ ), while the slopes of all remaining combinations differed significantly (for all combinations:  $p < 0.05$ ).

For the same length, omnivores with preference to animal material weighed less than carnivores (carnivores with preference to fish and decapods and carnivores with preference to fish and cephalopods) (Fig. 1c). When habitat type was examined (Fig 1d), for the same length, the following pattern was observed for weight:

$$D < P < BP = RA.$$

Category	W	MA	GL
<b>Functional Trophic Groups</b>			
Herbivores (H)	1		5
Omnivores with preference to plants (OV)		1	5
Omnivores with preference to animals (OA)	33	36	55
Carnivores with preference to decapods and fish (CD)	8	9	16
Carnivores with preference to fish and cephalopods (CC)	18	22	18
<b>Habitat type</b>			
Pelagic (P)	15	15	17
Benthopelagic (BP)	14	14	29
Demersal (D)	25	29	45
Reef-associated (RA)	6	7	8
Total number of species	60	68	99

Table 1. Number of species per functional trophic group and habitat, for which weight (W), mouth area (MA) and intestine length (GL) relationships with body length were retrieved from the literature (W: Karachle & Stergiou (2008b); MA: Karpouzi & Stergiou (2003) and Karachle & Stergiou (2011a); GL: Karachle & Stergiou (2010a, b)).

### 3.2 Mouth characteristics

The distribution of the 68 species used for mouth morphometrics by FTGs and habitat is given in Table 1. The vast majority of species were omnivores with preference to animals, followed by carnivores with preference to fish and cephalopods. In the present study, among the 68 studied species, demersal species outnumbered those living in the remaining habitats, followed by pelagic and benthopelagic species, which were equally represented.

Plots of the regression lines of species per FTG revealed that for the same TL (Fig. 2a), MA dimensions change as followed:

$$OA < OV < CC < CD.$$

Comparison between the different habitats (Fig. 2b) did not reveal a clear pattern. Only benthopelagic species seemed to largely differentiate from the remaining three habitat-related groups, at lengths >20cm.

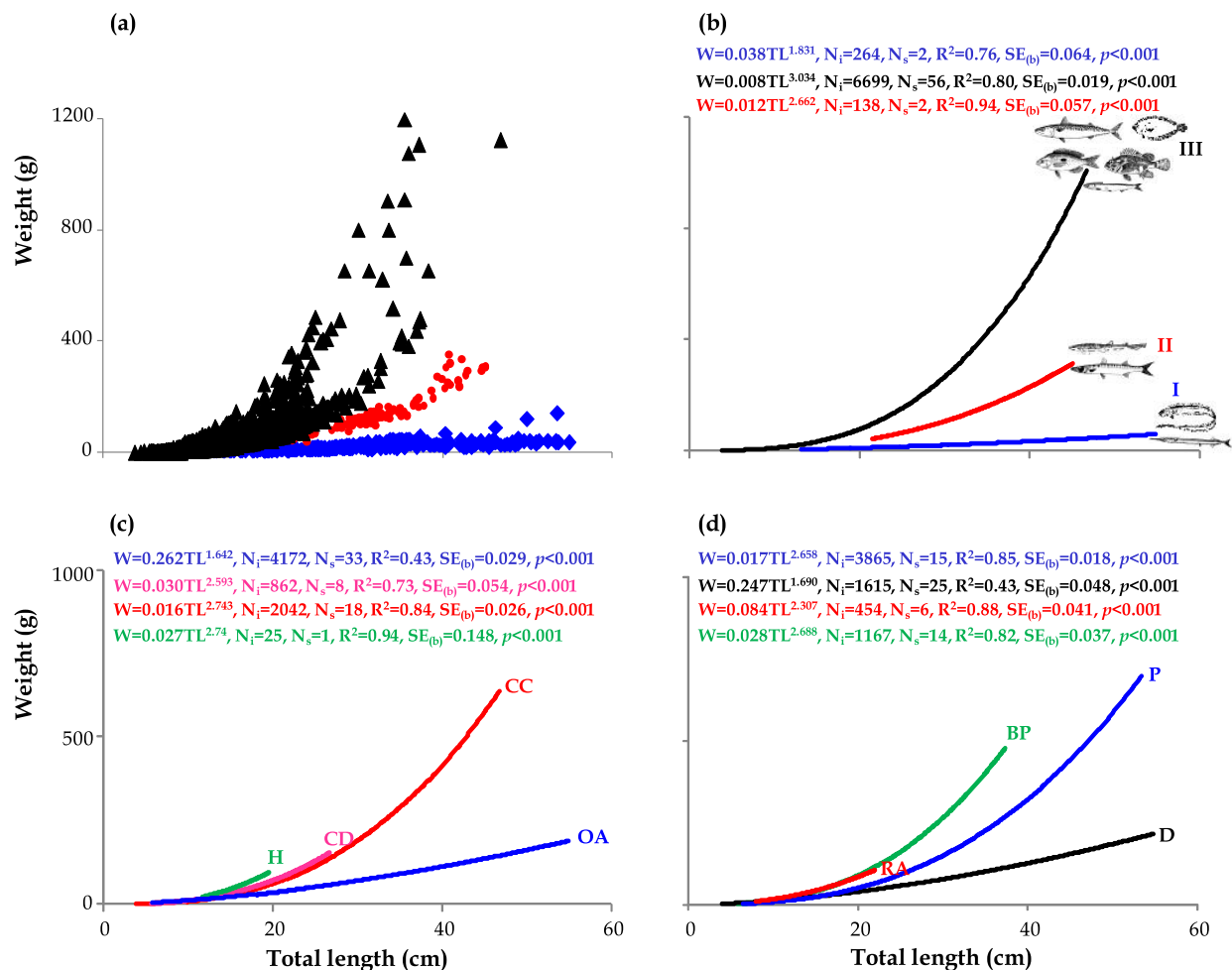


Fig. 1. Regressions between total body length (TL) and weight (W) based on data from Karachle & Stergiou (2008b) for 60 fish species North Aegean Sea, Greece, June 2001-January 2006: (a) original individual data, (b) groups identified in (a), (c) functional trophic group, as identified by Stergiou & Karpouzi (2002) and (d) habitat type (from Fishbase; www.fishbase.org; Froese & Pauly 2011). **H**: herbivores; **OA**: omnivores with preference to animal material; **CD**: carnivores with preference to decapods and fish; **CC**: carnivores with preference to fish and cephalopods; **P**: pelagic; **BP**: benthopelagic; **D**: demersal; **RA**: reef-associated;  $N_i$ =number of individuals;  $N_s$ =number of species;  $R^2$  = coefficient of determination; and  $SE_{(b)}$  = standard error of slope b. Fish drawings are from FishBase (www.fishbase.org; Froese & Pauly 2011).



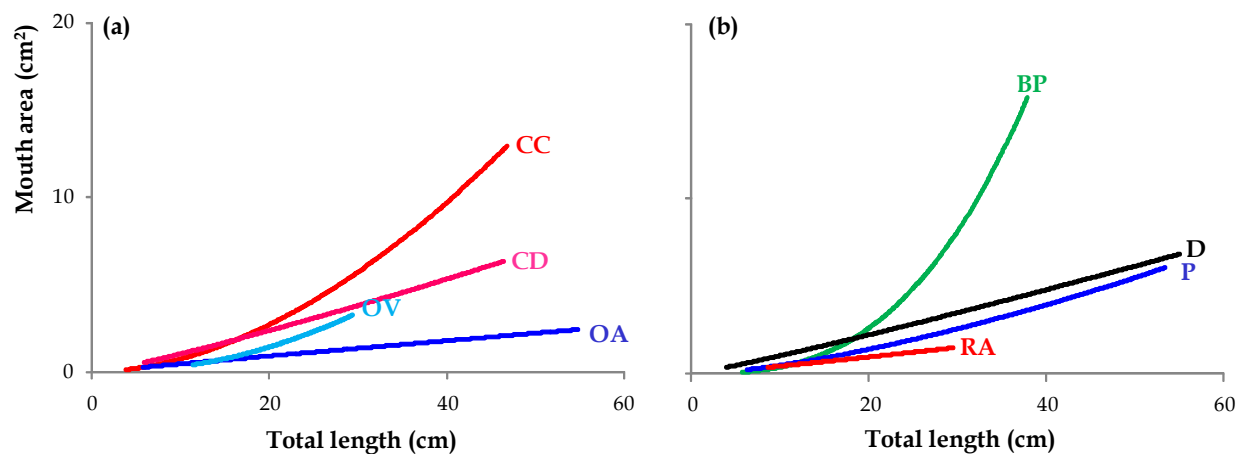


Fig. 2. Regressions between total length and mouth area based on literature data for 68 fish species (from Karpouzi & Stergiou (2003) and Karachle & Stergiou (2011a)) grouped by: (a) functional trophic group, as identified by Stergiou & Karpouzi (2002), and (b) habitat type. **OV**: omnivores with preference to vegetable material; **OA**: omnivores with preference to animal material; **CD**: carnivores with preference to decapods and fish; **CC**: carnivores with preference to fish and cephalopods; **P**: pelagic; **BP**: benthopelagic; **D**: demersal; **RA**: reef-associated.

### 3.3 Intestine morphometrics

Of the 99 different species for which GL-BL relationships were used, more than half (55 out of 99 species) were omnivores with preference to animals, and the vast majority of them were demersal species (Table 1).

The regression lines of the species per FTG showed a clear formation of two separate groups: one including herbivorous species and omnivores with preference to plants (group I), and another one including omnivores with preference to animal material, carnivores with preference to fish and decapods, and carnivores with preference to fish and cephalopods (group II) (Fig. 3a). Additionally, for the same BL, GL was higher for the species of the first group than in those of the second one.

Finally, GL changed with habitat type as follows (Fig. 3b):

$$D < BP \leq P < RA.$$

### 3.4 Tail

Overall, TA, TH and A values were estimated for 61 fish species (2703 individuals; Table 2). The number of individuals examined ranged from 6 (for *Lophius piscatorius* and *Pomatomus saltatrix*) to 100 (for *Arnoglossus laterna*) (Table 2).  $A_m$  ranged from 0.23, for *Gaidropsarus mediterraneus* and *Lesueurigobius suerii*, to 4.38, for *Scomber scombrus*.

The TA-TL and TH-TL relationships are shown in Table 2. They were all significant ( $p < 0.05$ ). In the case of TA-TL relationships, in 32 out of the 61 species (52.5%), the b value of the relationship was statistically different from 2 (t-test:  $p < 0.10$ ), indicating the predominance of the allometric relationship of TA and TL. This relationship was positively allometric (i.e.,  $b > 2$ )

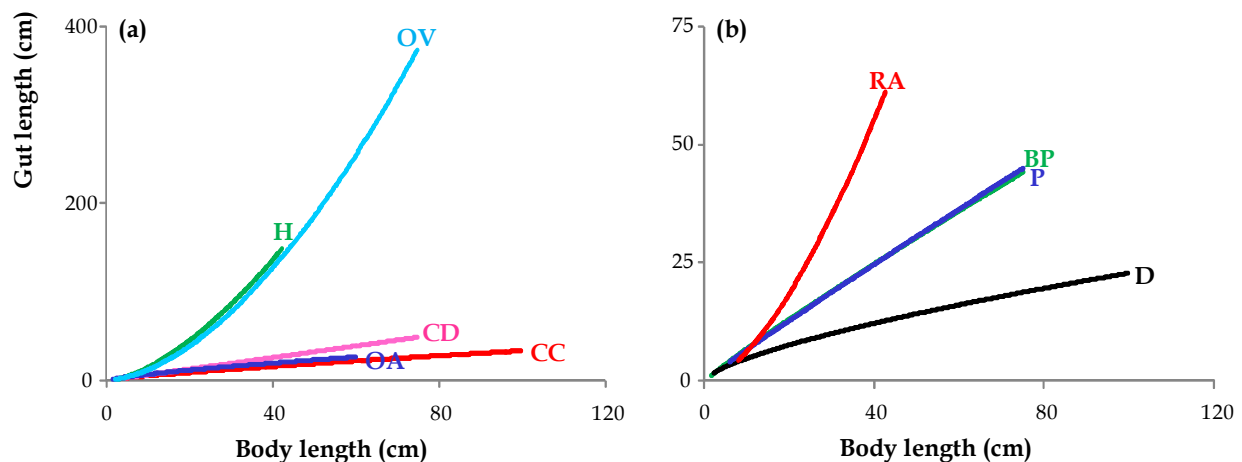


Fig. 3. Regressions between body length and gut length based on literature data for 99 fish species (from Karachle & Stergiou (2010a, b) grouped by: (a) functional trophic group, as identified by Stergiou & Karpouzi (2002), and (b) habitat type (from Fishbase; www.fishbase.org; Froese & Pauly 2011). H: herbivores; OV: omnivores with preference to vegetable material; OA: omnivores with preference to animal material; CD: carnivores with preference to decapods and fish; CC: carnivores with preference to fish and cephalopods; P: pelagic; BP: benthopelagic; D: demersal; RA: reef-associated.

in 20 species (62.5%), and negatively allometric (i.e.,  $b < 2$ ) in 12 species (37.5%) (Table 2). For the remaining 29 species (47.5%) for which the power expression of the relationship was not statistically significant (t-test:  $p > 0.10$ ), and based on the  $R^2$  values, the relationship was of the power type for 14 species (48.3%), exponential ( $TA = a e^{bTL}$ ) for 8 species (27.6%), linear ( $TA = a + bTL$ ) for 5 species (17.2%) and logarithmic ( $TA = a + b \log TL$ ) only for *Diplodus annularis* and *Diplodus vulgaris* (6.9%) (Tables 2 and 3).

Likewise, in the case of the TH-TL relationships, the allometric model was statistically accepted (i.e.,  $b \neq 1$ ; t-test:  $p < 0.10$ ) for the majority of species (40 out of the 61 species; 65.6%). Positive allometry (i.e.,  $b > 1$ ) was found for 35 species (87.5%), and negative allometry (i.e.,  $b < 1$ ) for only 5 species (12.5%) (Table 2). For the remaining 21 species (34.4%) for which the assumption that  $b \neq 1$  was not statistically significant (t-test:  $p > 0.10$ ), the relationship type identified was: linear ( $TH = a + bTL$ ) for 8 species (38.1%), power for 6 species (28.6%), exponential ( $TH = a e^{bTL}$ ) for 5 species (23.8%) and logarithmic ( $TH = a + b \log TL$ ) only for *Coris julis* and *Dentex dentex* (69.5%) (Tables 2 and 3).

When individual data for each species were grouped per FTG (Fig. 4), there was a clear separation of omnivores with preference to animal material, from carnivores with preference to fish and decapods, and carnivores with preference to fish and cephalopods. Indeed, the slope of the regression of omnivores with preference to animal material differed significantly from that of the other two regressions (ANCOVA: for both cases  $p < 0.01$ ), whereas there was no difference between the slopes of the regressions for carnivores with preference to fish and decapods and carnivores with preference to fish and cephalopods (ANCOVA:  $p > 0.10$ ). Accordingly, when habitat type was used for the grouping of species (Fig. 5), two separate groups were formed, one including reef-associated and benthopelagic species and another one including pelagic and demersal species and there was a significant difference among the slopes of all four regressions (ANCOVA: for all cases  $p < 0.01$ ).

Species	N	H	TL range (cm)		TL <sub>m</sub> (cm)	TH - TL				TA-TL				Aspect ratio				
			min	max		a	B	SE <sub>(b)</sub>	R <sup>2</sup>	b#1	ToR	a	b	SE <sub>(b)</sub>	R <sup>2</sup>	b#2	ToR	A <sub>m</sub>
<i>Alosa fallax</i>	25	P	15	46.8	24.4	0.3634	0.9239	0.065	0.90	Li	0.0314	1.8886	0.083	0.96	P	3.71	0.026	Pn+
<i>Anthias anthias</i>	9	RA	12.7	16.6	14.6	0.0853	1.4855	0.505	0.55	P	0.0436	1.8632	0.279	0.87	L	3.29	0.204	Pn-
<i>Apogon imberbis</i>	30	RA	8	11.5	10.2	0.1842	1.2405	0.243	0.48	Li	0.0289	2.2014	0.281	0.69	E	2.25	0.053	Pn+
<i>Arnoglossus laterna</i>	100	D	4.5	16.6	11.4	0.1016	1.2101	0.030	0.94	x	0.0159	2.1737	0.040	0.97	P	1.18	0.397	Pn+
<i>Belone belone</i>	67	P	27.2	53.5	33.7	0.0534	1.1974	0.065	0.84	x	0.0017	2.2382	0.094	0.90	x	2.97	0.046	P
<i>Blennius ocellaris</i>	22	D	7	13.7	10.2	0.1117	1.2885	0.064	0.95	x	0.0188	2.264	0.091	0.97	x	1.37	0.396	Pn-
<i>Boops boops</i>	75	P	11.2	19.9	15.4	0.1196	1.2863	0.054	0.89	x	0.01	2.2408	0.065	0.94	x	3.54	0.265	Pn+
<i>Bothus podas</i>	21	D	11.3	17.2	13.5	0.1291	1.1635	0.140	0.78	Li	0.0287	2.0078	0.183	0.86	Li	1.34	0.221	Li
<i>Cepola macrophthalmia</i>	84	D	13.2	54.9	31.8	0.1318	0.4876	0.027	0.80	x	0.0109	1.4079	0.069	0.84	x	0.38	0.419	P*
<i>Chelidontichthys lucernus</i>	15	D	6	21.6	10.7	0.1033	1.2364	0.071	0.96	x	0.0147	2.1671	0.072	0.99	x	1.47	0.725	Pn-
<i>Chromis chromis</i>	41	RA	8.6	13.3	10.9	0.2582	1.024	0.154	0.53	Li	0.0621	1.7038	0.209	0.63	Li	2.46	0.172	Pn+
<i>Citharus linguatula</i>	95	D	3.9	24.3	14.2	0.135	1.1694	0.02	0.95	x	0.0244	2.0817	0.031	0.98	x	1.48	0.447	Pn+
<i>Coris julis</i>	49	RA	11.3	18.2	15.8	0.103	1.2629	0.160	0.57	P	0.0181	2.124	0.203	0.70	P	1.79	0.137	Pn+
<i>Dentex dentex</i>	9	BP	11.7	15.3	13.0	0.3396	0.8961	0.320	0.50	Li	0.0167	2.1909	0.265	0.91	E	2.59	0.034	Pn+
<i>Diplodus annularis</i>	72	BP	6.1	17.5	11.1	0.1929	1.117	0.058	0.84	x	0.022	2.0722	0.066	0.93	E	2.51	0.086	Pn+
<i>Diplodus vulgaris</i>	38	BP	9	16.7	11.7	0.3501	0.9558	0.103	0.71	Li	0.0452	1.83	0.128	0.85	Li	3.33	0.115	Pn+
<i>Engraulis encrasicolus</i>	83	P	6.7	16.2	11.0	0.2314	0.9106	0.046	0.83	x	0.0574	1.3809	0.057	0.90	x	2.70	0.397	Pn-
<i>Eutrigla gurnardus</i>	10	D	6.3	14.8	12.8	0.2196	0.9916	0.082	0.95	P	0.0458	1.7016	0.114	0.97	x	2.16	0.552	P
<i>Gaidropsarus biscayensis</i>	53	BP	9.1	15.3	12.1	0.0755	1.1428	0.069	0.84	x	0.0117	2.0096	0.091	0.91	E	0.97	0.224	Pn+
<i>Gaidropsarus mediterraneus</i>	15	D	8.4	14.5	11.4	0.1055	0.973	0.183	0.69	E	0.0215	1.713	0.190	0.86	P	0.23	0.579	Pn+
<i>Lesueurigobius suerii</i>	47	D	5.8	9.3	7.8	0.0878	1.2393	0.098	0.78	x	0.0109	2.4033	0.119	0.90	x	0.23	0.558	E
<i>Lophius budegassa</i>	29	D	5.5	38.4	13.2	0.0231	1.5419	0.046	0.98	x	0.0043	2.3834	0.076	0.97	x	2.41	0.923	Li
<i>Lophius piscatorius</i>	6	D	7.7	12.7	9.6	0.0215	1.558	0.221	0.93	x	0.0087	2.1066	0.405	0.87	Li	0.52	0.974	Pn+
<i>Merlangius merlangus</i>	39	BP	14.1	29.1	20.2	0.0788	1.2887	0.067	0.91	x	0.0175	2.0713	0.084	0.94	P	1.62	0.592	Pn+
<i>Mertuuccius mertuuccius</i>	21	D	11.7	37	20.5	0.0454	1.3958	0.029	0.99	x	0.011	2.1227	0.037	0.99	x	1.39	0.944	Li
<i>Micromesistius poutassou</i>	47	P	9.2	24	12.2	0.0746	1.2386	0.071	0.87	x	0.01	2.089	0.087	0.93	E	1.47	0.352	Pn+
<i>Monochirus hispidus</i>	23	D	9.2	12.8	11.0	1.1012	0.2909	0.336	0.04	Li	0.157	1.2828	0.336	0.41	x	1.46	0.249	Pn+
<i>Mullus surmuletus</i>	51	D	9.1	23.1	15.5	0.2367	1.0922	0.030	0.96	x	0.0204	2.1134	0.040	0.98	x	3.34	0.068	Pn-
<i>Oblada melanura</i>	55	BP	12.6	22.7	18.0	0.178	1.2173	0.054	0.90	x	0.0258	2.046	0.080	0.93	L	3.78	0.532	Pn-
<i>Pagellus acarne</i>	52	BP	10.5	19.2	14.7	0.1583	1.2167	0.080	0.82	x	0.0247	1.9979	0.100	0.89	E	3.27	0.435	Pn+
<i>Pagellus bogarneo</i>	64	BP	9.3	22.8	15.1	0.1634	1.2359	0.022	0.98	x	0.0197	2.1315	0.027	0.99	x	3.39	0.688	Pn+
<i>Pagellus erythrinus</i>	36	BP	8.4	16.4	12.8	0.1196	1.3379	0.132	0.75	x	0.0161	2.1964	0.122	0.91	P	3.03	0.179	E
<i>Pagrus pagrus</i>	10	BP	10.2	15.5	12.2	0.2158	1.1379	0.188	0.82	L	0.0165	2.2497	0.146	0.97	Li	3.02	0.227	Pn-

Species	N	H	TL range (cm)		TL <sub>m</sub> (cm)	TH - TL			TA - TL			Aspect ratio								
			min	max		a	B	SE <sub>(b)</sub>	R <sup>2</sup>	b≠1 ToR	a	b	SE <sub>(b)</sub>	R <sup>2</sup>	b≠2 ToR	A <sub>m</sub>	R <sup>2</sup>	ToR		
<i>Phycis blennioides</i>	27	BP	8.1	37.4	20.4	0.0489	1.2646	0.032	0.99	x	P	0.0077	2.1216	0.033	0.99	x	P	1.04	0.839	P
<i>Pomatomus saltatrix</i>	6	P	13.1	18.5	16.1	0.0765	1.4859	0.110	0.98	x	P	0.0102	2.3803	0.223	0.97	x	P	1.42	0.970	Pn+
<i>Sardina pilchardus</i>	65	P	7.9	16.7	13.2	0.219	0.9747	0.109	0.56	E	E	0.0299	1.7494	0.094	0.85	x	P	2.73	0.130	Pn+
<i>Sardinella aurita</i>	76	P	8.9	23.9	18.0	0.3459	0.9054	0.053	0.80	x	P	0.0575	1.5718	0.055	0.92	x	P	4.17	0.136	P
<i>Sarpa salpa</i>	25	BP	11.7	19.5	14.9	0.063	1.5451	0.077	0.95	x	P	0.0044	2.6085	0.092	0.97	x	P	3.28	0.417	Pn-
<i>Sciaena umbra</i>	11	D	12.2	16	14.2	0.0059	2.3463	0.478	0.73	x	P	0.0007	3.4917	0.531	0.83	x	P	1.25	0.461	Pn+
<i>Scomber colias</i>	85	P	8.8	21.7	16.2	0.0582	1.4591	0.075	0.82	x	P	0.009	2.0946	0.063	0.93	x	P	3.78	0.504	Pn-
<i>Scomber scombrus</i>	79	P	13.4	27.4	21.1	0.0307	1.6515	0.057	0.92	x	P	0.0042	2.3351	0.041	0.98	x	P	4.38	0.829	Pn-
<i>Scorpaena notata</i>	43	D	8.3	17.8	14.2	0.0796	1.4706	0.079	0.89	x	P	0.0141	2.4631	0.080	0.96	x	P	1.60	0.438	E
<i>Scorpaena porcus</i>	69	D	8.2	26.4	14.0	0.0719	1.4471	0.052	0.92	x	P	0.0167	2.3395	0.053	0.97	x	P	1.33	0.669	Li
<i>Scyllorhinus canicula</i>	28	D	29.1	45.1	38.1	0.1343	0.8273	0.089	0.77	E	E	0.0294	1.6102	0.147	0.82	x	P	0.72	0.034	Pn+
<i>Serranus cabrilla</i>	43	D	9.5	23.1	14.8	0.1357	1.1982	0.063	0.90	x	P	0.0164	2.1648	0.076	0.95	x	P	2.10	0.199	Pn-
<i>Serranus hepatus</i>	61	D	5.7	13.1	9.6	0.2718	0.9589	0.057	0.83	P	P	0.0556	1.7351	0.067	0.92	x	P	2.01	0.102	Pn-
<i>Serranus scriba</i>	47	D	10.6	23.6	15.9	0.1866	1.0678	0.080	0.80	E	E	0.033	1.9766	0.106	0.89	x	P	1.64	0.101	Pn+
<i>Sphyræna sphyraena</i>	29	P	28.3	34.4	31.6	0.9351	0.5448	0.259	0.14	x	P	0.0239	1.7857	0.350	0.49	x	E	3.32	0.197	Pn-
<i>Spicara maena</i>	83	P	9	20.2	13.7	0.197	1.0563	0.051	0.84	P	P	0.0253	1.9139	0.059	0.93	x	P	2.59	0.117	Pn+
<i>Spicara smaris</i>	58	P	7	18.5	11.9	0.1315	1.2354	0.073	0.84	x	P	0.0232	1.93	0.079	0.92	x	P	0.82	0.744	P
<i>Spondyliosoma cantharus</i>	47	BP	9.7	14	11.6	0.413	0.8187	0.128	0.48	P	P	0.1106	1.4301	0.138	0.70	x	P	2.58	0.076	Pn-
<i>Symphodus mediterraneus</i>	10	RA	9.8	14.1	12.0	0.8979	0.4808	0.382	0.17	Li	Li	0.1463	1.4759	0.356	0.68	x	P	1.55	0.154	Pn+
<i>Symphodus tinca</i>	55	RA	11.4	22	15.8	0.2237	0.9867	0.085	0.72	E	E	0.0238	2.0875	0.097	0.90	x	E	1.55	0.039	Pn-
<i>Symphurus nigrescens</i>	9	D	6.4	11.1	9.2	0.0356	1.3422	0.126	0.94	x	P	0.0008	2.8561	0.209	0.96	x	P	1.10	0.106	Pn+
<i>Torpedo marmorata</i>	61	D	8.8	36.1	15.9	0.2478	0.9101	0.027	0.95	x	P	0.0385	1.7915	0.037	0.98	x	P	1.73	0.209	Pn-
<i>Trachinus draco</i>	23	D	15	30.5	22.6	0.1022	1.2455	0.105	0.87	x	P	0.0186	2.0407	0.106	0.94	x	P	2.27	0.265	P
<i>Trachurus mediterraneus</i>	74	P	7	25.8	15.2	0.1215	1.1995	0.047	0.90	x	P	0.0195	1.9248	0.038	0.97	x	P	2.76	0.515	Pn+
<i>Trachurus trachurus</i>	60	P	6.3	23.9	14.9	0.0741	1.3806	0.038	0.97	x	P	0.013	2.0438	0.038	0.98	x	P	2.88	0.837	P
<i>Trisopterus minutus</i>	69	BP	5.7	24.5	12.8	0.0979	1.1917	0.035	0.95	x	P	0.0165	2.069	0.042	0.97	x	P	1.29	0.556	Pn+
<i>Uranoscopus scaber</i>	55	D	8.7	26.9	14.5	0.2309	1.025	0.040	0.93	L	L	0.0606	1.86	0.044	0.97	x	P	1.46	0.227	Pn-
<i>Xyrichtys novacula</i>	12	RA	12.3	17.1	14.2	0.0159	2	0.311	0.81	x	P	0.0029	2.8918	0.456	0.8	x	P	1.68	0.808	Pn-

Table 2. Relationships between tail area (TA) and tail height (TH) with total body length (TL) for 61 fishes from the North Aegean Sea, Greece, June 2001- January 2006. N = number

of individuals; H = habitat type; P = pelagic; BP = benthopelagic; D = demersal; RA = reef-associated;  $SE_b$  = standard error of slope  $b$ ;  $R^2$  = coefficient of determination; ToR = type of relationship; E = exponential type; L = logarithmic type; Li = linear type; P = power type; Pn = Polynomial type;  $A_m$  = mean tail aspect ratio value. indicates that  $b \neq 2$  in the case of TA, and  $b \neq 1$  in the case of TH. \* indicates decreasing trend of the regression line. + indicates cases that polynomial relationship showed a minimum, and - indicates cases that polynomial relationship showed a peak.

The majority of the relationships between  $A$  and TL (Table 2) were of the polynomial type (46 out of the 61 species; 75.4%). Out of these 46 species, in 18 species (39.1%) the regression showed a minimum, indicating that  $A$  decreases with TL until a certain point and thereafter increases again (e.g., *Trachurus mediterraneus*; Fig. 6), and in the remaining 28 species (60.9%) the regression showed a peak, i.e.,  $A$  increases with TL up to a maximum and then decreases (i.e., *Engraulis encrasicolus*; Fig. 6). In addition, three other types of relationships were identified for the remaining 15 species: power (8 species; 13.1%); linear (4 species; 6.6%) and exponential (3 species; 4.9%). Among these 15 species, only in the case of *C. macrophthalma* the relationship showed a decreasing trend (Fig. 6).

Finally, the relationship between  $A_m$  and  $TL_m$  for the 61 species was polynomial (Fig. 7), with a peak at  $TL_m \approx 22-24$  cm, indicating that  $A$  increases with body length up to a maximum and then decreases.

#### 4. Discussion

The allometric model seems to be the most appropriate for describing morphometrics in fishes (Leonart et al. 2002) and applies to the vast majority of relationships of morphological characteristics with body length (e.g., Karpouzi & Stergiou 2003, Karachle & Stergiou 2008a, 2010a, b, 2011a). Yet, allometric calculations should not be considered optimally applicable to all metric comparisons, and one must always examine its validity (Peters 1983). Based on the results of the present study, as well as of previous ones (Karachle & Stergiou 2008a, 2010a, b, 2011a), it is also apparent that such relationships might reflect the effect of different factors such as habitat type and feeding habits.

There was a strong effect of body form and shape on W-L relationships and, thus, on  $b$  values, since group (I) was comprised of extremely elongated fishes with slim body (i.e., *C. macrophthalma* and *B. belone*), group (II) of elongated, yet more cylindrical body shape (i.e. *S. canicula* and *S. sphyraena*), and group (III) of stream-lined body shape. Furthermore, a values decreased and  $b$  values increased from group (I) to group (III), which is in accordance to the widely accepted norm for such relationships in fishes (e.g., Froese 2006). Additionally, based on the results presented here, there was also a strong effect of both feeding habits and habitat type. Nevertheless, the  $b$  value of the regressions of species grouped per FTG and habitat type, showed deviation from the widely accepted value  $b=3$  (Froese 2006), a fact that can be mainly attributed to the high dispersion of W-L data values, which resulted from the inclusion of species of different body forms. Thus, these regressions are given only for illustrative purposes.

Indeed, in the case of feeding habits the relationships between FTGs differed significantly, with the exception of that of herbivores. This could be attributed to the fact that only one

Species	N	TL range (cm)	Tail area		Tail height	
			TA - TL	R <sup>2</sup>	TH - TL	R <sup>2</sup>
<i>Alosa fallax</i>	25	15.0-46.8			TH = 0.1883 + 0.2782TL	0.94
<i>Anthias anthias</i>	9	12.7-16.6	TA = -24.708 + 11.635Ln(TL)	0.88		
<i>Apogon imberbis</i>	30	8.0-11.5	TA = 0.4682 e <sup>0.2278TL</sup>	0.70	TH = -0.9077 + 0.4127TL	0.49
<i>Bothus podas</i>	21	11.3-17.2	TA = -6.2966 + 0.8666TL	0.90	TH = -0.5264 + 0.2371	0.83
<i>Chromis chromis</i>	41	8.6-13.3	TA = -3.3347 + 0.6466TL	0.68	TH = -0.4049 + 0.3124TL	0.58
<i>Dentex dentex</i>	9	11.7-15.3	TA = 0.5339 e <sup>0.1651TL</sup>	0.92	TH = 0.1138 + 0.252TL	0.54
<i>Diplodus annularis</i>	72	6.1-17.5	TA = 0.3658 e <sup>0.1918TL</sup>	0.94		
<i>Diplodus vulgaris</i>	38	9.0-16.7	TA = -4.0126 + 0.6999TL	0.87	TH = -0.018 + 0.3168TL	0.75
<i>Gaidropsarus biscayensis</i>	53	9.1-15.3	TA = 0.2289 e <sup>0.1667TL</sup>	0.91		
<i>Gaidropsarus mediterraneus</i>	15	8.4-14.5			TH = 0.409 e <sup>0.0882TL</sup>	0.70
<i>Lophius piscatorius</i>	6	7.7-12.7	TA = -1.2229 + 0.2378TL	0.91		
<i>Micromesistius poutassou</i>	47	9.2-24.0	TA = 0.3156 e <sup>0.143TL</sup>	0.94		
<i>Monochirus hispidus</i>	23	9.2-12.8			TH = 1.4998 + 0.0667TL	0.04
<i>Oblada melanura</i>	55	12.6-22.7	TA = -43.498 + 18.522Ln(TL)	0.94		
<i>Pagellus acarne</i>	52	10.5-19.2	TA = 0.6787 e <sup>0.1387TL</sup>	0.91		
<i>Pagrus pagrus</i>	10	10.2-15.5	TA = -6.3463 + 0.9042TL	0.97	TH = -6.9748 + 4.2901Ln(TL)	0.86
<i>Sardina pilchardus</i>	65	7.9-16.7			TH = 0.9551 e <sup>0.0781TL</sup>	0.58
<i>Scylliorhinus canicula</i>	28	29.1-45.1			TH = 1.1434 e <sup>0.0227TL</sup>	0.79
<i>Serranus scriba</i>	47	10.6-23.6			TH = 1.1884 e <sup>0.0683TL</sup>	0.80
<i>Sphyræna sphyraena</i>	29	28.3-34.4	TA = 1.8514 e <sup>0.0574TL</sup>	0.50		
<i>Symphodus mediterraneus</i>	10	9.8-14.1			TH = 1.4974 + 0.1232TL	0.17
<i>Symphodus tinca</i>	55	11.4-22.0	TA = 0.9022 e <sup>0.1323TL</sup>	0.90	TH = 1.2383 e <sup>0.063TL</sup>	0.73
<i>Uranoscopus scaber</i>	55	8.7-26.9			TH = 0.0552 + 0.2438TL	0.93

Table 3. Relationships between tail area (TA) and tail height (TH) with total body length (TL) for 23 fishes from the North Aegean Sea, Greece, June 2001- January 2006, for which power type of the relationship was not statistically significant (for explanation see text). N = number of individuals; R<sup>2</sup> = coefficient of determination.

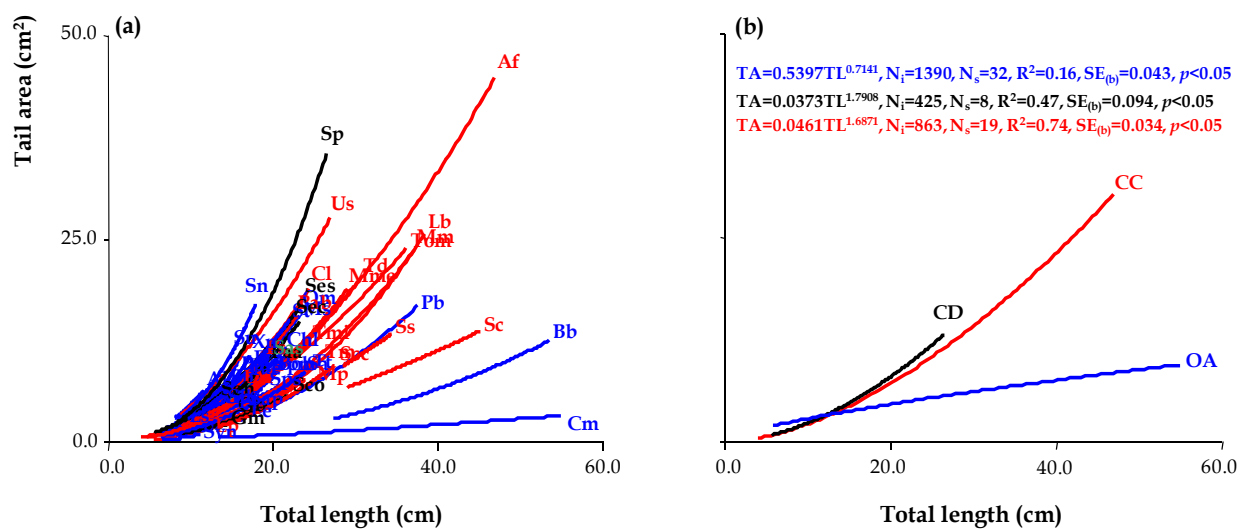


Fig. 4. Regressions between total body length (TL, in cm) and tail area (TA, in cm<sup>2</sup>) for 61 fish species from the North Aegean Sea, Greece, June 2001- January 2006. Equations are given in Table 2. (a) all regressions of species separately; and (b) regressions of groups of species, according to functional trophic groups based on Stergiou & Karpouzi (2002).

Green: herbivores; blue: omnivores with preference to animal material (OA); black: carnivores with preference to decapods and fish (CD); red: carnivores with preference to fish and cephalopods (CC). Af: *Alosa fallax*; Aa: *Anthias anthias*; Ai: *Apogon imberbis*; Al: *Arnoglossus laterna*; Bb: *Belone belone*; Bo: *Blennius ocellaris*; Bob: *Boops boops*; Bp: *Bothus podas*; Cm: *Cepola macrophthalmia*; Chl: *Chelidonichthys lucernus*; Cch: *Chromis chromis*; Cl: *Citharus linguatula*; Cj: *Coris julis*; De: *Dentex dentex*; Da: *Diplodus annularis*; Dv: *Diplodus vulgaris*; Ee: *Engraulis encrasicolus*; Eg: *Eutrigla gurnardus*; Gb: *Gaidropsarus biscayensis*; Gm: *Gaidropsarus mediterraneus*; Ls: *Lesueurigobius suerii*; Lb: *Lophius budegassa*; Lp: *Lophius piscatorius*; Mme: *Merlangius merlangus*; Mm: *Merluccius merluccius*; Mp: *Micromesistius poutassou*; Mh: *Monochirus hispidus*; Ms: *Mullus surmuletus*; Om: *Oblada melanura*; Paa: *Pagellus acarne*; Pab: *Pagellus bogaraveo*; Pae: *Pagellus erythrinus*; Pp: *Pagrus pagrus*; Pb: *Phycis blennoides*; Ps: *Pomatomus saltatrix*; Sap: *Sardina pilchardus*; Sa: *Sardinella aurita*; Sas: *Sarpa salpa*; Su: *Sciaena umbra*; Sco: *Scomber colias*; Scs: *Scomber scombrus*; Sn: *Scorpaena notata*; Sp: *Scorpaena porcus*; Sc: *Scyliorhinus canicula*; Sec: *Serranus cabrilla*; Seh: *Serranus hepatus*; Ses: *Serranus scriba*; Ss: *Sphyræna sphyraena*; Spm: *Spicara maena*; Sps: *Spicara smaris*; Spc: *Spondyliosoma cantharus*; St: *Symphodus tinca*; Syn: *Symphurus nigrescens*; Tom: *Torpedo marmorata*; Td: *Trachinus draco*; Tm: *Trachurus mediterraneus*; Tt: *Trachurus trachurus*; Tmi: *Trisopterus minutus*; Us: *Uranoscopus scaber*; Xn: *Xyrichtys novacula*.

herbivore species, namely *Sarpa salpa*, was included in the dataset, with a low number of individuals. Thus, this must be verified by including more herbivorous species. Additionally, based on the results presented here, for a given length carnivores are more robust than omnivores. The effect of diet could be anticipated, since, with food, organisms attain the necessary energy and nutrients for somatic growth and reproduction. Carnivorous feeding is considered as more profitable in terms of energy, whereas herbivorous diets or inclusion of plants in the daily "menu" (such as in the case of omnivores) requires larger

quantities of food (e.g., Gerking 1994, Wootton 1998) or morphologic adaptations (e.g., longer intestines: Wootton 1998, Pennisi 2005, Karachle & Stergiou 2010b) to meet with energetic demands. When habitat type was examined, there was also a significant difference in the weight-length relationships. From an ecological point of view, body form and habitat of any given species are strongly related. In general, pelagic and benthopelagic species are characterised by a more stream-lined body shape, reef-associated species are more roundish and demersal species seem to have more or less compressed (both dorsoventrally and laterally) bodies. This ecological adaptation in body form is also reflected in the weight-length relationships, since the only case where no difference was identified in the weight-length regressions was between pelagic and benthopelagic species; in all the remaining combinations the differences in weight-length relationships were highly significant.

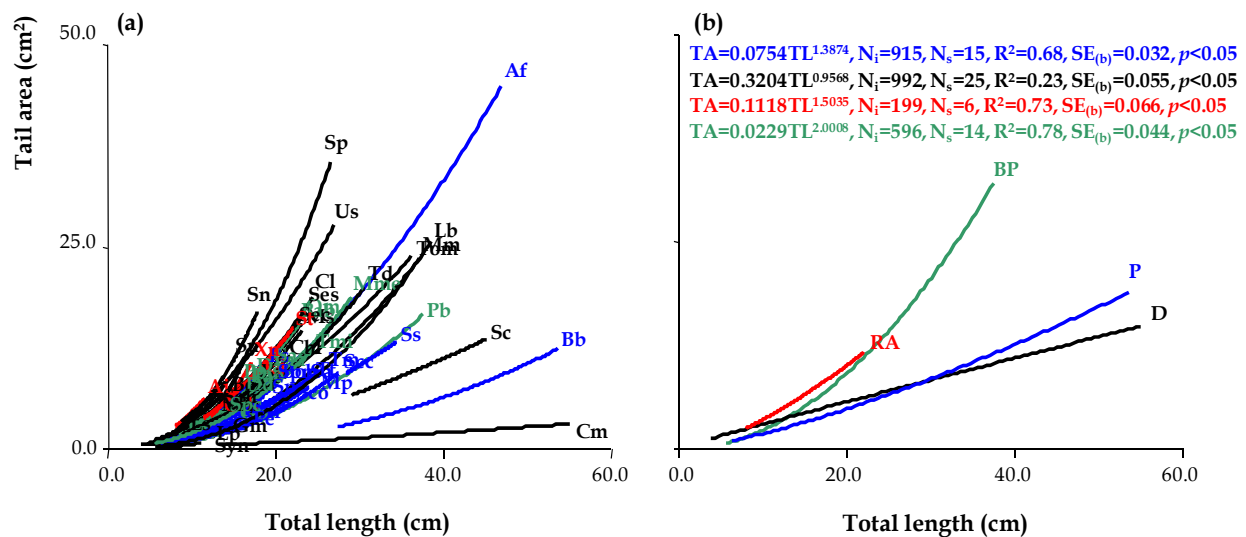


Fig. 5. Regressions between total body length (TL, in cm) and tail area (TA, in cm<sup>2</sup>) for 61 fish species from the North Aegean Sea, Greece, June 2001- January 2006. Equations are given in Table 2. (a) all regressions of species separately; and (b) regressions of groups of species, according to habitat type (from FishBase, [www.fishbase.org](http://www.fishbase.org); Froese & Pauly 2011). Blue: pelagic (P); green: benthopelagic (BP); black: demersal (D); red: reef-associated (RA). Abbreviations of species names are given in figure 4.

It has been previously shown (Karpouzi & Stergiou 2003, Karachle & Stergiou 2011a) that for the same body length omnivorous fishes tend to have smaller mouth area than carnivorous ones. The larger mouths of carnivores could be attributed mainly to: (a) adaptations of the structural capacity in order to meet with increasing energetic demands (Galis et al. 1994) and (b) more effective handling and consumption of prey with large size (Scharf et al. 2000, Pauly et al. 2001). Indeed, according to the optimal foraging theory (Gerking 1994), carnivorous fishes that mainly feed with prey of high motility (e.g., other fishes) need to consume higher amounts of food or food of larger size in fewer feeding attempts, a fact that can be achieved by larger mouth gape and other adaptations (e.g., vision acuity, fast swimming and effective digestion; Keast & Webb 1966, Kaiser & Hughes 1993, Juanes 1994, Juanes & Conover 1994, Hart 1997, Wootton 1998, Fordham & Trippel 1999). On the other hand, there was no clear effect of habitat on mouth area. For example, in the category of reef-associated species are included species with large differences in mouth



size; *Apogon imberbis* and *Anthias anthias* are two such species, which prey on fishes and benthic crustaceans (Karachle & Stergiou 2010c, [www.fishbase.org](http://www.fishbase.org)), with rather big mouth gapes, whereas *Coris julis* and *Symphodus tinca* (which prey upon worms, bivalves, gastropods and small crustaceans, such as amphipods (Karachle & Stergiou 2010c, [www.fishbase.org](http://www.fishbase.org)) are two species with small mouths, yet strong dentition. Likewise, pelagic species include a wide range of predators: from small pelagic filter feeders, such as sardines and anchovies, which prey on small-sized zooplankton (copepods) ([www.fishbase.org](http://www.fishbase.org)) to apex predators such as tunas, which feed on fishes ([www.fishbase.org](http://www.fishbase.org)). The same is also true for the remaining two categories of fishes (demersal: *Lesueurigobius suerii* and *Blennius ocellaris* that prey on small crustaceans and molluscs (Karachle & Stergiou 2010c), with small mouths, and flatfishes, such as *Arnoglossus laterna* and *Citharus linguatula*, that prey on fishes (Karachle & Stergiou 2011b) with large mouth gape; benthopelagic: *Diplodus annularis* and *Oblada melanura*, that mainly feed on worms, molluscs and small crustaceans, with small mouths, and large-mouthed species as *Gadus morhua* and *Merlangius merlangus*, that prey on fishes ([www.fishbase.org](http://www.fishbase.org)).

With respect to intestine length, there was a strong grouping of species according to their feeding habits: species that fed exclusively on plants and those which included large amounts of vegetable material in their diet (omnivores with preference to plants) formed a group that clearly separated from carnivorous species (omnivores with preference to animal material, carnivores with preference to fish and decapods and carnivores with preference to fish and cephalopods). Additionally, for the same body length, species of the first group had remarkably longer intestines than species in the second one. The above differences mainly result from the fact that plant material is more resistant to digestion, and hence longer intestines are required in order adequate amounts of nutrients and energy to be absorbed (e.g., Wootton 1998, Pennisi 2005). The effect of habitat type was also clear, yet no difference was observed between the pelagic and benthopelagic species studied here, a fact also observed in the case of weight-length relationships, and can be attributed to the fact that intestine growth, form and shape is strongly affected by the general body form, which in turn, as mentioned above, is related to habitat type (Verigina 1991, Karachle & Stergiou 2010b).

The effect of both feeding habits and habitat type on tail morphometrics was also strong, with TA for the same body length increasing faster in carnivorous than in omnivorous species, and for benthopelagic than pelagic and demersal species. This fact can be attributed both to the differentiation of the general body form of fishes with habitats, as mentioned above, and to the importance of tail shape and area to the acquisition of food (Keast & Webb 1966, Ward-Campbell & Beamish 2005).

Despite the extensive search for relative literature on tail characteristics, and especially on relationships linking TA and TH to body length, no such information was found. The only available information is restricted to estimates of A, and the majority of such estimates are from photographs and/or fish drawings ([www.fishbase.org](http://www.fishbase.org)). Additionally, there are differences in A estimates for the same species, a fact that has been attributed to one or a combination of the following parameters (García & Duarte 2002): (a) the method used for the estimation of TH and TA, (b) the type of picture (i.e., photograph or drawing) used for A estimation and (c) the disposition of tail. According to Palomares & Pauly (1998) the most appropriate way of acquiring more accurate A estimates is a disposition of tail resembling

that of swimming position and estimating TA to the point where caudal peduncle was the lowest height. The prevalence of the polynomial type in the relationships between A and TL adds a further factor responsible for such differences, notably the body length of the specimen used for A estimation. Hence, when A values are needed for the estimation of Q/B ratio, the body length of the species in question should be taken into consideration as well. Nevertheless, this needs further investigation, since there were 15 species that did not show polynomial type of relationship. Among these 15 species, only in the case of *C. macrophthalma* the relationship showed a decreasing trend. This could be attributed to the fact that tail shape in this species differs with sex (Stergiou 1991): in males the central spines of the caudal fin are rather elongated and therefore tail total area is larger than that in females, and hence A is lower. It must be stressed that the length range of the individuals of each sex used in the present study differed, with males being generally lengthier than females (males: 18.2-54.9 cm; females: 13.2-47.6 cm).

Additionally, the relationship between  $A_m$  and  $TL_m$  of the examined 61 species was also polynomial, showing a maximum at  $TL_m \approx 22-24$  cm. The decline after this threshold of TL should be attributed to the fact that species which are located to the right of the peak are those with a rather elongated body form (i.e., *B. belone*, *C. macrophthalma*, *S. canicula* and *S. sphyraena*). This agrees with Pauly (1989b) who maintains that body depth ratio (i.e., the ratio between body length and maximum body depth) is positively related to food consumption, which, in turn, is positively related to A. Hence, fishes with a rather elongated body form, and therefore low body depth ratios, should be expected, for the same TL, to have lower A values than species with a streamlined or diamond-shaped body.

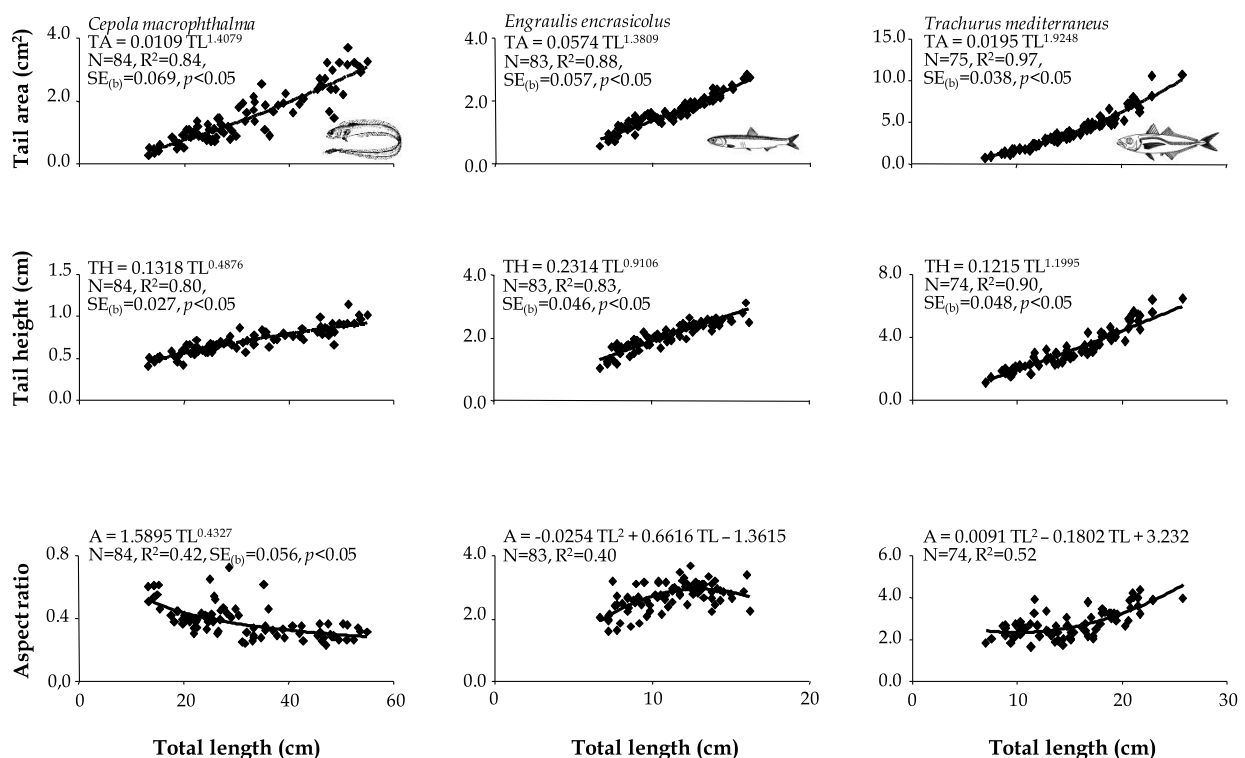


Fig. 6. Relationships between tail area (TA; top), tail height (TH; center) and tail aspect ratio (A; bottom) and total body length (TL) for 3 fish species, from the North Aegean Sea, Greece, June 2001- January 2006. Fish drawings from FishBase ([www.fishbase.org](http://www.fishbase.org): Froese & Pauly 2011).

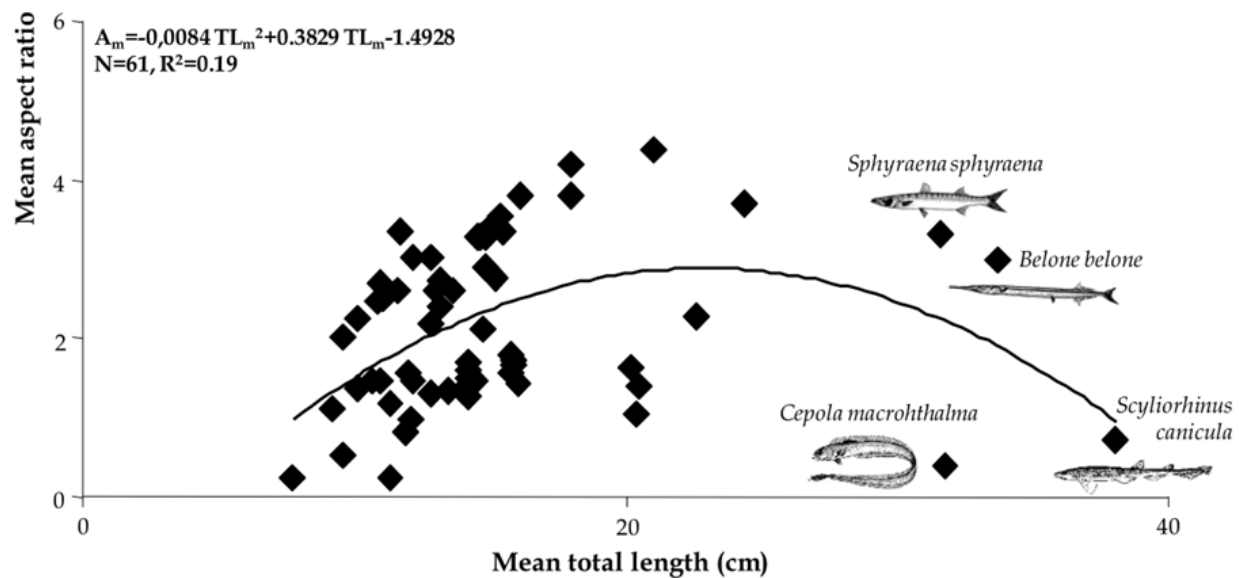


Fig. 7. Relationship between the mean values of tail aspect ratio ( $A_m$ ) and mean total body length ( $TL_m$ ) for 61 fish species, from the North Aegean Sea, Greece, June 2001- January 2006. Fish drawings from FishBase ([www.fishbase.org](http://www.fishbase.org); Froese & Pauly 2011).

## 5. Conclusions

1. The allometric model is the most appropriate in describing morphometric relationships in fishes, yet its validity should not be taken for granted.
2. There is a strong effect of feeding habits on the way the morphological characteristics presented here (weight, mouth, intestine and tail) change with body length.
3. Habitat type was found to affect the way that weight, intestine and tail change with body length. Yet, this is not true of mouth area.
4. Tail aspect ratio shows, in the majority of cases, a polynomial type of relationship with total body length. The only case where there was a decrease in tail aspect ratio with size was for *Cepola macrothalma*, in which there is a strong a sexual dimorphism in tail size/shape.
5. Mean tail aspect ratio is related to total body length with a polynomial type of model, showing a peak at a mean TL of  $\approx 22-24$  cm.
6. The polynomial type of model found between 46 out of the 61 species (75.4%) indicates that when estimating Q/B ratios, the body length of the individuals should also be taken into account.

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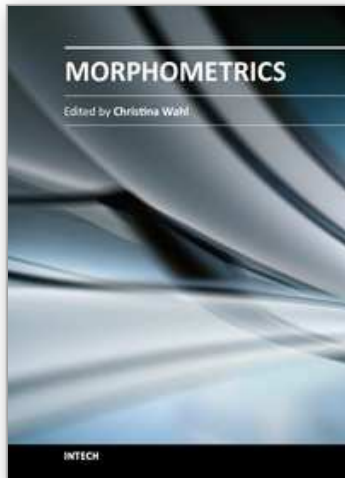
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ISBN 978-953-51-0172-7

Hard cover, 108 pages

**Publisher** InTech

**Published online** 02, March, 2012

**Published in print edition** March, 2012

It is human nature to measure things, and this holds true for science as well as everyday life. The five papers in this book demonstrate the usefulness of a morphometric approach to a variety of subjects in natural history, including systematics, phenotypic plasticity in response to environmental variation, and ontogenetic adaptation. As our understanding of genetic control mechanisms and epigenetics has matured over the last several decades, it has become clear that morphometric assessment continues to be important to our overall understanding of natural variability in growth and form. The tremendous growth of our knowledge base during the last century has necessitated that we find new ways to measure and track greater detail as well as greater numbers of parameters among populations and individuals.

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