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Observations on body surface area and aspect ratio in various species of the order Syngnathiformes

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A B S T R A C T

Swimming ability in fish is directly related to body shape, manifesting in various values for swimming speed and body surface area. The constant value used in calculating body surface area derived from length or weight measurements differs between pelagic and benthic species. Furthermore, the aspect ratio is closely related to the feeding pattern, as well as being connected to the swimming speed which is effective in executing escape movements from existing predators in their natural environments. This study presents body surface area and aspect ratio values for nine Syngnathiformes species caught off Turkish coasts. It aims to provide a comparative scientific contribution for members of this order.

INTRODUCTION

Displacement is a fundamental aspect of fish behaviour, occurring either actively or passively within a three-dimensional aquatic environment. The scientific community's understanding of fish swimming physics and physiology has evolved significantly, with seminal works by Blake (1983) and Webb (1984) laying the groundwork. Videler's (1993) comprehensive study further advanced this field of research. To elucidate the correlation between swimming performance and body morphology in fish, a thorough examination of their functional anatomy is essential.

Swimming essentially relies on three fundamental movements: rising, forward acceleration, and stabilization. Fish can coordinate backward thrust movements while maintaining a stationary position against the current, primarily through tail movements (Bainbridge, 1963). Sambilay Jr. (1990) noted that lift and drag forces work together to propel a fish's body forward. The ratio or relation between these forces determines the performance needed for movement.

Swimming performance is understood within the paradigm of general morphology, performance, and harmony (fitness); however, the importance of a fish's body shape in swimming ability is particularly significant (Langerhans and Reznick, 2010). Videler (1993) explained that swimming performance depends on drag force and propulsive force-both closely related to body morphology. This relationship enables fish to effectively forage, escape or hide from predators, and migrate (Fisher and Bellwood, 2002). Furthermore, understanding a fish's body surface area provides insight into the relationship between body weight and surface area. Kayser (1951) claimed the "surface law," which explains the direct, linear relationship between energy metabolism and body surface. Determining body surface area may allow several important comparisons: such as gill areas of marine fish (Gray, 1953), attachment surfaces of external parasites relative to fish size (Jaworski and Holm, 1992; O'Shea et al., 2006), and aspects of body energy metabolism (Sébert et al., 2004).

Sébert et al. (2004) simplified the methods for calculating body surface area in fish, focusing on eels. The basic formula for surface area is $S = K w^{2/3}$, where 'S' is the surface area, 'w' is the body weight, and 'K' is a species-specific "constant." While K values typically range from 5 to 18, they hover around 10 for species other than fish with rounded or elongated bodies (Gray, 1953).

Generally, K values of laterally compressed (depressiform) and dorsoventrally flattened (compressiform) species are higher than those of streamlined or fusiform fish (Gray, 1953). Body surface area can vary even among individuals of the same species. Recent studies have shown that three-dimensional fish structures provide more accurate calculations of body surface area (O'Shea et al. 2006). Expressing metabolism in terms of surface area rather than body weight is considered a more accurate approach for marine fish. This method could be particularly advantageous for fish populations in aquaculture. For instance, it may help establish standards for determining the sizes of potential pathogens (Sébert et al., 2004).

The aspect ratio of a fish's caudal fin is closely linked to its swimming speed, which in turn affects how it consumes food and escapes predators in its natural habitat. Pauly (1989) noted that this ratio correlates with a fish species' average level of movement. This key feature influences not only a fish's swimming speed but also its metabolism, food consumption, and ultimately, its survival in the wild.

Westneat and Wainwright (2001) stated that a fish's body profile and surface area contribute to drag calculations in the water column, while the caudal fin's shape primarily determines thrust force. Consequently, the relationship between a fish's pelagic or demersal lifestyle and its aspect ratio warrants careful consideration (Ayana and Ganga, 2019). Aspect ratio values vary among families and species due to differences in fin shapes (Ayana and Ganga, 2019). For instance, Scombrid species exhibit aspect ratio values between 4 and 9, which influences how wing-like their caudal fin's morphometric structure appears (Westneat and Wainwright, 2001). This study focuses on determining the body surface area and aspect ratio values of select Syngnathiformes species found along Türkiye's coastline.

MATERIALS AND METHODS

This study examined the relationship between body surface area and weight for 233 fish specimens among nine species of the order Syngnathiformes collected from Turkish seas between 2018 and 2022. *F. petimba* (Lacepède, 1803) individuals were collected from the nets of commercial fishermen by seasonal sampling as bycatch, while individuals of *S. abaster* (Risso, 1827), *S. acus* (Linnaeus, 1758), *S. tphyle* (Linnaeus, 1758), *S. tenurostris* (Rathke, 1837), *S. variegatus* (Pallas, 1814), *N. ophidion* (Linnaeus, 1758), *H. hippocampus* (Linnaeus, 1758) and *H. guttulatus* (Cuvier, 1829) were obtained by monthly sampling using beach seine. The total length (TL, cm) of all samples was measured with a 0.1 mm precision ruler, while their weights (W, g) were measured with a 0.1 g precision scale. Body height, body width, and the dimensions of the caudal fin (length, height, and width) were measured using digital calipers.

The length-weight relationship was evaluated using Ricker's (1975) equation $W= a \times L^b$, where a and b are regression constants, L represents total length (cm), and W represents body weight (g). Gray's (1953) formula $S=Kw^{2/3}$ was used to determine the body surface area, where K represents the constant value and w represents body weight. Additionally, Pauly's (1989) formula $A=h^2/L$ was used to calculate the Aspect Ratio, where h represents the height of the caudal fin and L represents its length. The obtained data was evaluated using the Microsoft Excel program.

RESULTS AND DISCUSSION

Although the body surface area and K (constant) values for each species in Table 1 were calculated using both weight and total length, all evaluations were based on body weight. Species belonging to the order Syngnathiformes exhibit different K values. Table 1 shows that the minimum body surface area constant (K) value, determined as a function of weight, was lowest in *Syngnathus variegatus* at 0.17 and highest in *Fistularia petimba* at 33.59. Based on body weight calculations, the surface area value of *S. abaster*, which has the lowest body weight, is 12.88, while *F. petimba*, with the highest body weight, has a value of 33.59.

The table reveals that K values are low for slender or stocky species, while high K values are found in relatively flattened and laterally compressed ones. Gray (1953) suggests that fish with the lowest K values represent semi-stocky and short-bodied species, while the highest K value indicates flattened fish species. In this context, *S. variegatus* is classified among the semi-stocky and short-bodied species within the order, whereas *F. petimba* appears to be among the fish species that have undergone relative flattening in the dorsoventral direction. The K value relates to taxonomic position, body shape, and body weight (Gray, 1953). The b values express the total length-weight relationship of the species. Species showing positive allometric growth (b > 3) include *H. hippocampus*, *F. petimba*, *S. variegatus*, and *S. abaster*. In contrast, species exhibiting negative allometric growth (b < 3) are *N. ophidion*, *H. guttulatus*, *S. tenuirostris*, and *S. typhle* (Table 1).

Table 1. Estimated body surface area and length-weight relationships of species determined according to length and weight function (S: Body surface area, TL: total length (cm), W: weight (g))

Species	N	TL	W	Surface Area Formulas		LWR
				TL	W	
Syngnathus abaster	21	3.4-10.0	0.03-0.4	S=0.0006L$^{2.86}$	S =12.88W$^{0.33}$	W=0.0003L$^{3.04}$
Syngnathus acus	21	4.5-10.2	0.04-0.5	S=0.0004L $^{3.11}$	S =12.45W$^{0.30}$	W= 0.0004L$^{3.11}$
Syngnathus tphyle	19	11.2-19.8	0.4-3.3	S = 0.0009L$^{2.63}$	S =2.20W$^{0.18}$	W=0.0009L$^{2.62}$
Syngnathus tenurostris	21	6.7-12.2	0.1-0.6	S =0.0012L$^{2.46}$	S =6.80W$^{0.92}$	W=0.0012l $^{2.46}$
Syngnathus variegatus	11	7.3-11.2	0.2-0.5	S = 0.0003L$^{3.04}$	S =0.17W$^{0.18}$	W=0.0003L$^{3.04}$
Nerophis ophidion	40	8.4-21.4	0.1-0.6	S = 0.0511L$^{0.63}$	S =15.29W$^{0.05}$	W=0.051L$^{0.62}$
Hippocampus hippocampus	12	8.0-13.9	0.95-6.5	S =0.001L$^{3.39}$	S =8.19W^{0,29}	W=0.001L$^{3.39}$
Hippocampus guttulatus	35	11.3-16.5	4.3-11.8	S = 0.0178L$^{2.31}$	S =7.48W^{0,29}	W=0.017L$^{2.31}$
Fistularia petimba	22	37.8-50.0	20.7-80.5	S = 0.0002L$^{3.24}$	S =33.59W$^{0.01}$	W=0.0002L$^{3.23}$

Table 2. Allometric growth models of species' body surface area (according to length and weight)

Species	Length			Weight		
	a	*b*	r^2	*a*	*b*	r^2
Syngnathus abaster	-3.52	3.29	0.55	0.97	0.17	0.55
Syngnathus acus	-0.36	2.56	0.95	1.09	0.31	0.96
Syngnathus tphyle	-0.44	3.06	0.64	1.17	0.25	0.65
Syngnathus tenurostris	-0.46	2.28	0.67	1.11	0.28	0.69
Syngnathus variegatus	-0.44	2.88	0.85	1.11	0.28	0.85
Nerophis ophidion	-0.67	0.72	0.05	1.18	0.08	0.05
Hippocampus hippocampus	0.39	3.51	0.85	0.91	0.25	0.83
Hippocampus guttulatus	0.55	2.58	0.67	1.16	0.24	0.67
Fistularia petimba	-1.07	5.36	0.95	1.43	0.47	0.94

Table 2 presents the regression results of body surface area dependent on fish total length and body weight for each species in the order. These results offer preliminary insights for calculating the average surface area of the fish species studied. The allometric results of body surface area, based on length and weight in Table 2, show that the b value differs from 1. The highest correlation values-indicating that body surface area relates to both total length and weight are 0.95-0.96 for *S. acus*, and 0.95-0.94 for *F. petimba*, respectively. Table 3 displays the aspect ratio (A) values for some species in the order Syngnathiformes.

Table 3. Aspect ratio (A) values of the species.

Species	Min-Max	Mean ± SE
Syngnathus abaster	0.26-2.80	0.99±0.22
Syngnathus acus	0.01-2.00	0.92±0.20
Syngnathus tphyle	2.11-2.46	2.65±0.60
Syngnathus tenurostris	0.30-0.40	0.28± 0.05
Syngnathus variegatus	0.40-2.55	0.47±0.14
Nerophis ophidion	N/A	N/A
Hippocampus hippocampus	N/A	N/A
Hippocampus guttulatus	N/A	N/A
Fistularia petimba	0.11-1.18	0.27±0.06

N/A: Not Avaliable

In Table 3, among the species of the order, the lowest aspect ratio value was observed in *S. acus* (0.01), while the highest value was detected in *S. abaster* (2.80). However, these values cannot be calculated for seahorse species as they morphologically lack a caudal fin. Few studies have determined the aspect ratio (A) values of marine fish species. Among these, the AR value in Scombrid species ranges between 4–9 (Westneat et al., 2001). The high AR values in Scombrid species' swimming performance are attributed to the functional structure of the myomeres in the caudal region. Ayana and Ganga (2001) found that aspect ratio (AR) values of some pelagic and demersal species along the Indian coast range from 1.1 to 8.76. They observed that fast-swimming fish (e.g., tuna) have high AR values, while slow-swimming fish (e.g., groupers) have low values. Notably, groupers, as ambush predators, benefit more from the thrust provided by AR for sudden acceleration during prey capture. In our study, many members of the Syngnathiformes order, which exhibit ambush feeding behaviour, have AR values ranging approximately between 1 and 2.65. So, in this study, our findings are pioneering as there are no studies on Body Surface Area and Aspect Ratio for the Syngnathiformes.

CONCLUSION

These results suggest that pipefish species, like slow-swimming groupers, show AR results closely tied to body acceleration movement and feeding behaviour. In conclusion, we expect that the fin performances supporting the swimming ability of Syngnathiformes species in Turkish seas will provide valuable data for future studies.

Compliance with Ethical Standards

Authors' Contributions

ŞG: statistical calculations, writing of the article, ET: preparing the text for publication, SB: preparation of the article. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required. All relevant international, national, and/or institutional guidelines for the care and use of animals were adhered to.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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