



Comparative Analysis of Morphometric and Meristic Characters of Turbot *Scophthalmus maximus* (Linnaeus, 1758) (Actinopterygii: Scophthalmidae) from Four Sites along the Bulgarian Black Sea Coast

Petya P. Ivanova¹, Ivelina Y. Zlateva¹, Violin S. Raykov¹, Maria H. Yankova¹,
Nina S. Dzhebekova¹, Violeta H. Slabakova¹ & Yordan R. Raev²

¹Institute of Oceanology – Varna, Bulgarian Academy of Sciences, 40 Parvi May Street, 9000 Varna, Bulgaria; PO Box 152; E-mail: pavl_petya@yahoo.com, ibikarska@yahoo.com, vio_raykov@abv.bg; maria_y@abv.bg; sonata_bg@yahoo.com; v.slabakova@io-bas.bg

²Executive Agency of Fisheries and Aquacultures, 1 Alexander Battenberg Blvd., 8000 Burgas; E-mail: j_raev@abv.bg

Abstract: Morphometric and meristic characters of fish are important for species differentiation, overall stock status assessment, in the analysis of the population structure and genetic variations within and between populations and as an indicator for utilization of environmental resources or habitat diversity. Comparative analysis of morphometric and meristic characters of *Scophthalmus maximus* L. sampled in the regions of Shabla, Shkorpilovtsi, Nesebar and Tsarevo along the Bulgarian Black Sea coast was carried out. Selected growth models as length-weight relationship (LWR) and relationships and ratios as standard length (SL) – total length (TL), head length (HL) – body depth/height (BD/BH), BD/BH – SL were studied, aiming at identification of specific or significant differences in the sampled specimens and indirect differentiation of specific environment constraints in species habitat. The studied turbot populations demonstrated considerable intra-species morphometric variations, which are further to be justified by thorough analysis of genetic diversity at a local and regional level. Environmental differences between sites in the sampling period have not been recorded and the species habitat appeared to be homogenous in terms of abiotic environment.

Key words: Black Sea, Morphology, Population, Stock management, Turbot

Introduction

Black Sea turbot *Scophthalmus maximus* (L., 1758) is one of the most valuable commercial species in all countries of the Black Sea basin. The dramatic depletion of turbot stocks and catches that began in the 1980s was caused by overfishing and adverse ecological conditions. The wild populations of turbot are still subject to strong anthropogenic pressure, regardless of the stock management measures (Bulgaria has been applying Quotient principle for turbot fisheries since 2007).

Fish stocks represent fundamental units in fisheries management, and their identification, especially in mixed fisheries, represents one of the primary challenges to ensure sustainable harvest (DAHLE et al. 2018). Most stocks for which regular and validated assessments are available are still reported as being fished outside biologically sustainable limits. Nevertheless, recent trends continue to show a consistent decrease of stocks in overexploitation (FAO: GFCM 2020).

Turbot in the Black Sea is represented by several local populations that could be considered

independent units of the same stock (DASKALOV & RATZ 2011). Reported tagging and morphometric data also support the hypothesis that Black Sea turbot forms several local populations or subpopulations (POPOVA 1954, KARAPETKOVA 1964, 1980, ZENGIN & DUZGUNES 2003, NADOLINSKIY et al. 2018). However, data on genetic diversity of local Black Sea turbot populations are still very scarce. The geographical features of the broadest shelf zone in the north-western part of the Black Sea and the limited migration activity of turbot contribute to the greatest isolation of the entire fish population (HULAK et al. 2021). Accordingly, turbot population of the north-western part could be considered as a separate stock unit isolated at the largest shelf area (SHLYAKHOV 2014).

Assessment of population structure and genetic diversity is essential for both conservation and management strategies of highly exploited and endangered species (ALKARALZ & GOLHAMI 2019). Spatial information on fisheries resources underpins sustainable management; moreover, in the last years, genetic methods for defining stock boundaries are well developed (OVENDEN et al. 2015). Molecular markers have already been applied for determination of the *S. maximus* population structure in the Black Sea (ATANASSOV et al. 2011, NIKOLOV et al. 2015, TURAN et al. 2019, BESSONOVA & NEBESIKHINA 2019, FIRIDIN et al. 2020, IVANOVA et al. 2020, 2021). Turbot inhabiting the northern part of the Black Sea showed significant genetic differences in comparison to fishes inhabiting the south-eastern and south-western parts of the Black Sea shelf (FIRIDIN et al. 2020). Therefore, assessing the turbot stock in the north-western part separately from the entire Black Sea population is well justified (HULAK et al. 2021).

The admixture and lack of genetic structuring of turbot along the Bulgarian Black Sea coast was found and pointed that the populations probably belong to the same genetic unit, which was supported by the morphological data analyses (IVANOVA et al. 2020). The latter identifies the need of a thorough comparison between population characteristics and variation, including morphological diversity, biological potentials and habitat diversity.

The morphometric and meristic characteristics of fish are extremely important in terms of species differentiation, species stock assessment, the analyses of population structure as well as an indicator of species adaptation to specific environment (abiotic factors and biotic interactions) and their physiological status. Morphological variation of populations can be caused by either additive genetic variation or processes of morphological diversity in response

to a wide range of selective stressors or seascape variables. For fishes, the body shape has been interpreted as a result of interaction between genetic and environmental factors, explicitly in their early development stages. Two major sources of morphometric variance are produced by ontogeny: isometric size variation due to growth and allometric shape variance due to evolutionary developmental change in form (BARLOW 1961, FUNK et al. 2005, DRESLER et al. 2013, VIEIRA et al. 2016, UKENYE et al. 2019, VASCONCELOS et al. 2021, WENJING et al. 2021).

The aim of the present study is to assess intra-species diversity in morphometric and meristic characters variations of *Scophthalmus maximus* L. along the Bulgarian Black Sea coast addressing the need to add more knowledge towards population identification, implementation of successful conservation strategies, optimised design of stock assessment surveys and sustainable exploitation of the studied species.

Materials and Methods

A total of 131 turbot were obtained from four sampling sites between 2019 and 2021 (Fig. 1). Eight meristic characteristics were investigated, i.e. total length (TL), standard length (SL), dorsal fin ray (DFR), pectoral fin ray (PFR), anal fin ray (AFR), ventral fin ray (VFR), back pectoral fin ray (BPFR) and caudal fin ray (CFR), as well 17 morphometric traits commonly used to describe species of the family Scophthalmidae (Fig. 2). Multiple methods such as tests for normality of data, linear regression and non-parametric tests were employed to identify groups and quantify statistically significant differences within and between the samples.

The morphometric analysis involved the use of selected growth models such as the Length-weight relationship (LWR) as well as relationships and ratios such as standard length (SL) – total length (TL), head length (HL) – body depth/height (BD / BH), BD/BH – SL (FAKINMOJU et al. 2014) and Fulton's condition coefficient (nutrition factor). The parameters of these models were then evaluated.

The primary objective of the comparative study was to determine distinct, statistically significant variations between samples in order to differentiate indirectly the abiotic and biotic aspects of habitats. The LWR was chosen as a fundamental indicator for distinguishing the differences between the groups of studied samples, since the modelling outcomes can be utilised in several aspects of fish species research. These applications involve predicting weight based on measurements of total length, comparing growth

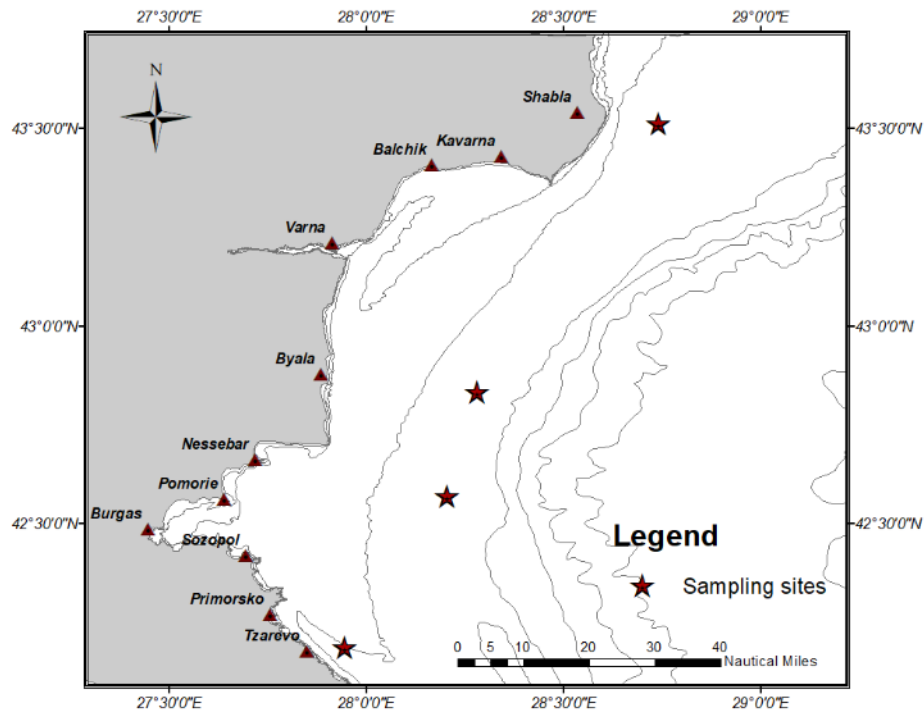


Fig. 1. Sampling sites along the Black Sea coast of Bulgaria.

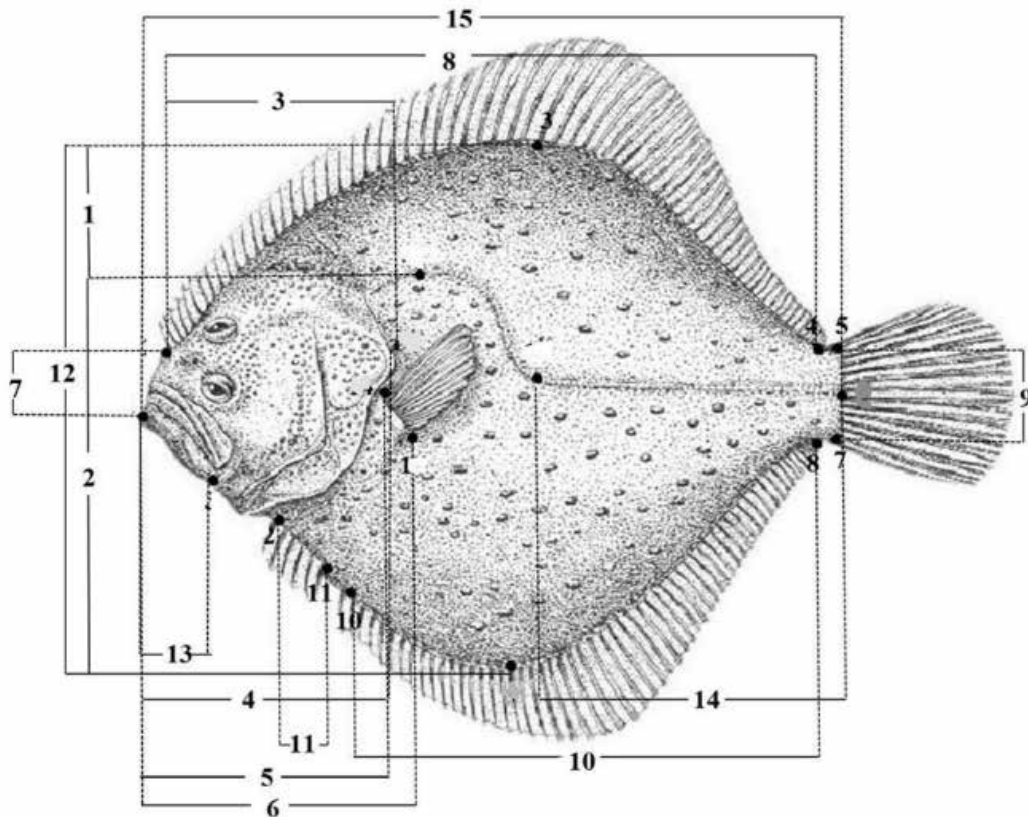


Fig. 2. Morphometric characters analysed (after TURAN et al. 2019). Legend: 1. Linea – Dorsal height; 2. Linea – Anal height. 3. Beginning of dorsal fin origin – End of operculum. 4. Mouth – Beginning of pectoral fin origin. 5. Mouth – Operculum distance. 6. Mouth – End of pectoral fin distance. 7. Mouth – Beginning of dorsal fin origin. 8 – Length of the dorsal base. 9 – Caudal fin base expanse. 10 – Anal base length. 11 – Ventral length. 12 – Body height. 13 – Starting-end mouth distance. 14 – Lateral line. 15 – Standard length.

parameters (such as average or reference weights) of the same species with different geographical distributions and providing information on the species' condition due to factors like nutrient availability, climate change and human activities.

Parametric tests were used to verify the normal distribution of data in linear regression models. Non-parametric tests were applied to identify statistically significant similarities between samples (Analysis of similarities – ANOSIM). All parametric and nonparametric statistical tests, models fitting and calculations were performed in the MATLAB programming environment (The Math Works, Inc. Matlab, Version 2020a), Package Vegan (OKSANEN 2019) and with RStudio (R, Version 4.0.5) (R CORE TEAM 2020).

Results

The ANOSIM test conducted on the morphometric and meristic data revealed a statistically significant difference in the morphometric characters of the specimens between the groups (sampling sites) ($R=0.1155$, Significance: $1e-04$). However, there was no statistically significant difference in the meristic characters of the studied specimens ($R=0.02774$, Significance: 0.1168). The findings from the LWR modelling (Table 1, Figs. 3 and 4) indicated a steady increase in the coefficient of allometry (b) of the examined samples in direction from the northern to the southern regions of the Bulgarian Black Sea coast. The samples taken from the Shabla site exhibited a negative coefficient of allometry less than 3, ranging from 2.8. This indicated that the animals in the samples had been experiencing more significant growth in length than in weight. At the Tsarevo location, the coefficient of allometric growth reached a positive allometry value of 3.33. The other three sites exhibited positive coefficients.

In general, a negative allometric coefficient suggested a shortage in nutrients and unfavourable environmental conditions that might be associated with limited access to food. Nevertheless, the Fulton's Condition Factor values (Table 1) indicated that the samples from Shabla exhibited a good condition (1.74) while the lowest value was observed in the samples collected from the Shkorpilovtsi sampling location (1.67). The Fulton's Condition Coefficient estimates indicated that the examined species were in good condition at all sites, suggesting the presence of a diverse and abundant source of nutrients. Additional notable disparities were discovered in the coefficients of the SL-TL model, with the lowest regression slope reported in the data

collected from the Shabla region. This could be attributed to the presence of the lowest average total sample length. Given this fact, it was not possible to make any generalized inferences about the model. The Shabla region had the lowest average HL-TL ratio, which was assessed to be 3.82.

An explanation for the observed morphological variability was sought in the abiotic factors at the sampling sites (Table 2). The Black Sea monthly mean environmental data for April over 2019–2021 (corresponding with the period of the sampling expeditions) were obtained from Copernicus Marine Environmental Service (CMEMS) data portal (<https://marine.copernicus.eu/>). The selected abiotic factors exhibited no significant variation across the study period, which could be attributed to the species' inherent preference for certain abiotic variables defined by environmental niche and developmental stages.

Discussion

The intra-species morphological variation in fish is archetypally associated with sexual dimorphism, variations in intensity of predation, prey composition and abundance. This variation has been explicitly highlighted as ecologically and evolutionarily important (ROBINSON 1994, PARKER et al. 2009). Intraspecific morphological variation has already been observed in a wide range of fish species; it has been reported as strongly associated with habitat environmental conditions, diet composition and other factors and underlying processes. Some of the resultant variations have been shown to be heritable (EHLINGER & WILSON 1988, SCHLUTER & McPHAIL 1992, MOLES et al. 2010, WEBSTER et al. 2011; SPOLJARIC & REIMCHEN 2011, COLLIN & FUMAGALLI 2011).

Turbot has been reported to have significant sexual dimorphism, with females growing faster (XU et al. 2022) and attaining size up to 50% larger than that of males. However, separate analyses of the morphometric traits of males and females of the studied species may reveal sex-dependent specifics in morphology and may contribute to better understanding of intra-species morphological variation of turbot.

Male and female turbot have been reported to differ in trophic preferences due to the differences in their feeding ecology. Such divergence may reflect nutritional requirements for reproduction in females or extreme (sex-dependent) differences between males and females in view of habitat use or body sizes. Ecological competition between

Table 1. Model parameters, ratios and coefficient estimates.

LWR models			
Sampling site	Shabla	Skorpilovtsi	Tsarevo
No of samples	N=30	N=15	N=28
q and b estimates	q = 3.817e - 05; b = 2.7953	q = 1.0219e - 05; b = 3.1233	q = 5.0968e - 06; b = 3.3053
LWR model	$W_m = 3.8e^{-05} * L^{2.8}$	$W_m = 1e^{-05} * L^{3.1}$	$W_m = 3e^{-06} * L^{3.3373}$
Statistical significance ($\alpha = 0.05$)	R = 0.7617 R ² = 0.58017	R = 0.9430 R ² = 0.8892	R = 0.9793 R ² = 0.9590
Fulton coefficient estimates			
Fulton coefficient $K = \frac{W}{L^3} * 100$	K = 1.74	K = 1.67	K = 1.71
Standard length (SL) – Total length (TL) relationship (SL = a + b * TL)			
a and b estimates	a = 0.8032 b = 0.7732	a = -11.4253 b = 1.0375	a = -1.3524 b = 0.7961
SL-TL model	$SL_m = 0.8 + 0.77 * TL$	$SL_m = -11.42 + TL$	$SL_m = -1.3524 + 0.8 * TL$
Statistical significance ($\alpha = 0.05$)	R = 0.9588 R ² = 0.9193	R = 0.9932 R ² = 0.9864	R = 0.9885 R ² = 0.9771
Ratios			
TL/SL ratio	SL _m = 37.97 cm std dev = 2.0083 cm TL _m = 48.0667 cm std dev = 2.4904 cm TL/SL ratio = 1.27	SL _m = 42.7 cm std dev = 4.2418 cm TL _m = 52.1667 cm std dev = 4.0606 cm TL/SL ratio = 1.22	SL _m = 43.8571 cm std dev = 6.3463 cm TL _m = 53.2857 cm std dev = 6.3936 cm TL/SL ratio = 1.22
HL-BH ratio (5-12)	BH _m = 25.8157 cm std dev = 3.0873 cm HL _m = 12.5687 cm std dev = 0.6754 cm BH/HL ratio = 2.05	BH _m = 25.4333 cm std dev = 3.2484 cm HL _m = 12.5287 cm std dev = 0.7481 cm BH/HL ratio = 2.03	BH _m = 26.1275 cm std dev = 2.43 cm HL _m = 12.6032 cm std dev = 0.5226 cm BH/HL ratio = 2.07
BH-SL ratio	BH/SL ratio = 1.47	BH/SL ratio = 1.68	BH/SL ratio = 1.68
HL-SL ratio	HL/SL ratio = 3.02	HL/SL ratio = 3.23	HL/SL ratio = 3.48
HL-TL ratio	HL/TL ratio = 3.82	HL/TL ratio = 4.16	HL/TL ratio = 4.23

Table 2. Comparison of selected abiotic factors by sites: mean monthly values for April (2019–2021)

Sampling site	Average Temperature* (C°)	Average Salinity * (psu)	Dissolved oxygen av. values * (mmol m ⁻³)
Shabla	8.47	18.61	278.66
Shkorpilovtsi	8.46	18.44	293.76
Nesebar	8.45	18.48	297.53
Tsarevo	8.44	18.22	301.67

the sexes may be responsible for intersexual niche divergence in some cases but the independent evolution of foraging specialisations by each sex may be more important. If ecological drivers for dimorphism can be demonstrated in sufficiently large number of cases, despite the inadequacies of the available criteria, the degree of sexual size dimorphism may also be predisposed by ecological factors (SHINE 1989).

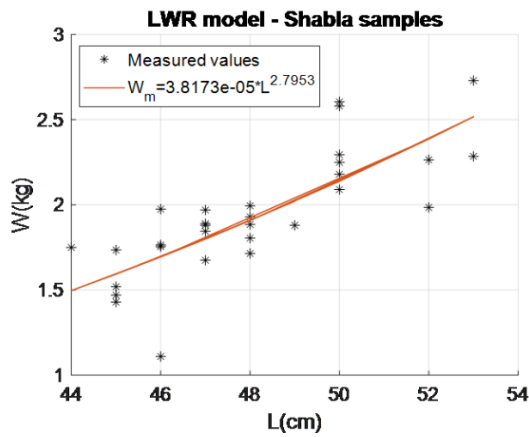
Variations in species diet composition have likewise been linked to morphological variation, though its generalization as a major causation is barely possible. Furthermore, this variation in diet and morphology among individuals could be both genetically determined and (or) environmentally-induced (SVANBÄCK 2004). For turbot, data on diet composition is still very scarce; however, overall, the information documented shows homogenous diet composition (mostly fish, molluscs and crustaceans), with a expressed seasonal dynamics (RAYKOV et al. 2009). Nevertheless, analysis of feeding ecology of specimens by sampling sites may give further specific details of whether the portion of the different taxonomic groups is evenly presented.

Genetic divergence due to the local adaptations have been addressed as a prerequisite for great morphological variation. Many organisms have demonstrated modifications in their morphology as a response to environmental stressors. Such plasticity is thought to be an important adaptive strategy for populations affected by environmental variations (STEARNS 1989, SCHEINER 1993) and it likely plays an important role in species diversification (WEST-EBERHARD 1989). Despite the fact that the abiotic characteristics of the sampling sites were homogenous, they only accounted differences among sampling periods and were rather related to species preferences to environment in accordance with their development stages. Inclusion of currents velocity, temperature and salinity time series in the analysis may help to better identify expected diversification of environment characteristics on a wider scale, e.g. for south and north regions.

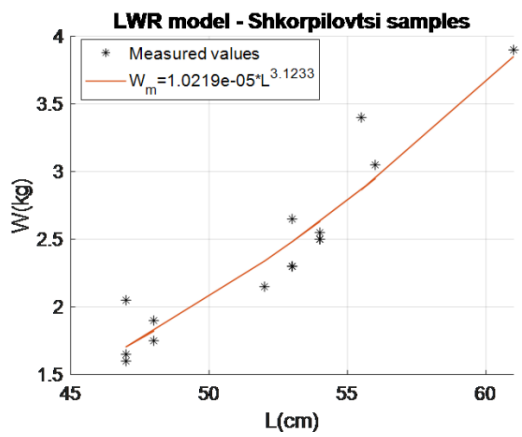
Overall, marine ecosystems are influenced by multiple stressors (climatic, oceanographic, ecological and anthropogenic); at the species level, they may affect survival, growth and reproduction processes (FU et al. 2020). Fishing has been identified as a major threat in exploited marine ecosystems around the globe for the past few decades (BOLDT et al. 2014), leading to substantial structural and quantitative changes in ecosystems (FU et al. 2020). By preferentially targeting individuals with given morphological traits (i.e., larger sizes, bolder behaviour, etc.), fishing may exert either direct or indirect selective pressure on exploited populations. Due to their highly selective nature, most fishing practices not only affect fish communities at the inter-stock level but also composition and diversity at the intra-stock level. In recent years, evidence that fishing not only affects populations demographically but also changes their genetic composition has accumulated (HEINO & GODØ 2002). These genetic variations are also expected to have an impact on species morphology as in some cases genetic differences correlate positively with morphology variation.

A recommended tool for population identification is utilisation of a holistic approach where, at least, one phenotypic-based method and one genetic technique are integrated. The combination of the latter is of major importance to obtain a more complete and precise view based on population differentiation and structure, which are essential to effectively assess and manage natural resources. A failure to recognise the population structure of an exploited species can lead to erroneous management actions, including the overexploitation and depletion of less productive stocks (VIEIRA et al. 2016).

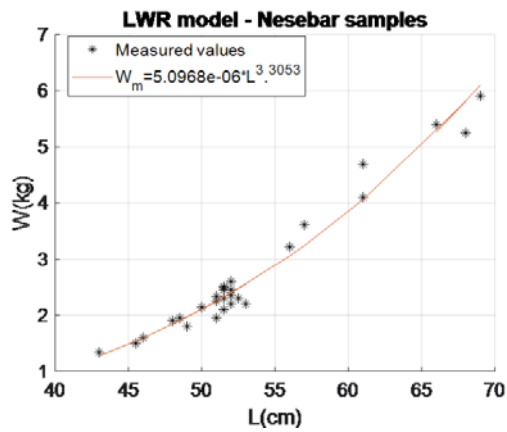
In conclusion, essential prerequisites for a sustainable fisheries management include matching of biologically-relevant processes and management actions. The implementation of complex and dynamic population structures into novel and less static management procedures should be a primary task for future fisheries management approaches (REISS et al. 2009).



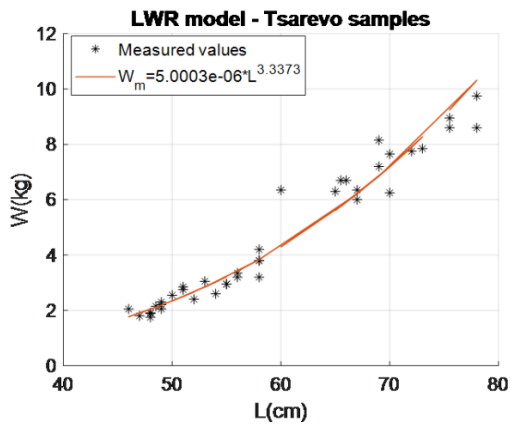
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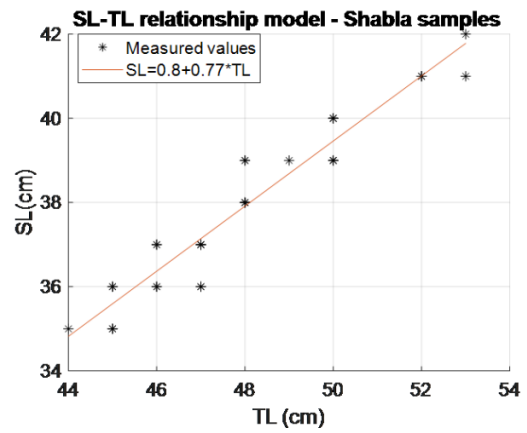
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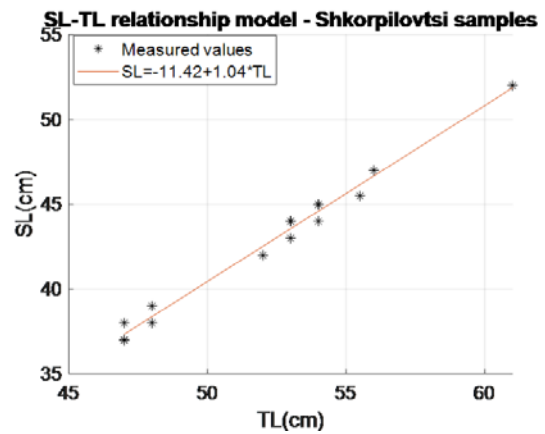
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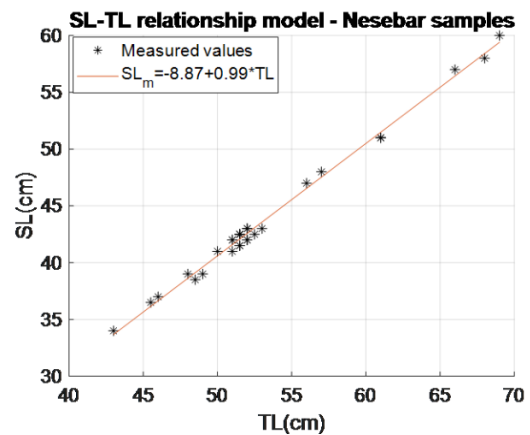
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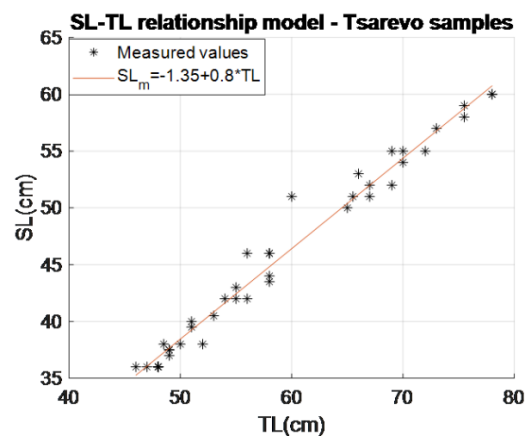
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Fig. 3. Length-weight regression models of turbot samples from the four studied localities.

Fig. 4. SL-TL models of turbot samples from the four studied localities.

Conclusion

The results of morphometric analysis showed a clear intra-species morphology variation by sites. Moreover, a strong trend was detected, increasing the values of the allometric coefficient of turbot starting from the north to the south region. The meristic features of the species are characterised by negligibly small variations compared to the morphometric characters.

Species preferences to habitat characteristics do not differ significantly by sites for the studied period. The observed morphometric variation by sites could be the diet composition, sex-dependent morphometric variation or population genetic diversification.

In subsequent studies, it is recommended to determine the sex of the samples and to apply analyses separately for males and females, especially in relation to the stomach content analyses and for identification of sex-dimorphism morphology traits variation.

Analysis of a wider range of habitat characteristics (e.g., currents, temperature, salinity variations, prey abundance and composition) may add more translucent evidence on the causations of intra-species morphology variation of turbot along the Bulgarian Black Sea coast.

Acknowledgements: This work has been carried out in the framework of the National Science Program “Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters” approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01-230/06.12.2018).

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