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RESEARCH ARTICLE

Morphometry of the gill respiratory area in ruffe, *Gymnocephalus cernuus* (L.)

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Leszek Satora, Marek Romek

Abstract. The structure of the gill respiratory surface area (GRSA) was analyzed in nine specimens of *Gymnocephalus cernuus* (L.) of different body weights. The observed GRSA values increased from 4638.46 mm^2 in the smallest specimen to 19522.8 mm^2 in the largest one. The allometric relationship of different gill components to body weight were estimated using the equation $Y = aW^b$. The calculated allometric relationship between GRSA and body weight is expressed with the equation: $Y=1348.16W^{0.687}$. The relationships between GRSA and body weight are statistically significant, the correlation coefficients are positive and significant ($P < 0.01$), and their values range from 0.95 to 0.99. The results obtained show that previously published GRSA values for ruffe were overestimated.

Keywords: gill surface, morphometry, ruffe

Introduction

Originally occurring throughout Europe and Asia, ruffe, *Gymnocephalus cernuus* (L.), is the most widespread species of the genus. Ruffe has no economic value, and on fish farms it is considered to be a pest fish. It is very common in Poland. The growth rate of the ruffe is slow (32-36 mm annually), and at the age of seven years it attains an approximate length of 120-130 mm (Specziar and Vida 1995). While the main food of adults living in lakes is Chironomidae and *Asellus aquticus* larvae (Werner et al. 1996), ruffe can also feed on benthic food (Bergman 1988) or fish eggs in the spring (Specziar and Vida 1995). In European waters, ruffe populations are mostly affected by predators such as pike, *Esox lucius* L., or pikeperch, *Sander lucioperca* (L.). In the 1980s, ruffe was introduced into the Great Lakes in the United States where it quickly became a competitor for the native fish fauna (Edsall et al. 1993). A similar expansion has been observed in European waters (Kubecka 1993). Investigations of all possible biological factors contributing to the expansion of ruffe in various types of waters is of practical significance for fish farming.

The fish gill is a multifunctional organ that constitutes the main site of respiratory gas exchange (Gray 1954). The gill respiratory surface area is linked closely with the activities and lives of particular species. Fish with high metabolic requirements or those inhabiting hypoxic environments generally have gill specializations that facilitate gas transfer (Gray 1954, De Jager and Dekkers 1975, De Jager et al. 1977). Despite the laboriousness of the research, studies of GRSA provide useful information related to fish growth (Pauly 1981, Hughes 1984), and this is especially significant in terms of changes in environmental

L. Satora [✉],
Medical Collage, Poison Information Center
Jagiellonian University
Os. Złotej Jesieni 1, 31-826 Kraków, Poland
Tel:+48 12 6468905, e-mail: satora@wp.pl

M. Romek
Department of Cytology and Histology, Institute of Zoology,
Jagiellonian University, Kraków, Poland

oxygen (Soivito and Tuurala 1981). The gill respiratory area in ruffe was investigated by Byczkowska-Smyk (1959). De Jager and Dekkers (1975) summarized all available data to establish the relationship between different parameters of the gill structure and oxygen requirements, mode of life, and fish activity. They call into question the reliability of the data concerning the morphometry of GRSA obtained by some authors for several fish species, including all the results obtained by Byczkowska-Smyk (1959). At present, there are no reliable data on gill respiratory surface area in ruffe available in the literature. The goal of the present study was to investigate precisely the gill dimensions of ruffe in relation to body mass.

Materials and Methods

Nine specimens of ruffe with different body masses were used in the investigation of GRSA. All the specimens were caught in fishing ponds in Mydlniki near Kraków. The animals were euthanized in MS 222. Fish mass was determined with an electronic scale. The specimens were preserved in 8% formaldehyde. All of the gill arches from one side of the body were excised, and each of them was divided into 3-9 sections. In each section, the number of filaments was counted, and their lengths were measured. Then a pair of filaments from the middle of each section was excised, and the average number of secondary lamellae per mm of filament length was determined. The basic methods of treatment of the gill material for measurements of lamellar surface area were essentially the same as those used by Jakubowski in a previous study (Satora and Jakubowski 1995). They were dehydrated in alcohol, cleared in xylene, and fixed in Canada balsam on microscope slides. The areas of 10 well-separated gill lamellae were measured with a light microscope coupled with a CDD camera connected to a computer running the MultiScan analytical program (Computer Scanning System, Warsaw, Poland). The total surface areas of GRSA were estimated using methods developed by Hughes (1995), and calculated as follows: GRSA = $Ln(b)_l$ where L is the total length of all gill filaments, n is the frequency of secondary lamellae on both sides of the filament, and b_l is the average bilateral surface area of the secondary lamellae. The allometric relation between GRSA and body weight was expressed with the equation $Y = aW^b$, or after logarithmic transformation by log Y = log a + b log W, where Y is the parameter analyzed, W is the body mass, and log a and log b are the parameters of the regression line. After logarithmic transformation, the data were analyzed using the linear regression method in the Statistica 5.0 program (StatSoft Inc., Tulsa, OK, USA). Both parameters of the regression line, Pearson's coefficient, and its statistical significance were all calculated.

Results

An approximate tenfold increase in body weight was accompanied by an increase in the number of total gill filaments (from 898 to 1132) by a factor of 1.26 (Table 1). Simultaneously, the total length of the filaments increased from 1831 to 5166, or 2.8 times (Table 1). Along with the body weight increases, the number of secondary lamellae per mm length of filament decreased, as did the area on both sides of the secondary gill lamellae (Table 1). The average area of the secondary lamellae increased with increased body mass (Table 1). The total area of the gill in the smallest specimen was 4.64×10^3 mm^2 and 1.96×10^4 mm^2 in the largest specimen (increased by a factor of 4.2). The respiratory surface per g of body weight in the smallest specimen was 1026.21 mm^2 g^{-1}, and 433.17 mm^2 g^{-1} in the largest specimen (in this case the decrease was by a factor of about 2.4). The results of the regression analyses for the relationship between body mass and total filament length, total filament number, average lamellar frequency, average bilateral lamellar area, as well as gill respiratory surface area are presented in Table 2. The allometric relationship calculated between GRSA and body weight can be expressed by the equation:

Table 1
Summarized results of GRSA measurements in ruffe (*Gymnocephalus cernuus*). GRSA = $Ln(b)_l$ where L is the total length of all gill filaments, n is the frequency of secondary lamellae on both sides of the filament, and b_l is the average bilateral surface area of the secondary lamellae

Body weight (g)	Total filaments number	Total filaments length (mm)	Average number of lamellae per 1 mm of filaments length	Surface area of an average lamella (mm^2)	GRSA (mm^2)
5	898	1831	40.20	0.062	4638.46
8	900	1917	39.98	0.062	5000.90
10	944	2294	35.20	0.072	5996.02
14	924	2418	33.80	0.086	8147.84
17	1030	3162	31.90	0.097	10011.26
27	1020	3402	27.76	0.137	13495.06
35	1062	4003	27.05	0.139	15289.70
40	1100	4308	28.68	0.133	16951.48
48	1132	5166	25.99	0.145	19522.80

Table 2
Results of regression analyses for measurements of gills and body mass for ruffe (*Gymnocephalus cernuus*); N – number of specimens, r – correlation coefficients, t – Student's statistics, ***P < 0.001

	N	Regression equation	r	t-test	P
Total filament length (mm)	9	$L = 737.9\ W^{0.104}$	0.95	7.8	***
Total filament number	9	$Nf = 790.68\ W^{0.462}$	0.98	13.0	***
Average lamellar frequency (mm^{-1})	9	$n = -57.15\ W^{-0.203}$	0.97	-11.0	***
Average bilateral lamellar area (mm^2)	9	$bl = -34.12\ W^{0.427}$	0.97	10.9	***
Gill respiratory surface area (mm^2)	9	$GRSA = 1348.16\ W^{0.687}$	0.99	19.1	***

Table 3
Gill respiratory surface area in ruffe (*Gymnocephalus cernuus*) according to various authors

Body weight (g)	Byczkowska-Smyk (1959) (mm^2)	Present data (mm^2)
5		4638.46
8		5000.90
10.0	27876.00	5996.02
10.0	26833.68	
14.0		8147.84
15.0	33766.32	
17.0		10011.26
18.0	25258.08	
25.0	29621.28	
25.0	33499.69	
27.0		13495.06
35.0	35317.68	15289.70
40.0		16951.48
45.0	42080.64	
48.0		19522.80

$Y = 1348.16W^{0.687}$. All of the studied gill parameters correlated very well with body weight. They exhibited logarithmic dependence as was indicated by the high correlation coefficients of linear regression with values ranging from $r = 0.95$ to 0.99 ($P < 0.001$), Table 2. The results differ from those obtained by Byczkowska-Smyk (1959) (Table 3).

Discussion

The structure and morphometry of the gills is a compromise between the mode of life and metabolic requirements. Gill dimensions, including the length and abundance of gill filaments, the number of respiratory lamellae on the filaments, and lamellar bilateral surface area, are altered by selective factors to augment gill surface area and increase oxygen uptake (Wegner et al. 2010). The role of fish gills in gas exchange has attracted considerable research effort over the last 40 years, and, importantly, gills have gained near universal appreciation as multifunctional organs. According to Gray (1954), the more active species posses a higher respiratory metabolism, and, consequently, the size of their GRSA is greater as well. In general, it seems that more active fish have a larger number of filaments which are of a longer length, and the secondary lamellae are more closely packed (30-40 lamellae per mm filament), but are smaller in area than those of more sluggish fish (De Jager and Dekkers 1975). In the other hand, the greater density in secondary lamellae reduces the physiological dead space between them. Studies of the structure and morphometry of the gill and some respiratory properties of the blood provide important indications as to the probable mode of life of ruffe. The general structure of the gill respiratory apparatus in ruffe is similar to that in other active freshwater fishes. Ruffe has four functional gill arches with holobranchs, all of which bear secondary lamellae. With respect to the size of GRSA per body weight unit, ruffe takes a high position among the freshwater fishes. Additionally, ruffe posses *tapetum lucidum*, a reflecting layer in the retina, increasing the visual sensitivity of the visual pigments and a well-developed lateral line system (Bergman 1988). These factors may increase the success of ruffe.

The current results differ from those obtained by Byczkowska-Smyk (Table 3). The major differences is in the size of the individual secondary lamellae, which were from 1.4 to 3.3 times larger than those recorded during the present study. The difference in GRSA in specimens of similar body weights (Table 3) was influenced by the very large size of the secondary lamellae, which was averaged for the entire studied population and used by Byczkowska-Smyk (1959) in GRSA calculations. The only explanation for the differences between the two studies seems to be a mistakenly converted magnification index for the lamellae, that was repeated under a magnification (methodology according to Byczkowska-Smyk 1959), and then applying generalizations from individual lamella to the entire population (Jakubowski 1992, Satora and Jakubowski 1995).

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Streszczenie

Badania powierzchni oddechowej skrzeli jazgarza *Gymnocephalus cernuus* (L.)

Badania rozwoju powierzchni oddechowej skrzeli zostały przeprowadzone na 9 osobnikach jazgarza *Gymnocephalus cernuus* (L.) o zróżnicowanej masie ciała. Otrzymane wartości całkowitej powierzchni skrzeli wynoszą 4638,46 mm^2 u najmniejszego osobnika i 19522,8 mm^2 u największego. Matematyczna zależność pomiędzy poszczególnymi komponentami składającymi się na całkowitą powierzchnię oddechową została obliczona za pomocą równania $Y = aW^b$ ($Y = 1348{,}16W^{0.687}$). Zależność pomiędzy powierzchnią oddechową skrzeli i masą ciała jest statystycznie istotna, współczynnik korelacji jest również statystycznie istotny ($P < 0{,}01$), jego wartości wynoszą od 0,95 do 0,99. Otrzymane rezultaty korygują badania przeprowadzone za pomocą innych metod.