Japanese Journal of Ichthyology
Vol. 34, No. 1 1987

魚類学雑誌
34巻1号 1987年

Effect of Body Size on the Dimensions of the Respiratory Organs of a Freshwater Catfish, *Mystus vittatus*

Jagdish Ojha and Randhir Singh

(Received March 15, 1986)

Abstract The data on gill and skin dimensions of 12 freshwater catfish *Mystus vittatus* ranging from 3 g to 23 g in relation to body weight have been analysed using logarithmic transformation. The exponent value for total gill area was 0.789; corresponding values for 1st, 2nd, 3rd and 4th gill arches and skin were 0.753, 0.772, 0.816, 0.823 and 0.631 respectively. The gill diffusing capacity (0.211) was greater than that for skin (0.002).

Mystus vittatus is a freshwater catfish belonging to the family Bagridae. In this catfish the gills and skin take care of O_2 uptake from water for its total metabolic activities. The fish sustains life outside water, if its skin is sprayed with water which confirms cutaneous respiration.

As in other animals, in fishes the metabolic O_2 requirement goes up with their growth. The growing O_2 demand is fulfilled by gradual increase in the respiratory surface area of the fish during their growth. Hence, a quantitative analysis of the growth patterns of the respiratory organs with special reference to their role in gaseous exchange is interesting.

Fish gills are intricate structures and therefore their dimensions can not be measured directly as can that of the skin. For gill area measurement various morphometric techniques have evolved during the last twenty years (Hughes, 1966; Muir and Hughes, 1969; Hughes and Morgan 1973; Hughes, 1984; Hughes and Ojha, 1985). These gradual modifications in the morphometric technique were aimed to achieve results with a minimum error. These techniques were applied for the measurements of gill surface area in air breathing (Hughes et al., 1973; Hughes et al., 1974; Munshi et al., 1980) amphibious (Niva et al., 1981) and purely water breathing (Muir and Hughes, 1969; Ojha and Munshi, 1974; Ojha et al., 1985; Oikawa and Itazawa, 1985) fishes.

The paper aims to present data on the relationship between body weight and respiratory surface area of the catfish to understand their modus operandi during growth of the fish.

Materials and methods

Live specimens of *Mystus vittatus*, collected from the Champanala, a tributary of the river Ganges, were transported to and maintained in running water of the glass aquarium (50 l). Running water ensured removal of mucus and sediments from the gills. After 48 h, 12 fish (3–23 g) were examined.

Gill morphometry. Prior to fixation the fishes were anaesthetized in MS222 (40 mg/l). The four gills were removed carefully from the left side of the fish and fixed in separate tubes containing aquous Bouin's fluid. The fixed materials were stored at 4°C in the refrigerator. After 48 h of fixation every 5th filament along both hemibranchs of the four gills was used for the measurements of filament length, secondary lamellar frequency and bilateral surface area of an average secondary lamella. Detailed method adopted is similar to that used by Hughes and Morgan (1973).

Skin morphometry. The entire skin of the sampled fish was removed carefully and its shape was traced on mm^2 graph paper. The data on the respiratory surfaces (gills and skin) for 12 weight groups of *M. vittatus* were analysed by linear-logarithmic transformation using the least-square regression method. Gill and skin diffusing capacity (Dt) were estimated with the help of modified Fick-equation ($Dt = K \cdot A/t$) where, $K =$ Krogh's coefficient (0.00015 ml $O_2/min/\mu m/cm^2/mmHg$), $A =$ respiratory area (cm^2) and $t =$ diffusion distance (μm).

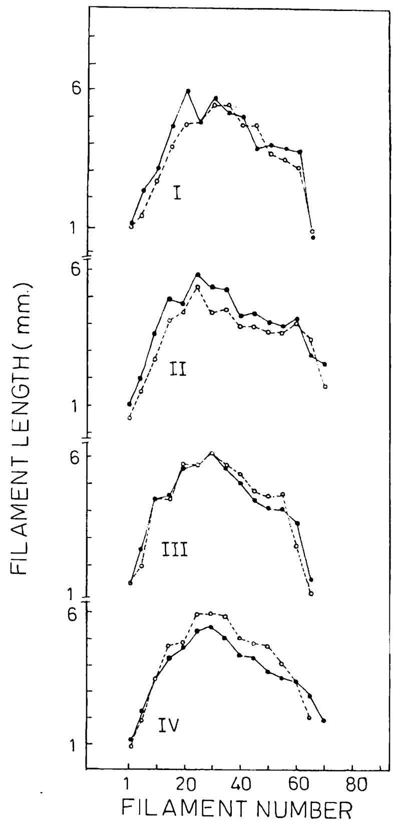


Fig. 1. Plots showing the length of gill filaments at different points of the anterior and posterior hemibranchs of the four gill arches (1–4) of 15 g *Mystus vittatus*.

Results

Gross morphology of the gills. The four pairs of moderately developed gills of *Mystus vittatus* are present in the branchial cavities. Each gill comprises two hemibranchs which showed heterogeneity in the relative size of gill filaments at different points along the arches (Fig. 1).

Mean values of the various components of the four gill arches have been presented in Table 1. Paired t-tests on the mean values of the various gill parameters of four arches indicate that except the total secondary lamellae and total gill area ($P<0.05$), the differences in other parameters among the four arches are non-significant ($P>0.05$).

Dimensions of gill parameters in relation to body weight. Except secondary lamellar frequency, all other gill parameters tend to increase with increase in body weight. Regression analyses have been made of various gill parameters in relation to body weight for each gill and the values of the intercept (a), the regression coefficient (b) and correlation coefficient (r) are summarised in Table 2 and shown in Figs. 2–10.

The diffusing capacity (ml O_2/min/mmHg/kg) for gills and skin were 0.211 and 0.002 respectively.

Discussion

Regression analyses were made between body weight and observed gill parameters (filament number, average filament length, lamellar frequency and lamellar area) to relate the independent (body weight) and dependent (gill parameters) variables. Intercept (a) and slope of the regression line (b) relating body weight and estimated gill parameters (total filament length, total secondary lamellae, total gill area and weight specific gill area) were estimated by simple mathematical deductions (Ojha et al., 1985).

A comparative account of the data on total gill filaments indicates that the values for 100 g of *M. vittatus* is about 4 and 2.7 times lower than those of the same weight groups of active marine skipjack tuna, *Katsuwonus pelamis* (Muir and Hughes, 1969) and the free swimming riverine carp, *Catla catla* (Hughes and Ojha, 1985) respectively. However, this value is about 2.7 and 5.5 times greater than the values reported respectively for the same weight groups of the sluggish marine toadfish, *Opsanus tau* (Hughes and Gray, 1972) and the air breathing climbing perch, *Anabas testudineus* (Hughes and Ojha, 1985). Such critical review of the data on total gill filaments suggests an intermediate activity for *M. vittatus*. Secondary lamellar frequency is an important gill parameter which determines the lamellar flow and total respiratory area. Lamellar frequency on one side of gill filament is often considered for the fineness of the gill sieve. Density of secondary lamellae per mm of a gill filament is directly proportional to the fineness of gill sieve and indirectly proportional to the lamellar flow. Small physiological spaces between two adjacent lamellae and slow water flow through them determine the efficacy of the gills.

Lamellar frequency for a 100 g *M. vittatus* (44.4) is lower than the values reported for the active

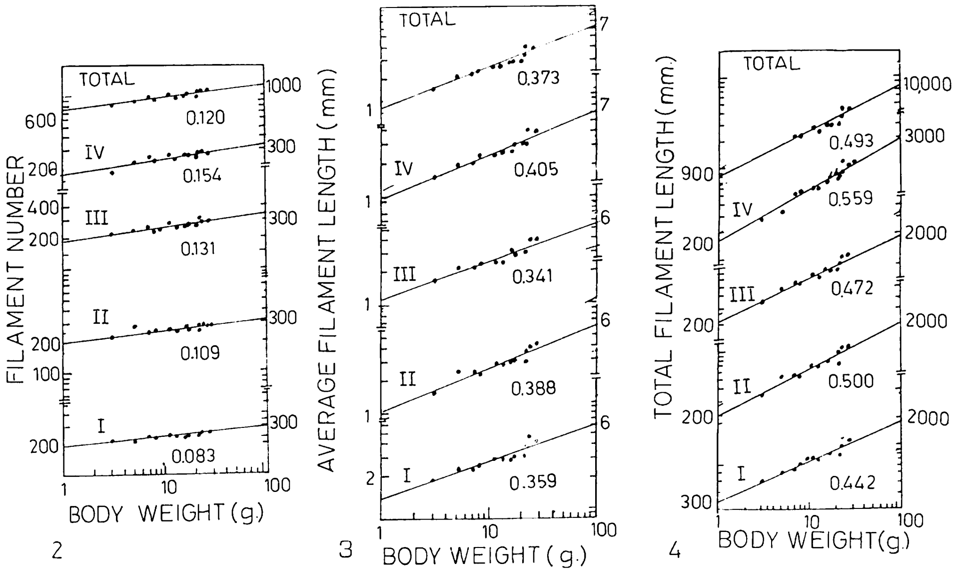


Fig. 2. Bilogarithmic graphs showing the relationship between body weight and total filament number.
Fig. 3. Bilogarithmic graphs showing the relationship between body weight and average filament length.
Fig. 4. Bilogarithmic graphs showing the relationship between total filament length and body weight.

marine tuna (83.2) and the Indian riverine carp (54.22), but higher than those for the sluggish toadfish (22.54) and the air breathing climbing perch (41.69). From these findings, it can be concluded that the density of secondary lamellae on the gill filaments is directly proportional to the activity of the fish.

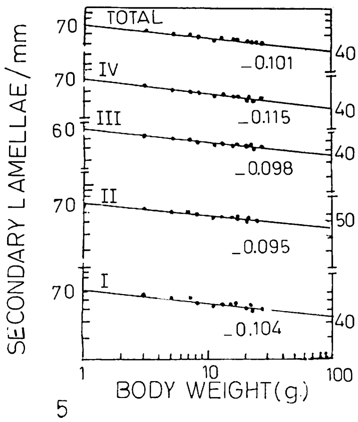
Lamellar frequency in *M. vittatus* decreases by a power of −0.101 with unit increase in body weight. Such a quantitative relationship suggests

Table 1. Mean values of the various components of the four gill arches of *Mystus vittatus* (14.417 g±2.158; n=12).

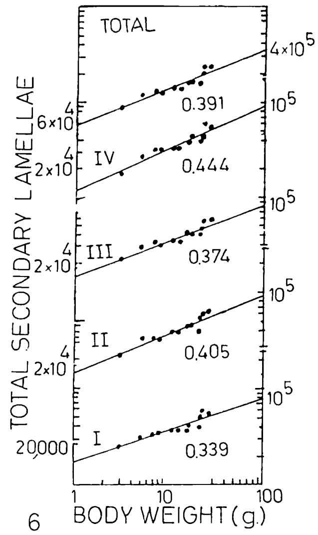
Gill Parameters	First gill		Second gill		Third gill		Fourth gill	
	Value	S.E.	Value	S.E.	Value	S.E.	Value	S.E.
Total gill fil. no.	239.333	4.212	257.000	5.660	259.000	7.410	252.000	7.817
Av. fil. length (mm)	3.055	0.229	2.904	0.216	2.731	0.186	2.694	0.214
Total fil. length (mm)	741.107	67.591	761.077	71.597	719.829	64.936	678.166	77.607
Secondary lam./mm (Both sides)	54.931	1.224	54.979	1.043	55.541	1.119	55.915	1.303
Total sec. lam.	39863.893	2892.252	41068.142	3291.238	39240.902	962.436	37887.154	3249.427
Av. bil. surf. area of a sec. lam. (mm^2)	0.027	0.002	0.025	0.002	0.024	0.002	0.023	0.002
Total gill area (mm^2)	1130.242	144.371	1074.998	143.084	1004.448	142.148	919.196	116.182
Gill area/g body weight (mm^2)	85.272	4.720	80.675	4.989	74.010	3.916	68.189	3.457

Table 2. Intercept (a), slope of the regression line (b) and correlation coefficient (r) to show the relationship between body weight and various gill parameters of the 4 pairs of gills of *Mystus vittatus*.

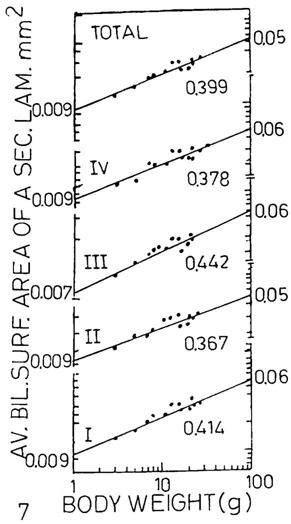
Body weight (W) vs	1st gill arch			2nd gill arch			3rd gill arch			4th gill arch			Total gill arches		
	Intercept (a)	Slope (b)	Correl. coef. (r)	Intercept (a)	Slope (b)	Correl. coef. (r)	Intercept (a)	Slope (b)	Correl. coef. (r)	Intercept (a)	Slope (b)	Correl. coef. (r)	Intercept (a)	Slope (b)	Correl. coef. (r)
Total gill fil. (nos.)	194.285	0.083	0.877	195.119	0.109	0.923	185.768	0.131	0.856	170.471	0.154	0.871	745.075	0.120	0.917
Av. fil. length (mm)	1.209	0.359	0.920	1.066	0.388	0.942	1.137	0.341	0.940	0.946	0.405	0.950	1.089	0.373	0.951
Total fil. length (mm)	234.801	0.442	0.929	207.343	0.500	0.950	211.310	0.472	0.956	161.243	0.559	0.958	811.353	0.493	0.957
Secondary lam./mm	70.878	−0.104	−0.893	69.418	−0.095	−0.959	70.742	−0.098	−0.942	74.293	−0.115	−0.961	71.152	−0.101	−0.947
Total sec. lam.	16642.172	0.339	0.911	14393.288	0.405	0.926	14948.238	0.374	0.932	11978.709	0.444	0.937	57728.464	0.391	0.937
Av. surface of a sec. lam. (mm^2)	0.0089	0.414	0.935	0.0096	0.367	0.905	0.0077	0.442	0.920	0.0087	0.378	0.884	0.0089	0.399	0.932
Total gill area (mm^2)	154.757	0.753	0.971	138.644	0.772	0.946	114.712	0.816	0.959	104.354	0.823	0.969	512.566	0.789	0.970
Gill area/g body wt. (mm^2)	154.757	−0.247	−0.803	138.634	−0.227	−0.652	114.725	−0.184	−0.605	104.359	−0.177	−0.646	512.613	−0.211	−0.734



5



6

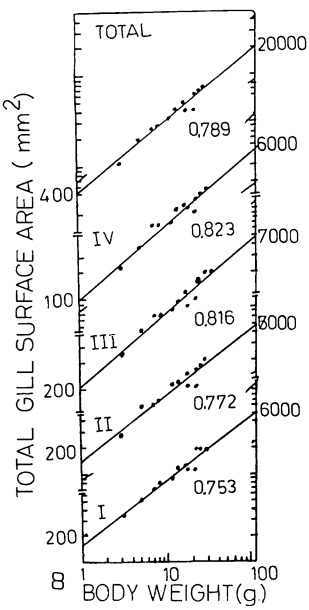


7

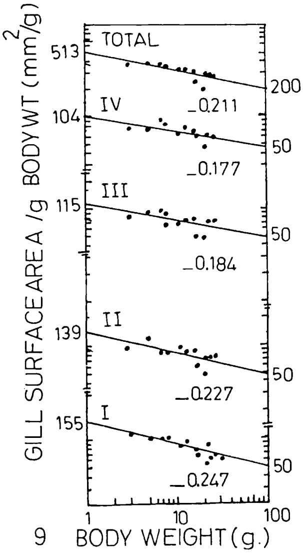
Fig. 5. Bilogarithmic graphs showing the relationship between body weight and secondary lamellae per mm.

Fig. 6. Bilogarithmic graphs showing the relationship between body weight and total secondary lamellae.

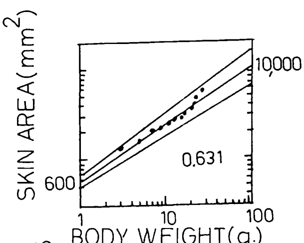
Fig. 7. Bilogarithmic graphs showing the relationship between body weight and average bilateral surface area of a secondary lamella.



8



9



10

Fig. 8. Bilogarithmic graphs showing the relationship between body weight and tota lgill area.

Fig. 9. Bilogarithmic graphs showing the relationship between body weight and gill area/g body weight.

Fig. 10. Bilogarithmic graphs showing the relationship between body weight and skin area.

that the gill filaments grow at a faster rate than the number of secondary lamellae added to them. This is one of the factors responsible for lower efficacy of the gills of older fishes than those of young ones.

A critical review of the literature on lamellar area presents an opposite trend to that of lamellar frequency. Bilateral surface area of an average secondary lamella (0.3347 mm^2) of the sluggish toadfish is about 3.5 and 13 times greater than those reported for active marine tuna (0.0940 mm^2) and the Indian riverine carp (0.0251 mm^2) respectively.

The aforesaid findings confirm the previous assumptions that the gill filaments of active and sluggish fishes are characterized by densely packed smaller and sparsely distributed larger secondary lamellae respectively (Hughes, 1966).

With reference to the growth the bilateral surface area of an average secondary lamella increases by a power of 0.399.

Total filament length, lamellar frequency and area contribute to the total gill area. The total gill area for a 100 g *M. vittatus* (19,417 mm^2) is about 13 and 1.5 times lower than the values reported for the active tuna (261,038 mm^2) and the riverine carp (28,536 mm^2). Such findings suggest low level of activity for the catfish under study.

The slope of the regression line relating body weight and total gill area for *M. vittatus* (0.789) is close to an average value (0.82) reported earlier (Jager and Dekkers, 1975). It is interesting to note that similar relationship exists between body weight and O_2 uptake of fishes (Winberg, 1956). Review of these data indicates that the gill area in fishes tend to grow in proportion to their O_2 uptake rate.

In *M. vittatus* the skin also plays an important part in gaseous exchange. The skin area (10,544 mm^2) is about 36% of the total respiratory area (29,308 mm^2) of a 100 g fish. Higher gill area in this catfish indicates its dominant role in gaseous exchange.

Respiratory organs act as an interface between external (water) and internal (blood) respiratory media. In this context, the diffusion distance plays an important part in determining the efficacy of the respiratory structures. It is inversely proportional to the effectiveness of the respiratory structures. The diffusion distance of the gills (1.38 μm) is about 41 times lower than that for skin (57.9 μm).

The diffusing capacity of the gills and skin for a 100 g *M. vittatus* were estimated with the help of their respiratory area and diffusion distances. The diffusing capacity (ml O_2/min/mmHg/kg) of gills (0.211) was about 105 times greater than that of skin (0.002). These findings confirm the dominance of gills in aquatic O_2 uptake for this catfish.

Literature cited

Hughes, G. M. 1966. The dimensions of fish gills in relation to their function. J. Exp. Biol., 45: 177–195.

Hughes, G. M. 1984. Measurement of gill area in fishes. Practices and problems. J. Mar. Biol. Ass. U. K., 64: 637–655.

Hughes, G. M. and I. E. Gray. 1972. Dimensions and ultrastructure of toadfish gills. Biol. Bull., 143: 150–161.

Hughes, G. M. and M. Morgan. 1973. The structure of fish gills in relation to their respiratory function. Biol. Rev., 48: 419–475, pls. 1–2.

Hughes, G. M. and J. Ojha. 1985. Critical study of the gill area of a free-swimming river carp, *Catla catla* and an airbreathing perch, *Anabas testudineus*. Proc. Indian Natn. Sci. Acad., B51: 391–404.

Hughes, G. M., S. C. Dubey, and J. S. D. Munshi. 1973. Surface area of the respiratory organs of the climbing perch, *Anabas testudineus*. J. Zool., Lond., 170: 227–243.

Hughes, G. M., B. R. Singh, G. Guha, S. C. Dubey and J. S. Datta Munshi. 1974. Respiratory surface areas of an air-breathing siluroid fish, *Heteropneustes fossilis* in relation to body size. J. Zool., Lond., 172: 215–232.

Jager, S. D. and W. J. Dekkers. 1975. Relationships between gill structures and activity in fish. Nether. J. Zool., 25: 276–308.

Muir, B. S. and G. M. Hughes. 1969. Gill dimensions for three species of tunny. J. Exp. Biol., 51: 271–285, pl. 1.

Munshi, J. S. D., J. Ojha and Asha L. Sinha. 1980. Morphometrics of the respiratory organs of an air-breathing catfish, *Clarias batrachus* in relation to body weight. Proc. Indian Natn. Sci. Acad., B46: 621–635.

Niva, Biswas, J. Ojha and J. S. D. Munshi. 1981. Morphometrics of respiratory organs of an estuarine goby, *Boleophthalmus boddaerti*. Japan. J. Ichthyol., 27: 316–326.

Oikawa, S. and Y. Itazawa. 1985. Gill and body surface areas of the carp in relation to body mass, with special reference to the metabolism—Size relationship. J. Exp. Biol., 117: 1–14.

Ojha, J. and J. S. D. Munshi. 1974. Morphometric studies on the gill and skin dimensions in relation to weight in a freshwater mud-eel, *Macrognathus aculeatum*. Zool. Anz., 193: 364–381.

Ojha, J., R. Singh and N. K. Singh. 1985. Structure and dimensions of the respiratory organs of a freshwater catfish, *Mystus cavasius*. Proc. Indian Natn. Sci. Acad., B51: 202–210.

Pütter, A. 1909. Die Ernährung der Wasser Tiere, und der Stoffhaushalt der Gewasser. Z. F. Allgem. Physiol., 7: 148.

Winberg, G. G. 1956. Rate of metabolism and food requirements of fishes (Nauchrye Trudy Belo-. russkogo Gosudarvennogo Universitata imen. V. I. Lenina, Minsk). Fish. Res. Bd. Can., Trans. Ser. No. 194, 253 pp.

(Post-Graduate Department of Zoology, Bhagalpur University, Bhagalpur-812007 (Bihar), INDIA)

淡水産ナマズの一種 *Mystus vittatus* における呼吸器官の表面積と体の大きさの関係

Jagdish Ojha • Randhir Singh

淡水産ナマズの一種 *Mystus vittatus* の 3 g から 23 g までの 12 個体について，鰓や表皮の表面積と体重との相関関係を，対数変換により分析した．鰓の全表面積についての回帰係数は 0.789 で，第 1–4 鰓弓と表皮についてはそれぞれ 0.753, 0.772, 0.816, 0.631 であった．鰓の酸素交換能力は 0.211 ml/min/mmHg/kg で表皮のそれ (0.002) よりも大きかった．