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Oxygen Uptake Through Water During Early Life of an Air Breathing Fish *Osphronemus nobilis* (McClelland)

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Abstract

Oxygen uptake (mg/h) during early life of fish *Osphronemus nobilis* in relation to body size at 28 ± 1 C showed a statistically significant two component curves, one related to the fish larvae depending wholly on aquatic respiration (b_W = 0.8449, b_L = 1.9497) and the other related to the fry respiring bimodally b_W = 0.6018, b_L = 1.8608). The point of intersection being at 18 mg body weight and 1.15 cm body length. These were the theoretical values of weight or length at which the fish acquired air-breathing habit during the period of day 20—22 after hatching, resulting about 39.5% decline in O_2 uptake through branchio-cutaneous system in water, which was made good through the newly developed air-breathing organs. The total O_2 uptake calculated during exclusively aquatic respiration of fish was 466.32 ml/kg per ha, which became 282.03 ml/kg per ha when they started relying on aerial respiration in addition to gills. One of the important causes forcing developing fry to adopt bimodal gas exchange machinery seemed to be nearly three fold increase in the water-blood diffusion distance at the secondary gill lamellae.
Key words : Oxygen uptake, Metabolism, Respiration, Early life.

Metabolism of fish is defined in terms of O_2 uptake, CO_2 released and heat evolved which depends on the physiological state of its respiratory organs. The rate of O_2 uptake has been considered to be an indication of the intensity of metabolism (Fry 1957, 1971). In fishes any alteration in the morphological design of its respiratory organs would affect the rate of oxygen consumption. Many species of teleosts inhabiting hypoxic and hyper-capnic water have acquired accessory respiratory organs which enable them to breathe atmospheric air in addition to gills. Oxygen uptake through water or air varies considerably among these air-breathing fishes (Rahn and Howell 1976). The air-breathing organs in these fishes are either pre-existing structures such as the intestine, air-bladder, skin and the gills which are vascularized to facilitate oxygen uptake or the neomorphic organs which are variously designed and structured for direct aerial gas exchange. The first characteristic component of the neo-morphic air-breathing organ (NAO) to develop is the supra-branchial chamber of the bucco-pharnyx, which is immediately pressed into the service to take oxygen from air. The second characteristics components of the NAO are the labyrinthine organ, air-sac, respiratory trees and dendritic plates develop quite late in the larval life to augment O_2 demand from air. The air-breathing organs show low gas exchange ratio and function primarily in oxygen absorption. Oxygen uptake in fishes vary with age, sex, and season, quality of ambient environment (pH, temperature, dissolved oxygen and CO_2) and with activity level. Measurement of oxygen uptake in the young and adult specimen of different air-breathing fishes showed that the the aquatic respiration is more important than the aerial one (Hughes and Singh 1970, Prasad and Singh 1984, Prasad 1986, Job 1976, Singh et al. 1982, 1986) except *Amphipnous cuchia* (Lomholt and Johansen 1976, Patra et al. 1978, Singh and Thakur, 1979) in which aerial respiration dominates.

The metabolism has been suggested to be limited by the total respiratory surface area available for gas exchanges which is directly related to the rate of oxygen uptake. Estimation of routine oxygen reflects the normal level of spontaneous activity. It has been well documented (e.g., Mishra and Singh 1979 ; Sheel and Singh 1981, Singh et al. 1986) that routine oxygen uptake in the early life of air-breathing fish showed a biphasic plan i.e. aquatic phase when the fish depends exclusively on aquatic respiration to meet

Table 1. Relationship between oxygen uptake (mg/h) and wet weight (mg) and length (mm) of *Osphronemus nobilis* (McClelland).

Condition	VO_2 vs W or L	Equation	SD of Slope	Corre-lation coeffi-cient	Mean O_2 uptake rate (cm^3/kg/h)
(A) Fish respiring exclusively through water (15)	W	Log Y=–3.0279+0.8449 Log W $Y=0.0009\ W^{0.8449}$	0.1158	0.9977	466.32
	L	Log Y=3.9762+1.9497 Log L Y=0.0001 L	0.7288	0.9937	
(B) Fish respiring bimodally (15)	W	Log Y=–2.7082+0.6018 Log W $Y= 0.00201\ W^{0.6018}$	0.2125	0.9841	282.03
	L	Log Y=–3.9614+1.8608 Log L $Y=0.0001\ L^{1.8608}$	1.3687	0.9938	
(C) Combined data (30)	W	Log Y=–2.9725+0.7436 Log W $Y=0.00107\ W^{0.7436}$	0.1249	0.9985	309.2
	L	Log Y=–3.8056+1.7708 Log L $Y=0.00016\ L^{1.7708}$	0.0556	0.9971	
(D) Per g. body weight for (A) & (B) (30)	W	Log Y=–0.5881+(–0.1554) Log W $Y=0.2582\ W^{-0.1554}$	0.1199	0.9437	
	W	Log Y=–0.86511+(–0.3983) Log W $Y=0.13642\ W^{-0.3983}$	0.2490	0.9655	

its entire metabolic demand and the bimodal phase, when oxygen uptake is supplemented by means of NAO. The pattern and magnitude of either aquatic or aerial respiration depends upon the body weight, diffusion barrier, the extent to which the gas exchanger develops their respiratory surface area in the ambient condition of water.

Osphronemus nobilis (McClelland) locally known as ‘Novel’ or ‘Hajminiya’ fish in north-eastern India belongs to family Osphronemidae of the order Perciformes. It is an obligate air breathing fish possessing a suprabranchial chamer above the gill arches on either side of the the pharynx. Each suprabranchial chamber contains a simple labyrinthine organ within which it is attached to epibranchial of the first gill arch. The fish with moderate length of 8—12 cm has laterally compressed body and protruding snout. The body is provided with silvery texture with three transverse bands of black color. The fish is quiet, sluggish and on the verge of extinction. The fish shows mouth brooding parental care behavior for the larvae stage. The interest shown to study the metabolic oxygen demand of the fish during the early life and its comparison with another species, is to search out the factors of its limited distribution and leading cause towards extinction.

(The author is thankful to Shankar Sahani, fisherman for providing larvae and fry of fish during studies).

Methods

Larvae, fry and fingerlings were obtained during breeding season (March-April) from the fisher-

Table 2. Comparison of oxygen uptake rate (cm^3 /kg/h, 1) and O_2 uptake for 1 g fish (cm^3/h, 2) in three species of the labyrinthic fishes at 28 ±1 C.

	Fish species	Aquatic phase of respiration 1	2	Bimodal phase of respiration 1	2	Reference
1.	*Anabas testudineus*	1255.0	0.714	240.5	0.127	Mishra and Singh (1979)
2.	*Colisa fasciatus*	224.0	0.397	359.6	0.158	Prasad and Singh (1984)
3.	*Osphronemus nobilis*	466.32	0.225	282.03	0.088	Present authors

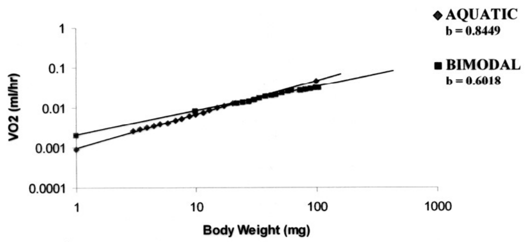

Figure 1. Log/log plot of oxygen uptake (ml/h) in relation to body weight (mg).

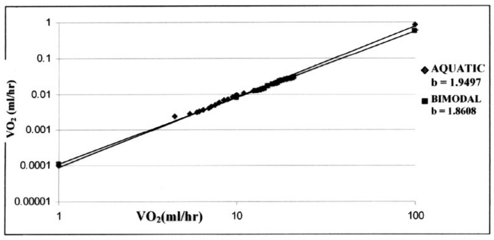

Figure 2. Log/log plot of oxygen uptake (ml/h) in relation to body length (mm).

men in the vicinity of Dhanauti Mann near Pipra Kothi, Motihari, Bihar (India), because induced breeding and rearing of the fish itself is a tough task. The developing fry, oozed out from the spent female brooder's mouth were stocked and maintained carefully in the large glass aquaria at 28 ± C with regular supply of oxygen and insects larvae.

Routine oxygen uptake for different groups in relation to nearly equal body weight and length at 28 ± 1 C during aquatic phase (3—20.5 mg weight and 5—12.5 mm length) and bimodal phase (22—105 mg weight and 13—21 mm length) was measured by placing 40 larvae and 30 fry in a glass respirometer separately. Following Winkler's iodometric method the rate of oxygen uptake was determined by estimating the difference in dissolved oxygen of water without the larvae or fry and same water with larvae or fry. The quantity of oxygen consumed was divided by the number of fry taken for the experiment to find out the average value of oxygen uptake by a single fry.

Oxygen uptake for the individual fish (VO_2, mg/h) was plotted against the body weight (mg) and length (mm) on log/log co-ordinates by employing exponential equation.

$$Y=aX^b \text{ or ; } \log Y=\log a + b \log X$$

Where, Y=Rate of O_2 uptake (mg/h), X=Weight (W) or length (L), a=Intercept, b=Regression coefficient

Table 3. Comparison of the slope values for oxygen uptake in relation to body size in their early life among labyrinthic fishes.

	Fish species	Length (mm) at which air breathing habit develops	Slope of the weight (mg) vs oxygen uptake curve Wholly aquatic phase	Bimodal phase	Slope of the length (mm) vs oxygen uptake curve Wholly aquatic phase	Bimodal phase	Drop in oxygen uptake (%) through water at the onset of air breathing habit	Reference
1.	Anabas testudineus	11—12	0.950	0.587	1.1123	1.6461	40	Mishra & Singh (1979)
2.	Colisa fasciatus	11—12	0.835	0.645	2.1360	1.7030	36	Prasad & Singh (1984)
3.	Osphronemus nobilis	11—12	0.8449	0.6018	1.9497	1.8608	39.5	Present authors

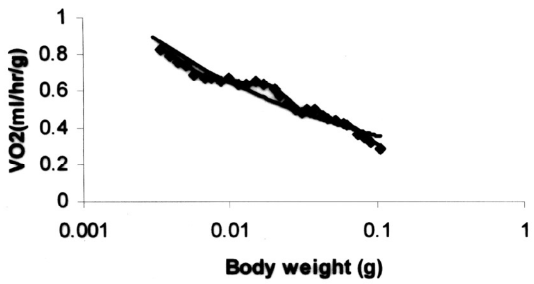

Figure 3. Semilog plot of oxygen uptake (ml/hr/g) in relation to body weight (g).

(slope).

O_2 uptake rate/g body weight/ hour was plotted on a semi-log graph. The data were analyzed through linear logarithmic transformations, using the method of least square and the significance of differences in the result was measured by Student's *t*-test.

Results

Osphronemus nobilis live in the hypoxic water and the pattern and magnitude of either aquatic or aerial respiration depends on ambient condition of the water. Average oxygen uptake for a fish showing 9.07 mg weight and 7.97 mm length while depending on aquatic respiration alone was 466.32 ml/kg per h. In a log/log plot of oxygen uptake in relation to body weight a slope of 0.8449 was obtained (Fig. 1). The relationship is denoted by the equation $Y=-3.9762\ W^{0.8449}$.

The data on measurement of oxygen uptake in relation to body weight or length have been summarized in Table 1. The air-breathing habit in the fish begins around day 20 —22 after hatching, as a result, larvae come to the water surface to gulp atmospheric air. The habit of surfacing depends on the growth rate of the fish and is concerned with availability of food, oxygen and pH content of the water. During the onset of the air gulping habit, their visit to the water surface become more frequent in the beginning but slower down considerably later.

The impact of developing air-breathing habit causes decline of the rate of oxygen uptake through water. Such a decline in oxygen uptake takes place due to supplementation of oxygen requirement partly through the newly developed air breathing organs. In a fish having bimodal breathing habit, the rate of oxygen uptake through water was 282.03 ml/kg per h. In log/log plot of oxygen uptake in relation to body weight (mg) a slope of 0.6018 was obtained (Fig. 1). The relationship is denoted by the equation $Y=0.002\ W^{0.6018}$.

The slope of the regression lines for oxygen uptake in relation to body weight or length of the fish depending either on wholly aquatic phases or bimodal phase of respiration differ significantly from one another ($P < 0.1$). The point of intersection of two components curves are at 18 mg body weight and 11.5 mm body length. The relationship between length (L) and oxygen uptake (Y) in fishes relying exclusively on aquatic respiration is $Y=0.001\ L^{1.9497}$ and those practising bimodal gas exchange (Fig. 2) is

$$Y = 0.001\ L^{1.8608}$$

The plotting of data for oxygen uptake through water on per g body weight (mg/h per g body weight) in a semi-log graph (Fig. 3) indicates a sudden drop in oxygen uptake around 19 mg and a steady decline when the body weight of nearly 40 mg is achieved.

In the sections of gills of different age groups of fishes, a variation occurs in the water-blood path way at secondary gill lamellae which forms an important limiting factor for diffusion of gasses. In the larvae depending entirely on oxygen uptake through the gills, the diffusion distance measured 0.5—0.7 µm whereas fishes utilizing bimodal gas exchange, this distance became 1.2—2 µm .

Discussion

In body weight the exponent reduces from 0.8449 in aquatic phase to 0.6018 in bimodal phase which reveals that oxygen uptake decreases with the increase of the body weight. The higher rate of oxygen uptake during early life of the fish forms a basis of increased metabolic activity in the early phase of larval development.

In body length, the exponent is also greater (1.9497) during the aquatic phases of respiration and reduced when the fish adopts a bimodal breathing habit (1.8608). This reduction in the exponent for oxygen uptake indicates that length increases more rapidly when the fish adopts a bimodal breathing habit than at a stage when the fish remains an aquatic breather. The same trend was reported also in *Colisa fasciatus* (Prasad and Singh 1984) but a reverse of same trend occurred in *Anabas testudineus* (Mishra and Singh 1979). In other words, there occurs a rapid growth of fry in girth rather than in length before the air-breathing organs come into existence.

The rate of oxygen uptake through water is comparatively greater in the larvae of *Anabas testudineus* and *Osphronemus nobilis* than *Colisa fasciatus* (Tables 2 and 3). When the air-breathing organs become functional in the larvae of *Osphronemus nobilis,* oxygen uptake through the branchio-cutaneous system in water declines to nearly 39.5%. In other words, in a fry performing bimodal respiration, the air-breathing organ fulfils nearly 39.5% of total oxygen demand and remaining 60.5% continues to be met by the branchio-cutaneous system in water. This view is fully supported by reviewing the oxygen uptake by these fishes in their aquatic and bimodal phase of respiration (Mishra and Singh 1979, Prasad and Singh 1984, Prasad et al 1993).

Measurements of oxygen uptake made on the larvae of another species of laberinthic fishes (*Anabas testudineus* and *Colisa fasciatus*) showed different proportions of sharing by the air-breathing organ and the branchio-cutaneous system in total oxygen uptake. It is nearly 40 and 60% respectively in *Anabas testudineus* (Mishra and Singh 1979) and 36 and 64% respectively in *Colisa fasciatus* (Prasad and Singh 1984). The branchio-cutaneous system in *Osphronemus nobilis* is less functional than *Colisa fasciatus* and nearly equal to *Anabas testudineus* but the air-breathing organs are comparatively more developed and also supplemented by highly vascularised bucco-pharyngeal epithelium.

The two component curves for oxygen uptake in relation to body size intersect at 18 mg body weight and 1.15 cm body length coincide with the figures for body size when the air-breathing habit develops in the fish. Oxygen uptake/g body weight shows a sudden drop in the rate of around 0.019 g body weight, which is the body weight when the fish develops a fully functional air-breathing organ.

Interspecies difference in oxygen uptake is well shown by the larvae of *Osphronemus nobilis*, *Anabas testudineous* and *Colisa fasciatus* (Table 2). For example, the mean rate of oxygen uptake in *Osphronemus nobilis* is nearly double to the *Colisa fasciatus* and three times less than *Anabas testudineus* during aquatic phase of respiration but nearly 0.784 times less than *Colisa fasciatus* and 1.173 times more than *Anabus testudineus* during bimodal phase of respiration. Oxygen uptake obtained for 1 g fish through regression analysis also becomes one and a half times more in *Colisa fasciatus* and three times more in *Anabas testudineus* than *Osphronemus nobilis* while their larvae depend upon the aquatic phase of respiration alone. When they become habituated to a bimodal breathing habit, this difference in O_2 uptake for 1 g fish narrows down considerably to 0.088.

Osphronemus nobilis is active in the beginning but as soon as the fish starts breathing bimodally, the diffusion barrier increases rapidly and since the thickness of water-blood or air-blood barrier influences the oxygen tension difference (PO_2) providing the driving force for diffusion of oxygen in the blood (Hughes et al. 1973), extraction of oxygen by the gills reduces and fish became less active.

A three fold increase in the diffusion distance in bimodal phase than the aquatic phase shows the less active nature of fish and indicates that the fish has to face a greater need of atmospheric oxygen to satisfy its metabolism. The increase in diffusion distance of the gill reduces oxygen diffusion capacity. During the larval stage of *Osphronemus nobilis*, the rate of oxygen uptake through the gills has been 466.32 ml/kg per h and in the adult fish oxygen uptake rate increases from 96.62 ml/kg per h to 317.44 ml/kg/h (Prasad et al. 1993) in experimental condition of free access to air and when surfacing was prevented respectively.

The slope of oxygen uptake in *Osphronemus nobilis* (0.6018) is lesser compared to *Colisa fasciatus* (0.645) but greater compared to *Anabas testudineus* (0.587) when they become adapted to a bimodal breathing habit (Table 3). Similarly, during aquatic phase of respiration oxygen uptake in *Osphronemus nobilis* (0.8449) is lesser than *Anabas testudineus* (0.950) but greater than *Colisa fasciatus* (0.835). However, the three species showed almost a similar slope for O_2 uptake when they rely on aquatic phase of respiration alone. Such a similarity is not due to the reason that they belong to the same group of labyrinthic fish but because the increase in O_2 uptake in the early life of almost all the Indian air-breathing teleosts investigated so far is known to be a directly proportional to increase in the body weight (Mishra and Singh 1979, Sheel and Singh 1981, Singh et al 1982, Prasad and Singh 1984, Singh et al. 1986).

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