Proc. Indian natn. Sci. Acad. **B49** No 6 pp 566–574 (1983)

Oxygen Consumption of the Freshwater Air-breathing Indian Siluroid fish, *Clarias batrachus* (Linn.) in relation to Body Size and Seasons

A K PATRA, J S DATTA MUNSHI and G M HUGHES
Post-Graduate Department of Zoology, Bhagalpur University, Bhagalpur 812007
and
Research Unit for Comparative Animal Respiration, Bristol University, England

(Received 5 May 1982; after revision 19 September 1983)

Oxygen-uptake through air-breathing organs, gills and skin in relation to body size was studied in young and adult air-breathing catfish, *Clarias batrachus*, during winter (20.0±1°C), rainy (25.5±1°C) and summer (30.5±1°C) seasons. Regression analysis gave different exponent values which may be attributed to the varied growth patterns and physiological status of young and adults.

The larger fishes were more air-dependent in comparison to smaller ones at all temperatures studied as shown from the slope values $\dot{V}o_2$ (aerial breathing: $b = 0.864$ at 20.0±1°C; 0.8411 at 25.0±1°C; 1.0687 at 30.5±1°C; aquatic breathing: $b = 0.7357$ at 20.0±1°C; 0.5172 at 25.5±1°C and 0.3162 at 30.5±1°C), from air and water respectively.

Key Words: Oxygen consumption, *Clarias batrachus* (Linn.), Siluroid fish, Body weight, Environmental temperature

Introduction

Many zoologists have investigated the structural modifications and adaptations of air-breathing fishes (Das 1927, 1933, 1935, 1940, Carter & Beadle 1931, Schottle 1931, Hora 1935, Marlier 1938, Nawar 1955, Munshi 1961, 1962). However, during the last 20 years comparative physiologists have become more interested in the study of various adaptive features of amphibious vertebrates (Hughes 1966, Johansen 1966, Rahn 1966, Johansen et al. 1967, 1970, Farber & Rahn 1970, Lenfant & Johansen 1972, Hughes & Weibel 1976, Singh 1976).

Gas exchange and respiratory patterns of some Indian air-breathing fishes such as *Anabas testudineus*, *Heteropneustes fossilis*, *Clarias batrachus*, *Channa gachua* and *Trichogaster fasciatus* have been studied by Hughes and Singh (1970a, b,

1971), Singh and Hughes (1971, 1973), Hakim et al. (1978, 1983), Ojha et al. (1977), Munshi et al. (1977), Ojha and Dandotia (1978).

As no comparable work is available on the relationship between oxygen consumption and body size of *Clarias batrachus* at different ambient temperatures, this study was undertaken using the common magur fish of India.

Materials and Methods

Live specimens of *Clarias batrachus* of various body sizes were collected from the swamps of North Bihar in different seasons and healthy specimens maintained in large glass aquaria with running water. They were fed goat liver on alternate days for 15 days, and were fasted at least 12 hr before experiments. The fishes were acclimatised to the experimental conditions in the respirometer at least overnight.

The experimental set-up and method of measuring $\dot{V}o_2$ from water and air were essentially the same as described by Munshi et al. (1982). Experiments were conducted at various seasonal temperatures, 30.5±1°C (summer), 25.0±1°C (rainy), and 20.0±1°C (winter).

Results

The accessory respiratory organs are mainly accommodated in the suprabranchial chambers which are lined by a membrane containing many respiratory islets (Munshi 1961, Hughes & Munshi 1973). Each suprabranchial chamber is separated from the ipsilateral opercular cavity by four leaf-like fans, formed by modified gill filaments on each of the arches. In addition, the 2nd and 4th gill arches bear much expanded arborescent organs which also contain vascularised respiratory tissue. Air enters each suprabranchial chamber by a narrow opening between the 2nd and 3rd arches and is exhaled through an aperture between the 3rd and 4th arches. The gill lamellae of the 4th fan protect the lips of this aperture (Munshi 1976).

Measurements of oxygen consumption ($\dot{V}o_2$) in relation to body size and temperature as well as computed data on regression analysis are summarised in table 1 and figures 1–3.

Table 1 *Intercept (a) regression (b) and correlation coefficient (r) to show the relationship of oxygen consumption ($\dot{V}o_2$) from water via gills, skin+gills and from air via dentritic organ to their respective body weights. The standard deviation (SD) of the intercept and regression coefficients are given*

Experimental conditions	Temp. of ambient water (°C)	Gas exchange organ	Intercept (*a*)		Regression coefficient (*b*)		Correlation coefficient (*r*)
			Estimated value	SD	Estimated value	SD	
In still water with access to air	20.0±1	Air-br. organ	—1.4387	0.0118	0.8641	0.0444	0.9594 $P<0.001$
-do-	-do-	Gills+skin	—0.8792	0.0095	0.7357	0.0361	0.9628 $P<0.001$
-do-	-do-	Air-br. organ+ gills+skin	—0.7902	0.0084	0.7806	0.0317	0.9742 $P<0.001$
-do-	25.5±1	Air-br. organ	—1.0725	0.0285	0.8411	0.0944	0.8688 $P<0.001$
-do-	-do-	Gills+skin	—0.4701	0.0237	0.5173	0.0782	0.7846 $P<0.001$
-do-	-do-	Air-br. or.+ gills+skin	—0.4308	0.0205	0.6737	0.0535	0.9296 $P<0.001$
-do-	30.5±1	Air-br. org.	—1.5491	0.0224	1.0687	0.0763	0.9469 $P<0.001$
-do-	-do-	Gills+skin	—0.2017	0.0378	0.3162	0.0914	0.5213 $P<0.001$
-do-	-do-	Air-br. org.+	—6.0949	0.0152	0.7613	0.0524	0.9507 $P<0.001$

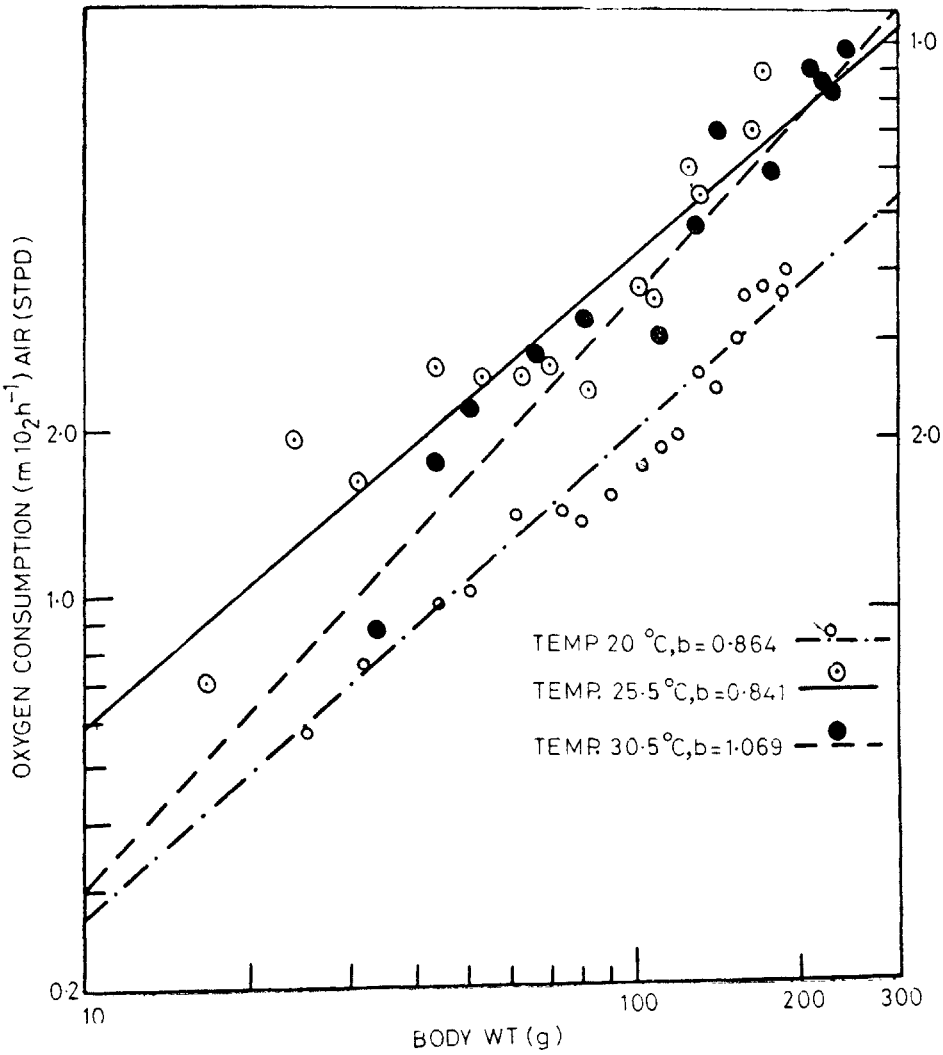

Figure 1 Bilogarithmic plots to show the relationship between body weight and oxygen consumption (ml/hr) from air in winter (20.2±1°C), summer (30.5±1°C), and rainy (25.5±1°C) seasons

Oxygen Consumption as a Function of Body Size

Clarias batrachus breathes from both water and air when placed in a 4 litre capacity respirometer containing 3 litres of still tapwater. The intervals between air breaths are irregular and are related to the oxygen pressure in water and air. Variations are also observed between individuals.

Oxygen consumption (ml/hr/fish) increases with increasing body size and the relation between the two variables may be expressed by the allometric equation:

$$\dot{V}o_2 = a\,W^b$$

or $$\log \dot{V}o_2 = \log_{10} a + b \log_{10} W \quad \ldots \quad (1)$$

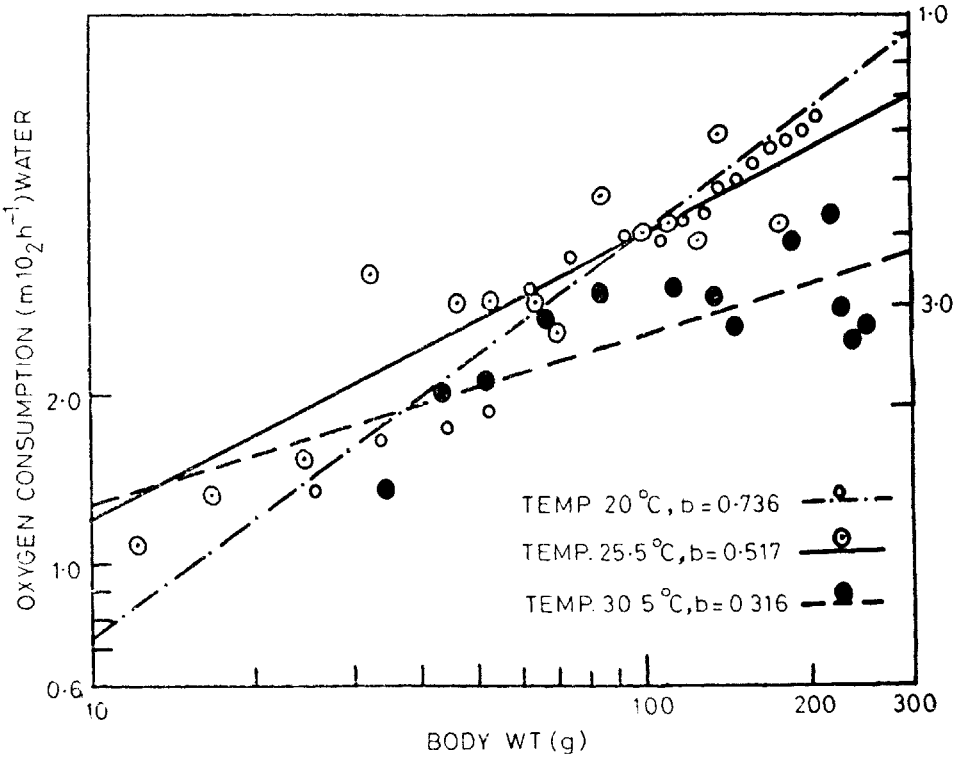

Figure 2 Log/log plots showing the relationship between body weight and oxygen uptake (ml/hr) from water in winter (20.0±1°C), summer (30.5±1°C) and rainy (25.5±1°C) seasons

Where, $\dot{V}o_2$ is the oxygen consumption/unit time; *a*, the rate of oxygen consumption for 1g fish; *W*, the body weight; and *b*, the regression coefficient.

$\dot{V}o_2$ from air and water at 20.0±1°C

From the observed data, an increase in the oxygen consumption (ml/hr/fish) with an increase of body size was quite evident from both air and water. For the range, 22.16 to 194.50g the increase in $\dot{V}o_2$ was 0.58 to 3.88 ml/hr; and 1.347 to 6.37 ml/hr from air and water respectively.

The larger fishes were more air-dependent than the smaller ones for oxygen consumption as is apparent from the exponent (*b*) values of the log/log plots shown below:

$$\dot{V}o_2 = 0.0364\ W^{0.8641}$$

or $\log \dot{V}o_2 = -1.4387 + 0.8641 \log W$ (*air*) ... (2)

$$\dot{V}o_2 = 0.132\ W^{0.7357}$$

or $\log \dot{V}o_2 = -0.8792 + 0.7357 \log W$ (*water*) ... (3)

The two variables are highly correlated and statistically significant (r=0.95941, P<0·001 from air; r= 0.96282, P<0.001 from water).

$\dot{V}o_2$ from air and water at 25.5±1°C

For body weights ranging from 17.0 to 174.0g in rainy season (25.0±1°C),

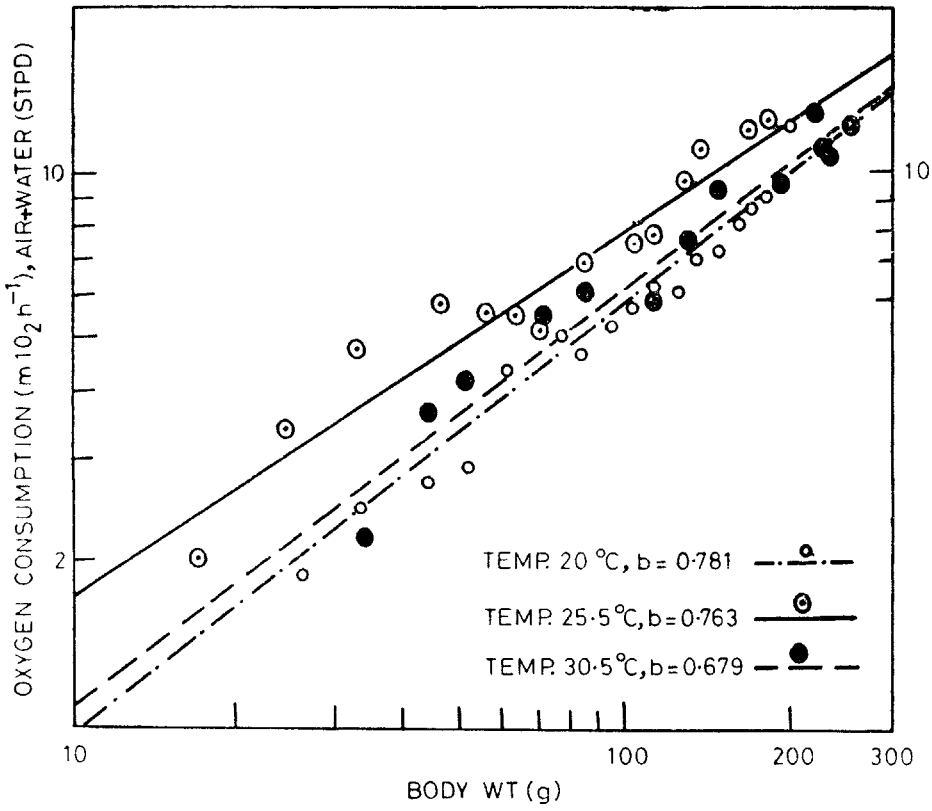

Figure 3 Log/log plots showing the relationship between body weight and oxygen uptake from both air and water at winter (20.0±1°C), rainy (25.5±1°C) and summer (30.5±1°C) temperatures

$\dot{V}o_2$ from air and water varied from 0.71 to 8.76 ml/hr and 1.36 to 4.188 ml/hr respectively.

The larger adult fishes depended more on air than water for oxygen uptake as shown from the '*b*' values in the following relationships:

$$\dot{V}o_2 = 0.0845\ W^{0.8411}$$

or $\log \dot{V}o_2 = -1.0725 + 0.8411 \log W$ *(air)* ... (4)

$$\dot{V}o_2 = 0.3707\ W^{0.5173}$$

or $\log \dot{V}o_2 = -0.4701 + 0.5173 \log W$ *(water)* ... (5)

There was a good correlation (0.8688, $P<0.001$) between body size and $\dot{V}o_2$ from air but the correlation coefficient was comparatively low ($r=0.7846$, $P<0.001$) for O_2 uptake from water.

$\dot{V}o_2$ from air and water at 30.5±1°C

In summer $\dot{V}o_2$ from air ranged from 0.87 to 0.59 ml/hr fish and 1.39 to 2.62 ml/hr from water for body weights from 34.50 to 244.13g. The difference in $\dot{V}o_2$ from air for this size range was quite marked but difference in O_2 uptake from water was not so great as is evident from the exponential values of two parameters studied.

$$\dot{V}o_2 = 0.0256\ W^{1.0687}$$

or $log\ \dot{V}o_2 = -1.549 + 1.0687\ log\ W$ *(air)* ... (6)

$$\dot{V}o_2 = 0.6137\ W^{0.3162}$$

or $log\ \dot{V}o_2 = -0.2017 + 0.3162\ log\ W$ *(water)* ... (7)

From the above data it was quite clear that larger specimens were more air-dependent, while the smaller fishes depended more on water for their metabolism.

The correlation coefficient showed a high correlation ($r = 0.94690$, $P<0.001$) from air but much lower ($r = 0.52131$, $P<0.001$) in water.

Oxygen Consumption as a Function of Temperature

It is evident that the size/O_2 uptake plots of figures 1, 2 and 3 have different exponential values at different seasonal temperatures such as 20.0±1°C (winter), 25.5±1°C (rainy) and 30.5±1°C (summer). Thus at 20.0±1°C, the 'b' value from air was 0.8641 while at 25.5±1°C, it gave a value of 0.8411 and at 30.5±1°C it was 1.0687. This variation indicates that the increase in $\dot{V}o_2$ with the increasing body size was not the same at all temperatures. In summer the slope of air-breathing is higher indicating that bigger fishes are very much air dependent, while the small fishes were found to be active gill-breathers, even at low temperature in winter. However, at all temperatures large adult fishes depend more on air than water for their supply of oxygen.

In case of aquatic breathing from still water the '*b*' slope was high ($b = 0.7357$) in winter than rainy season ($b = 0.5173$) but minimal ($b = 0.3162$) in summer.

When total oxygen consumption (ml/hr/fish) was studied, it gave a very interesting result, the slope '*b*' being higher ($b = 0.7806$) in winter than summer ($b = 0.7631$) and minimal ($b = 0.6737$) in the rainy season. Oxygen consumption for a 1g fish gave higher values at all temparatues studied in rainy season ($a = 0.3699$ ml/hr) than summer ($a = 0.1894$ ml/hr) and much lower ($a = 0.1616$ ml/hr) in winter. There was a high correlation coefficient between body size and total oxygen consumption of the fish ($r = 0.9742$, $P<0.001$) at 20.0±1°C, ($r = 0.9296$, $P<0.001$) at 25.5±1°C and ($r = 0.9507$, $P<0.001$) at 30.5±1°C.

Discussion

Many studies have been made on the relationship between the metabolic rate of animals and their body weight. Winberg (1956) found 0.81 to be an average value for a large number of fish species and concluded that for oxygen consumption, the overall relationship would be:

$$\dot{V}o_2 = W^{0.81}$$

Paloheimo and Dickie (1965) suggested 0.80 to be the value characteristic of most teleost species. These exponent values are based on data available from water breathing forms. Munshi and Dube (1973) have evaluated the effect of growth on the uptake of oxygen through the gills in *Anabas testudineus*. According to them oxygen uptake by the gills in relation to body size increased by a power of 0.67 when the fish had free access to air at 27.0±1°C. Under similar conditions, *Channa punctata* showed an exponent value of 0.79 at 30.5±1°C (Hakim et al. 1977). In *Heteropneustes* (*Saccobranchus*) *fossilis*, oxygen uptake through gill+skin at 26.0±1°C gave a very high value ($b = 1.328$) (Munshi et al. 1977). They concluded that juveniles depend more on air breathing for their total metabolic demand and with growth and

maturation they depend more on aquatic respiration. A possible change in slope of the regression line for respiratory sac area at 25g in *Heteropneustes* was shown not to be statistically significant (Hughes et al. 1974).

In the present studies on *Clarias batrachus* different exponent values have been obtained for different body sizes (juvenile+adult) at three different ambient temperatures, when oxygen consumption from air and water was considered.

In fact the fish of different body sizes have different response patterns to temperature variations as is evidenced by the '*b*' values of the size metabolic curves (figures 1, 2 and 3). The '*b*' values for aerial breathing were always found to be more (b = 0.864159 at 20.0°C, 0.8411 at 25.5°C, 1.0687 at 30.5°C) than the values obtained for aquatic breathing (b = 0.7357 at 20.0°C, 0.517 at 25.5°C, and 0.3162 at 30.5°C). It may be due to the fact that the rate of increase in the area of accessory respiratory organs (b = 0.840) was higher than that for the gills (b = 0.781) during their growth in *Clarias batrachus* studied by Munshi et al. (1976). Therefore, it is expected that in large fishes the proportion of oxygen uptake through the air-breathing organs will be dominant over that of the gills.

It seems that in winter (20.0±1°C) the bigger fishes can tolerate the cold more easily than the smaller ones which get cold depressed; but the average oxygen consumption (ml/hr) remains higher from water than air because of the fact that in ambient cold water, enough dissolved oxygen is available for gill breathing.

Further, speculations can be made about $\dot{V}o_2$ in summer (30.5±1°C). In this season the highest regression coefficient value (1.0687) from air and low slope value (0.3162) from water indicates a preponderance of aerial breathing over aquatic in hot season. In senescent or semi-senescent swamps there is always oxygen depletion of the ambient water in the summer season.

In the rainy season (25.5±1°C), as it is the breeding season for the fish, the adult fishes remain busy with sexual activity and spend much of their time in shallow regions of their habitat and take recourse to more frequent air-breathing. The average oxygen consumption of adult fish is higher in the rainy season than in summer and winter mainly because of their breeding activities.

When total oxygen consumption (ml/hr) is considered, in winter and summer, it was found that the slope value is higher (b = 0.7806) in winter than in summer (b = 0.7631). It seems that the bigger fishes in winter are comparatively more cold-adapted because of their fatty integument than the younger ones. The same fishes in summer become heat-depressed in comparison to smaller ones. But the average of $\dot{V}o_2$ remains high in summer because the temperature is higher than in winter.

Acknowledgement

This work was financed by the Indian Council of Agricultural Research, New Delhi [No. 21 (47)/73-ASR (I)].

References

Carter G S and Beadle L C 1931 The fauna of the swamps of the Paraguayan chaco in relation to its environment. II. Respiratory adaptations in the fishes; *J. Linn. Soc. Lond. (Zool.)* **37** 327–368

Das B K 1927 The bionomics of certain air-breathing fishes of India, together with an account of the development of their air-breathing organs; *Phil. Trans. Roy. Soc. Lond.* **216** 183–219

—— 1933 On the bionomics, structure and physiology of respiration in an estuarine air-breathing fish, *Pseudopocryptes lanceolatus* with special reference to a new mode of aerial respiration; *Curr. Sci.* **1** 389–393

—— 1935 On ecology and bionomics of an air-breathing loach, *Lepidocephalus guntea* (Ham. Buch.) with a review on air-breathing fishes; *Int. Congr. Zool.* **12** 866–920

—— 1940 Nature and causes of evolution and adaptation of the air-breathing fishes; *Proc. Indian Sci. Congr.* **27** 215–260

Farber J and Rahn H 1970 Gas exchange between air and water and the ventilation pattern in the electrical eel; *Resp. Physiol.* **9** 151–161

Hakim A, Munshi J S Datta and Hughes G M 1978 Morphometrics of the respiratory organs of the Indian green snake-headed fish, *Channa punctata*; *J. Zool. London* **184** 519–543

——, —— and —— 1983 Oxygen-uptake from water through the respiratory organs in *Channa punctata* (Bloch) of different body weight; *Proc. Indian natn. Sci. Acad.* **B49** 73–85

Hora S L 1935 Physiology, bionomics and evolution of the air-breathing fishes of India; *Trans. natn. Inst. Sci. India* **1** 1–16

Hughes G M and Munshi J S Datta 1973 Nature of the air-breathing organs of the Indian fishes, *Channa, Amphipnous, Clarias* and *Saccobranchus* as shown by electron microscopy; *J. Zool. London* **170** 245–270

—— and Singh B N 1970a Respiration in an air-breathing fish, the climbing perch *Anabas testudineus*. I. Oxygen uptake and carbon dioxide release into air and water; *J. expl. Biol.* **53** 265–280

—— and —— 1970b Respiration in an air-breathing fish, the climbing perch *Anabas testudienus*. II. Respiratory patterns and the control of breathing; *J. expl. Biol.* **53** 281–298

—— and —— 1971 Gas exchange with air and water in an air-breathing cat fish, *Saccobranchus* (=*Heteropneustes*) *fossilis*; *J. expl. Biol.* **55** 667–682

——, Singh B R, Guha G, Dube S C and Munshi J S D 1974 Respiratory surface areas of an air-breathing siluroid fish, *Saccobranchus* (*Heteropneustes*) *fossilis* in relation to body size; *J. Zool. London* **172** 215–232

—— and Weibel E R 1976 Morphometry of fish lungs; in *Respitarion of Amphibious Vertebrates* ed. G M Hughes (London: Academic Press)

Johansen K 1966 Air-breathing in the teleost, *Synbranchus marmoratus*; *Comp. Biochem. Physiol.* **18** 383–395

——, Hansen D and Lenfant C 1970 Respiration in a primitive air-breather, *Amia calva*; *Resp. Physiol.* **9** 162–174

Lenfant C, Johansen K and Grigg G C 1967 Respiratory properties of blood and pattern of gas exchange in the lung fish, *Neoceratodus forsteri* (Krefft); *Comp. Biochem. Physiol.* **20** 2–12

—— and Johansen K 1972 Gas exchange in gill, skin and lung breathing; *Resp. Physiol.* **20** 835–854

Marlier G 1938 Considerations surles organs accessories, Servant a la respiration, aerienne chez les teleosteans; *Annls. Soc. r. zool. Belg.* **69** 163–185

Munshi J S D 1961 The accessory respiratory organs of *Clarias batrachus*; *J. Morph.* **109** 115–140

—— 1962 On the accessory respiratory organs of *Ophicephalus punctatus* (Bloch) and *O. striatus* (Bloch); *J. Linn. Soc. Lond. (Zool)* **44** 616–626

—— 1976 Gross and fine structure of the respiratory organs of air-breathing fishes; in *Respitation of Amphibious Vertebrates* ed. G M Hughes pp 73–104 (London: Academic Press)

—— and Dube S C 1973 Oxygen uptake capacity of gills in relation to body size of the air-breathing fish, *Anabas testudineus* (Bloch); *Acta Physiol. Acad. Sci. Hung.* **44** 113–123

——, Sinha A L and Ojha J 1976 O_2 uptake capacity of gills and skin in relation to body weight of the air-breathing siluroid fish, *Clarias batrachus* (Linn.); *Acta Physiological Hungaricae* **48** 23–33

——, Pandey B N, Pandey P K and Ojha J 1978 O_2 uptake through gills and skin in relation to body weight of an air-breathing siluroid fish, *Saccobranchus* (=*Heteropneustes*) *fossilis* (BL.); *J. Zool. London* **184** 171–180

——, Patra A K and Hughes G M 1982 Oxygen consumption from air and water in *Heteropneustes* (=*Saccobranchus*) *fossilis* (Bloch) in relation to body weight at three different seasons; *Proc. Indian natn. Sci. Acad.* **B48** 715–729

Nawar G 1925 On the anatomy of *Clarias lazera*. III. The vascular system; *J. Morph.* **97** 179–214

Ojha J, Dandotia O P, Munshi J S D 1977 Oxygen consumption of an amphibious fish, *Colisa fasciatus*, in relation to body weight; *Pol. Abch. Hydtobiol.* **24**

——, ——, Patra A K and Munshi J S D 1977 Bimodal oxygen uptake in relation to body weight in a freshwater murrel, *Channa* (=*Ophicephalus*) *gachua*; *Z. Tierphysiol. Tierernohrg. Futtermittelkde* **40** 57–66

Paloheimo J E, Dickie L M 1965 Food and growth of fishes. II. Effects of food and temperature on the relation between metabolism and body weight; *J. Fish. Res. Bd. Can.* **23** 869–908

Rahn H 1966 Gas transport from the external environment to the cell; in *Ciba Foundation Symposium on Development of the Lung* eds. A V S de Reuck and R Porter pp. 3–23 (London: Churchill Ltd.)

Schottle E 1931 Morphologie und physiologie der Atmug bei warser Schlam und lardle benden; *Gobifotmes z. wiss. zool.* **140** 1–114

Singh B N 1976 Balance between aquatic and aerial respiration; in *Respiration of Amphibious Vertebrates* ed. G M Hughes pp 125–164 (London & New York: Academic Press)

—— and Hughes G M 1971 Respiration of an air-breathing catfish, *Clarias batrachus* (Linn.); *J. expl. Biol.* **55** 421–434

—— and —— 1973 Cardiac and respiratory responses in the climbing perch, *Anabas testudineus*; *J. Comp. Physiol.* **84** 205–226

Welch P S 1948 *Limonological Methods*, (New York: McGraw Hill)

Winberg G G 1956 Rate of metabolism and food requirements of fishes (Original in Russian). Translation series No. 194 (*J. Fish. Res. Bd. Can.*)