Belg. J. Zool. — Volume 121 (1991) — issue 1 — pages 73-80 — Brussels 1991

(Manuscript received on 3 October 1989)

A NEW HYPOTHESIS ON THE AIR FLOW IN AIR BREATHING IN *CLARIAS GARIEPINUS* (TELEOSTEI, SILURIFORMES)

by

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SUMMARY

Clarias gariepinus (BURCHELL, 1822) breathes air at the surface. Aerial breathing requires a flow of air through intercommunicating cavities (buccopharyngeal cavity, opercular and suprabranchial cavities). Cinematographic observations on normal and abnormal catfishes lead to a new hypothesis about air-breathing in *Clarias*. 1) At rest on the bottom, the suprabranchial cavity is filled with air. 2) While coming up to the surface, a part of the air of the suprabranchial cavity passes to the opercular cavities, especially in their anterior part, through slits between the fan-like valves borne on the epibranchials. 3) Somewhat later, opercular adduction results in expulsion of bubbles through the opercular slits. 4) When the snout reaches the surface, the mouth is wide open. Depression of the hyoid bars and opercular abduction produce aspiration of air into the buccopharyngeal cavity. 5) Air is forced into the suprabranchial cavity, through the third branchial slit by mouth closure and buccopharyngeal constriction. Hyoid bars elevation plays a prominent role in that constriction as demonstrated by the partial impossibility for abnormal *Clarias* with locked hyoid bars to push air from the mouth to the suprabranchial cavities.

Key words : Pisces, *Clarias,* air breathing.

INTRODUCTION

Clarias gariepinus (BURCHELL, 1822) (a species of which Clarias lazera CUVIER and VALENCIENNES, 1840, is regarded as a synonym by TEUGELS, 1982) uses two modes of ventilation (POLL, 1959), aquatic and aerial. The latter takes place in two symmetrical and separated suprabranchial cavities which are posterodorsal outgrowths of the opercular cavities. The following description of the suprabranchial cavities and of their anatomical relations is compiled from MARLIER (1938), NAWAR

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(1955), MOUSSA (1956 and 1957), SINGH and HUGHES (1971), COCKSON (1972), HUGHES and MUNSHI (1973), MUNSHI (1976), SINGH (1976), SINGH *et al.* (1982), HELLIN and CHARDON (1983). Each one comprises an anterior region above the branchial region and a posteroventral one surmounting the opercular cavity and extending backward up to behind the level of the pectoral girdle. The communication between opercular and suprabranchial cavities is controlled by downward-bulging fan-like expansions of the first four branchial arches; these fans work as passive valves allowing one-way upward passage of air from buccal to suprabranchial cavities. They appear as the continuation on the epibranchials of transformed branchial filaments. The transformation consists of loss of vascularization, flattening, longitudinal fusion and greater development of the branchial rays which remain cartilaginous in their distal part. Moreover, the buccal and suprabranchial cavities may communicate through a unique dorsal prolongation of the third branchial slit between the second and third epibranchials. That part of the third branchial slit is separated from its ventral ceratobranchial part by two small fibrous cushions facing each another. In its resting state it seems to remain somewhat open, but the contraction of the obliquus communis branchial muscle (HOLSTVOOGT, 1965) may bring nearer the second and third epibranchials and close it. The suprabranchial cavities contain two highly vascularized arborescent organs which are the sites together with their walls, for gas exchanges to occur. The walls are three-fold. The volume of the cavities may be reduced by contraction of a striated muscle covering its posterior wall. Attempts were made to describe the movement of air-breathing and the path of the air in *Clarias* by MARLIER (1938), MUNSHI (1976), SINGH *et al.* (1982) and HELLIN and CHARDON (1983). Observations on *C. gariepinus* with the hyoid bars locked in their depressed position by a connective tissue thickening and careful observations on normal fish allow us to criticize the previous hypotheses about the path of the air through the cavity and to propose a new one.

MATERIAL AND METHODS

Four normal *Clarias gariepinus* of standard length 27 to 30 cm and one abnormal 28 cm specimen with locked hyoid bars were filmed at 32 and 48 frames/second with a Beaulieu and 1PL Photosonics 16 mm cameras. Twelve scenes of the normal fish and three of the abnormal one were analysed.

For technical reasons it was only possible to observe clearly on films the opening or closing of the mouth and the movements of the hyoid bars and opercles; the abduction and adduction of the suspensoria and the opening or closing of the opercular membranes could not be observed with certainty.

RESULTS

Observations on the normal specimens (Fig. 1)

Resting *Clarias* perform aquatic respiration by slow movements as it is described for other teleosts (for example BALLINTIJN (1969a and b) in *Cyprinus carpio* LINNE, 1758). At an apparently unexpected time, the fish swims to the surface of the water. In at least 4 cases out of 12, the mouth is clearly open during upward swimming, while according to HELLIN and CHARDON (1983) it is closed during that movement. While swimming up, the fish releases gas bubbles (average diameter at release : 11 mm) through the opercular slits. When the mouth reaches the surface, it is wide open and the opercles start to abduct. A few milliseconds later the mouth partially closes, the fish turns head down and begins to dive. In some cases it releases a small bubble through the opercular slits.

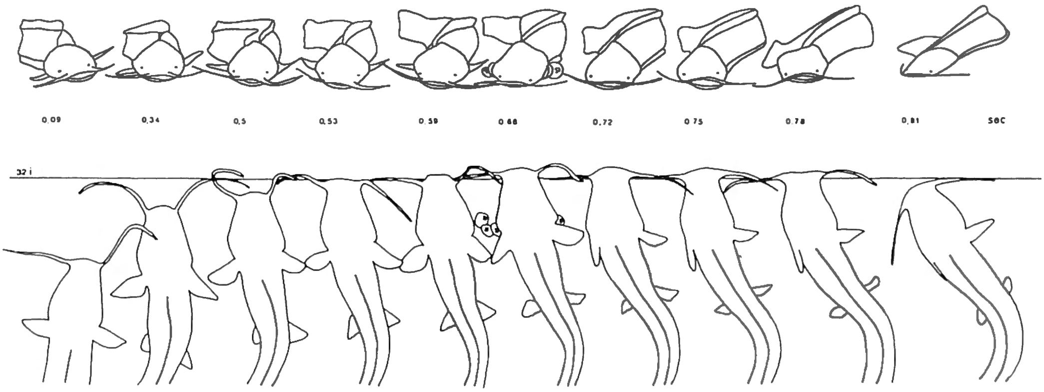

Fig. 1. — Sequence (redrawn after a film at 32 frames/sec) of the air-breathing in *Clarias gariepinus*. Notice that the intervals of time between the schemas are not constant. Bubbles are conspicuous on the sixth drawing. (unpublished drawing of HELLIN).

Observations on the abnormal catfish (Figs 2, 3)

The hyoid bars do not move conspicuously, neither at their articulation on the suspensoria, nor at their medial junction. At rest, slow aquatic respiration consists of movements of the mouth, opercles and branchiostegal membranes only. An air bubble can be observed in the mouth cavity against the palate. This bubble is released through the mouth opening at the beginning of the swimming up. The mouth remains open during the upward movement, and two gas bubbles, smaller (diameter of about 6 mm) than in normal specimens, are released through the gill slits. When reaching the surface, the mouth is open and the opercles begin abduction. Then, the fish dives and releases some air through the opercular slits, while the mouth closes incompletely. As soon as the fish is resting horizontally on the bottom, a bubble is again conspicuous against the palate.

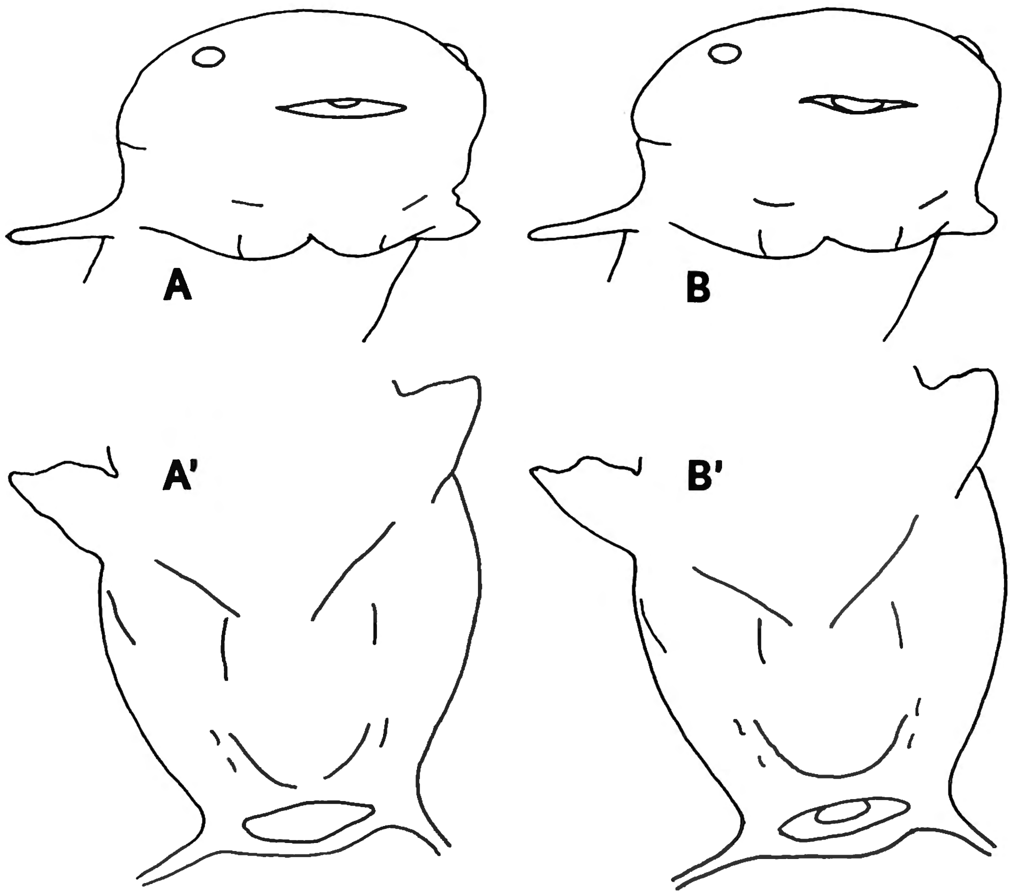

Fig. 2. — A and A'. Frontal and ventral views of the abnormal *Clarias gariepinus* resting on the bottom, showing an air bubble in the open mouth cavity during aquatic inspiration; notice that the bubble is conspicuous in frontal view only. B and B'. Similar views during aquatic expiration with the air bubbles conspicuous in both aspects.

DISCUSSION

The last hypothesis about the path-way of the air in the respiratory cavities of *Clarias* was proposed by HELLIN and CHARDON (1983) on basis of anatomical, optical, cinematographical and low speed cineradiographical observations. According to the latter authors, the air passes from the suprabranchial to the buccal cavity through the epibranchial part of the third branchial slit during up-swimming. As the mouth opening is closed, the air is kept there until it is pushed to the opercular cavities through the normal branchial slits; it is finally brought outside by opercular adduction. The catfish opens its mouth and lowers its hyoid bars when reaching the surface; so it breathes in air. Afterwards, it turns head down, shuts its mouth and actively swims downward. Then air passes to the opercular cavities by buccal cavity contraction and opercular abduction and also as a consequence of the difference in hydrostatic pressures ; some air bubbles may escape through the opercular slits. Afterwards, the air is pushed from the opercular to the suprabranchial cavities between the fans.

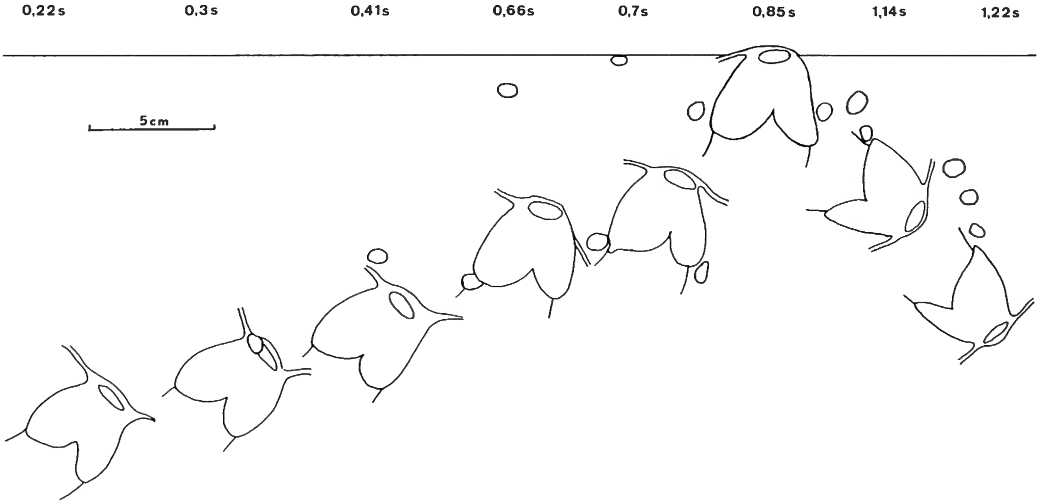

Fig. 3. — Sequence (redrawn after a film, at 100 frames/sec) of air-breathing in an abnormal *Clarias gariepinus*. The time intervals between the schemas are variable. Notice the air bubbles escaping through the mouth and, later, through the opercular slits.

A first objection concerns the possibility of pushing air from the opercular to the suprabranchial cavities ; it is hard to accept that only the dorsal part of the opercular slit opens during opercular adduction, and in any case, it would let escape much air. Further, the above described orientation of the fans prevents air flow from opercular to the suprabranchial cavities. Direct observations of the actual position of the opercular membrane unfortunately proved unsuccessful.

Secondly, our present observations of the mouth opening during up-swimming and careful reexamination of previous unpublished drawings of HELLIN (Fig. 1) clearly show that the mouth is open at that time, at least in most cases. Our observations on the abnormal catfishes are crucial because they demonstrate that gas contained in the buccal cavity cannot but escape by the mouth opening if it is open during the upward movement.

So, we cannot agree any longer with HELLIN and CHARDON's hypothesis. The path-way of the air must be more simple (Fig. 4), as follows. (1) At rest on the bottom, the suprabranchial cavities are filled with air and the other respiratory cavities with water (and maybe a small quantity of air). (2) The fish swims up to the surface, usually with it mouth open ; air is pushed into the opercular cavities by the

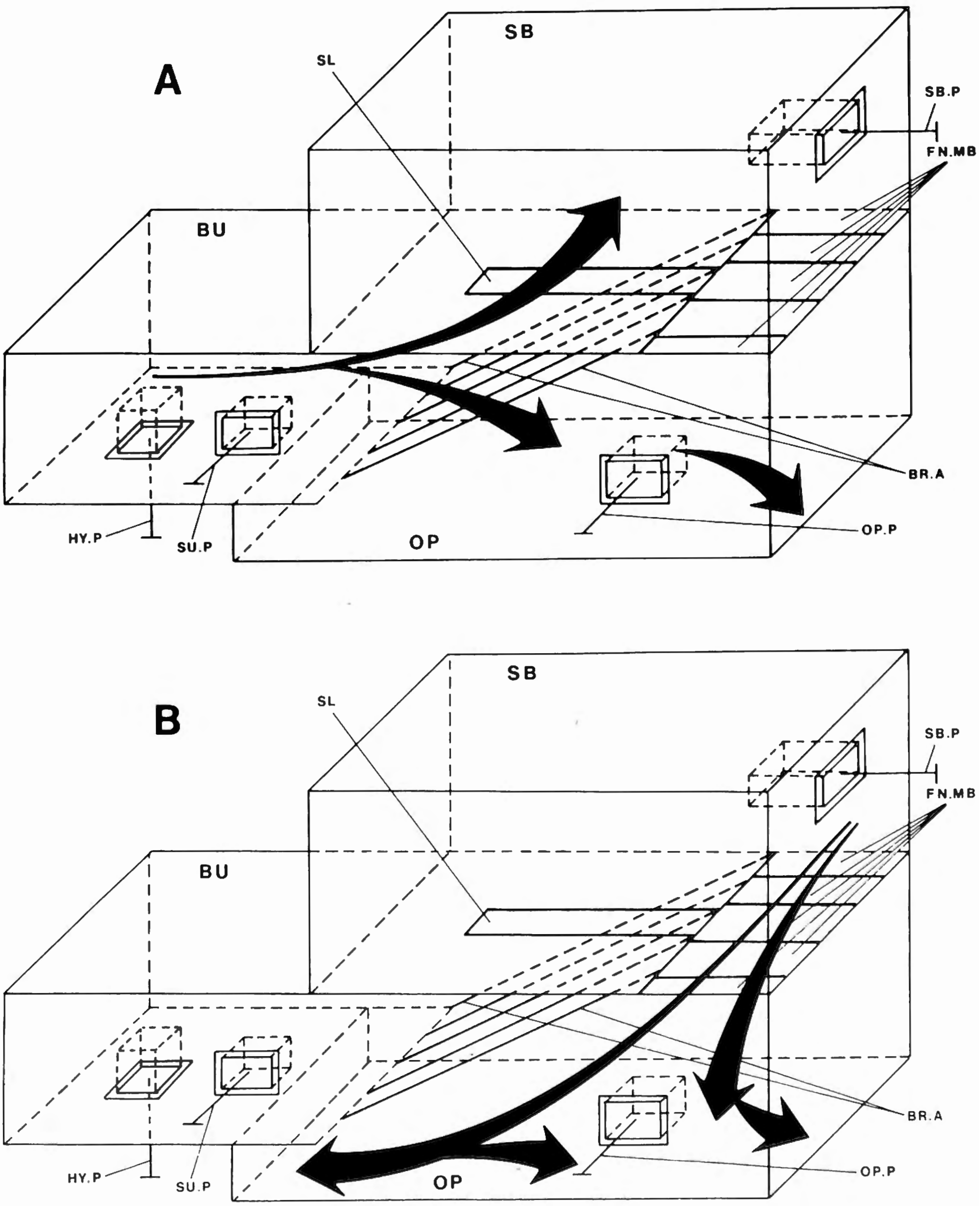

Fig. 4. — Diagram of the path of the air through the respiratory cavities in *Clarias gariepinus*. The proportions and shape of the structures are not respected. Muscular activities resulting in pressure changes in cavities are symbolized by pistons. A. Path of the air during inspiration,. B. Path of the air during expiration (BR. A : branchial arches ; BU : buccal cavity, FN. MB : fans and membranes ; HY.P : hyoidean piston ; OP : opercular cavity ; OP. P : opercular piston ; SB : suprabranchial cavity ; SB. P : suprabranchial piston ; SL : third branchial slit ; SU.P : suspensorial piston).

contraction of the posterior muscles of the suprabranchial cavities concomitent with the dilatation of the opercular cavities ; air flows between the fans which are easily pushed in that sense ; (3) while the fish keeps swimming upward, it adducts its opercles, it lifts and draws closer to each another its hyoïd bars so that air bubbles are emitted through the opercular slits. (4) The snout comes out of water, the mouth is open ; the fish lowers and abducts its hyoïd bars (HELLIN and CHARDON, 1983) so that air enters the mouth cavity ; somewhat later the opercles are abducted, so that the water that was contained in the buccal cavity flows down into the opercular cavities some air may pass to the opercular cavities too. (5) The fish closes its mouth, turns head down and starts diving. (6) Elevating the hyoid bars raises the pressure in the mouth cavity while opening the epibranchial part of the third branchial cleft, and dilatation of the suprabranchial cavities lets the air pass into the suprabranchial cavities ; this is helped by the higher hydrostatic pressure at the level of the buccal cavity. Passage of air into the opercular cavities is now prevented by opercles which explains the small bubbles escaping through the opercular slit ; the epibranchial part of the third branchial slits seems to be slightly open at rest, and to be closed only by the contraction of the obliquus communis muscle ; the dilatation of the suprabranchial cavities results from both the lowering of its ventral wall fastened to the epibranchials by the relaxation of its levatores branchiales muscles, and by the relaxation of its posterior muscles (for description of the branchial muscles, see HOLSTVOOGD, 1965). (7) The catfish reaches the bottom and lies on it ; water ventilation is possible through buccal and opercular cavities.

This interpretation of our data partially agrees with the incomplete hypotheses of MUNSHI (1976) and SINGH *et al.* (1982) but is mainly different about the way the air leaves the suprabranchial cavities.

The abnormal catfish is capable of respiration when resting on the bottom by opercular movements. It swims to the surface like normal fish do, but it seems not to be able to push much air into the suprabranchial cavities. This fact is related to the impossibility of elevating the hyoid bars. It clearly emphasizes the importance of the hyoid bars' movements in air breathing in *Clarias*. Inefficient aquatic and aerial ventilations explain death occurring several months after the disease is observed.

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