II. THE NATURE OF THE AIR-BREATHING ORGANS MET WITH AMONG INDIAN AIR-BREATHING TELEOSTS

Ever since the discovery of air-breathing habit among fishes, a number of investigators have published papers describing the morphology of the air-breathing organs. Carter (1931), Hora (1933), Anon (1939) and Das (1940) for instance, have given a detailed account of the structure and mechanism of accessory respiratory organs in a number of fishes. Das (1928_a, 1929, 1933, etc.) and Hora (1935, 1936, etc.), in addition to the papers mentioned above, have also published several other papers (cited in the bibliography) in which they have given accounts of the structures of the air-breathing organs in different Indian fishes. Recently a few more have been added to this list (e.g. Nayar-1951, Mathur-1953 and Kulkarni & Jaggi-1954). Descriptions of the accessory respiratory organs are also given in several text-books. So a full description of the air-breathing organs and their modes of action here would be superfluous. Only a brief account of the accessory organs which is relevant to the discussion on the different trends in the evolution of the air-breathing habit is therefore given here.

AERIAL RESPIRATION IN OCCASIONAL AIR-BREATHING TELEOSTS

It is observed that a number of habitual water-breathing teleosts resort also occasionally to air-breathing. Apart from

those occasional air-breathers, mention of which has been made by several authors, I have found this habit also in Notopterus kapirat (Lacep), N.notopterus (Pallas) and Macrones gulio (Ham.). No special respiratory devices as such seem to have been developed in these fishes. The air gulped through the mouth by these teleosts is retained inside the branchial chamber for some time and is then released to the outside through the opercular slits. The epithelial lining of the branchial chambers as well as the gills of these teleosts are possibly capable of breathing atmospheric air.

Kulkarni & Jaggi (1954), have recently observed occasional air-breathing habit in Megalops cyprinoides. Their studies have revealed that the air-bladder of this teleost is utilised for aerial respiration. The inner surface of this air-bladder has four well developed bands of highly vascular tissue. A distinct opening connects the pharynx with the air-bladder.

AERIAL RESPIRATION IN THE HABITUAL AIR-BREATHING TELEOSTS

The habitual air-breathing teleosts are found to raise their mouths above water periodically to breathe atmospheric air. There is a difference of opinion among several authors whether these teleosts die of asphyxiation, if prevented from breathing atmospheric air when they are placed in highly oxygenated waters. One thing is however fairly clear atleast under the normal

environmental conditions, that these fishes, if prevented from breathing atmospheric oxygen, die of asphyxiation.

The aerial respiratory organs observed in these fishes are of various types. In some forms, the aquatic respiratory organs are also capable of drawing atmospheric air. In some others, special accessory respiratory structures are developed in association with aquatic respiratory organs and the associated chambers. Still in some others, organs such as skin and the intestine which are primarily meant for functions other than respiration have been suitably modified and utilised for breathing atmospheric air also. The air-breathers have been therefore divided for the sake of convenience into three main categories depending on the nature of the air-breathing organs and their association with other parts of the body viz. (1) aquatic respiratory organs serving also as aerial respiratory structures, (2) aerial respiratory organs associated with aquatic respiratory equipment and (3) other parts of the body utilised for breathing atmospheric air in addition to their normal functions.

1. AQUATIC RESPIRATORY ORGANS ALSO SERVING AS AERIAL RESPIRATORY ORGANS

No marked organs of aerial respiration are observed in certain teleosts and it is believed that in such forms, the main organs of aerial respiration are gills themselves. The

gills of these forms serve a double purpose viz. for aquatic as well as aerial respiration. According to Carter & Beadle (1931) Hypopomus brevirostris and Symbranchus marmatus inhabiting the swamps of Paraguayan Chaco belong to this category. I believe, Haplochilus lineatus (Cuv. and Val.), an Indian fish in which no marked structural adaptations are found, uses its gills for breathing atmospheric air. This fish is always found swimming near the surface of the water and taking in a gulp of air, periodically.

According to Hora (1935), any respiratory epithelium can be used for aquatic and aerial respiration and gills of fishes are capable of sustaining life out of water.

The branchial chambers which are believed to be used for aerial respiration are usually spacious and their epithelial lining is highly vascular. In majority of fishes which resort to aerial respiration with the help of their branchial chambers, the opercular slits are narrow and obliquely situated. Those gobiids inhabiting sea-shores and estuaries belonging to the genera Periopthalmus and Boleopthalmus (Hora-1935, Das-1938 & 1948) which are popularly known as mud-skippers as well as certain other gobiids including Pseudapocryptes lanceolatus (Das-1933 & 1934) and Taenioides cirratus (Nayar-1951) belong to this category. Other teleosts which resort to this mode of aerial respiration are the hill-stream fishes (Hora-1922 & 1935) such as Amblyceps, Lepidocephalichthys and Acanthopthalmus, the rocky-shore fishes (Hora-1935) viz. Andamia, Salarias and

Petroscrites, the estuarine fishes Ophichthys (Pisoodonophis) boro (Das-1938 & 1940), Trypauchen vagina (Nayar-1951), the fresh-water Mastecembalus, Symbranchus (Nayar-1951) and many others. Possibly the gills of all these fishes are utilised for aerial respiration in addition to water-breathing (Hora-1935 & Das-1940).

2. AERIAL RESPIRATORY ORGANS ASSOCIATED WITH THE AQUATIC RESPIRATORY EQUIPMENT

2A. ORGANS ASSOCIATED WITH BUCCO-PHARYNGEAL CHAMBER

a. The epithelial lining of the bucco-pharyngeal chamber

The epithelial lining of the bucco-pharyngeal chamber of a number of air-breathing fishes is highly vascular. The estuarine eel Ophichthys (Pisoodonophis) boro is believed to breathe air chiefly through its bucco-pharyngeal chamber (Das-1940).

According to Rao (1938) many of the gobiid and certain blenniid fishes utilise bucco-pharyngeal chamber for aerial respiration in addition to the gill and branchial chambers.

b. Pharyngeal diverticulae

These are in the form of a pair of lateral shallow vascular depressions one on each side of the mid-dorsal line of the roof of the bucco-pharyngeal chamber above the gills.

Such structures are present in Periopthalmus koelreuteri found along the sea-shores (Das-1938 & 1940).

c. Pharyngeal pouches

These pouches (Fig.1) are situated in the pharyngeal region above the gill arches and extending backwards as far as the pharyngeal cleft. The inner lining of these pouches give out processes which are highly vascular. In adult

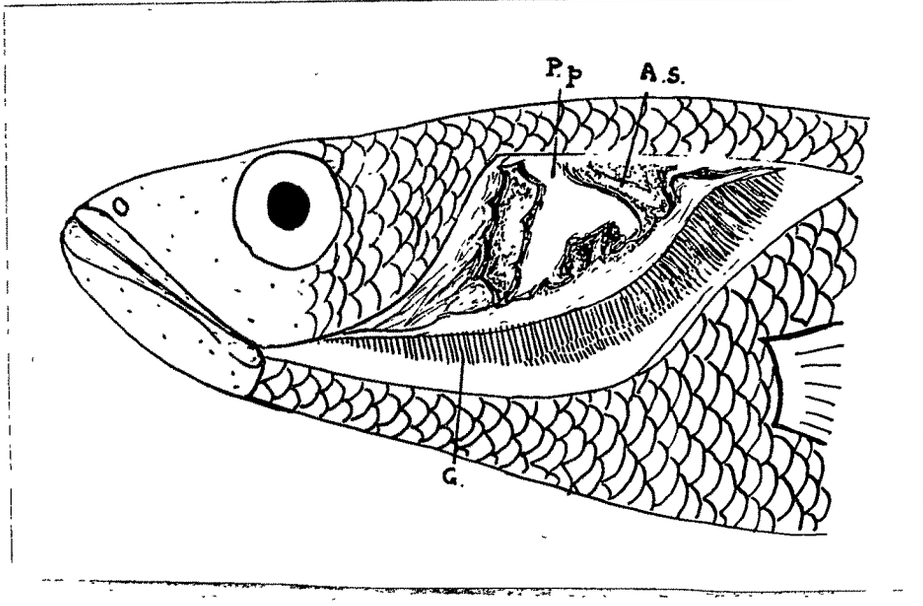

Fig.1. Pharyngeal pouches of Ophiocephalus.
A.S. - Accessory structures; G. - Gills; P.p. - Pharyngeal pouch.

condition the lining is thrown open into a number of ridges and grooves thus increasing the respiratory area. These accessory respiratory organs are found in fresh-water fishes belonging to the genus Ophiocephalus which are the most common Indian air-breathing fishes found in a variety of fresh-water habitats including pools, tanks and rivers.

d. Pharyngeal sacs

These are in the form of a pair of lung-like organs developed from the dorsal wall of the pharynx above the gills. The inner wall of these sacs are raised into numerous folds, the entire structure resembling superficially an amphibian lung. Each sac communicates with the bucco-pharyngeal chamber through an opening. The air which is admitted into these sacs is ultimately forced out through a single median opercular slit. The fresh-water fish Amphipnous cuchia (Hora-1935 & Das-1940) breathes air through the pharyngeal sacs.

2B. ACCESSORY RESPIRATORY ORGANS ASSOCIATED WITH THE BRANCHIAL CHAMBERS

a. Labyrinthine organs

These organs are found in special chambers developed above the gills and are formed by highly folded shelf-like plates situated above the gills (Fig.2). The

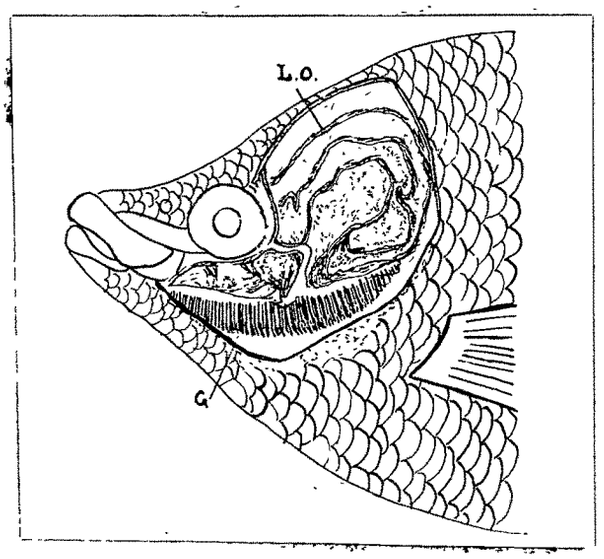

Fig.2. Labyrinthine organs of Osphronemus.

G. - Gills; L.O. - Labyrinthine organ.

epithelial lining of these plates is highly vascular. The fresh-water teleosts belonging to the family Anabantidae such as Anabas scandens, Osphronemus gourami, Macropodus cupanus, Trichogaster betta, etc. possess labyrinthine organs as organs of aerial respiration.

b. Arborescent outgrowths

These are tree-like structures (Fig.3) found in special chambers developed above the gills of certain

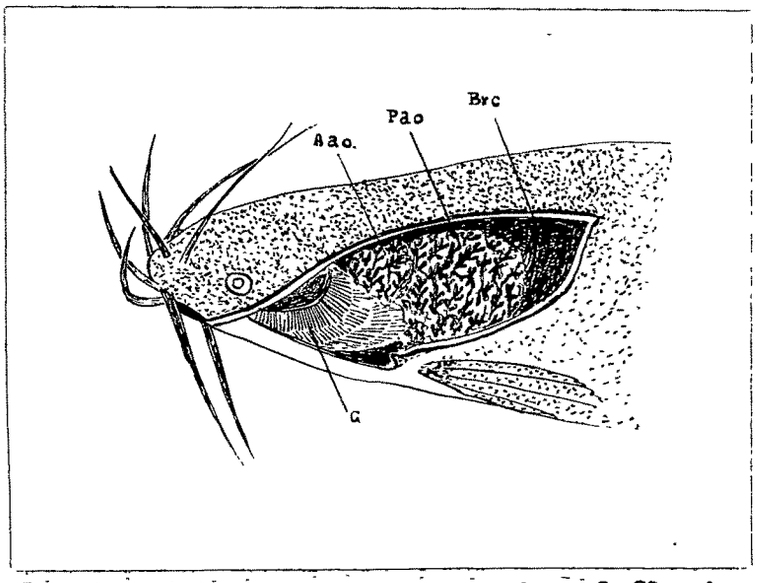

Fig.3. Arborescent outgrowths of Clarias.
A.a.o. - Anterior arborescent outgrowths; Br.c. - Gill chamber; G. - Gills; P.a.o. - Posterior arborescent outgrowths.

fresh-water cat-fishes viz. Clarius batrachus. They arise from the upper ends of the second and fourth gill arches. The anterior one developed from the second gill arch is small, while the posterior one developed from the fourth gill arch, is large.

In addition to the arborescent structures as described

above, highly vascular outgrowths project from the inner surface of the special chambers.

c. Opercular lungs

They are a pair of pulmonary sacs (Fig.4) present in the fresh-water Heteropneusteus (Saccobranchus) fossilis. Each of these sacs arises from the dorsal side of the branchial-chamber behind the gills and passes backwards through the body piercing the muscles on its side and extending as far back as the caudal region. The inner lining of the surface situated towards the posterior end of this sac is folded into a number of ridges and form structures comparable with the alveoli of the lungs of the frog.

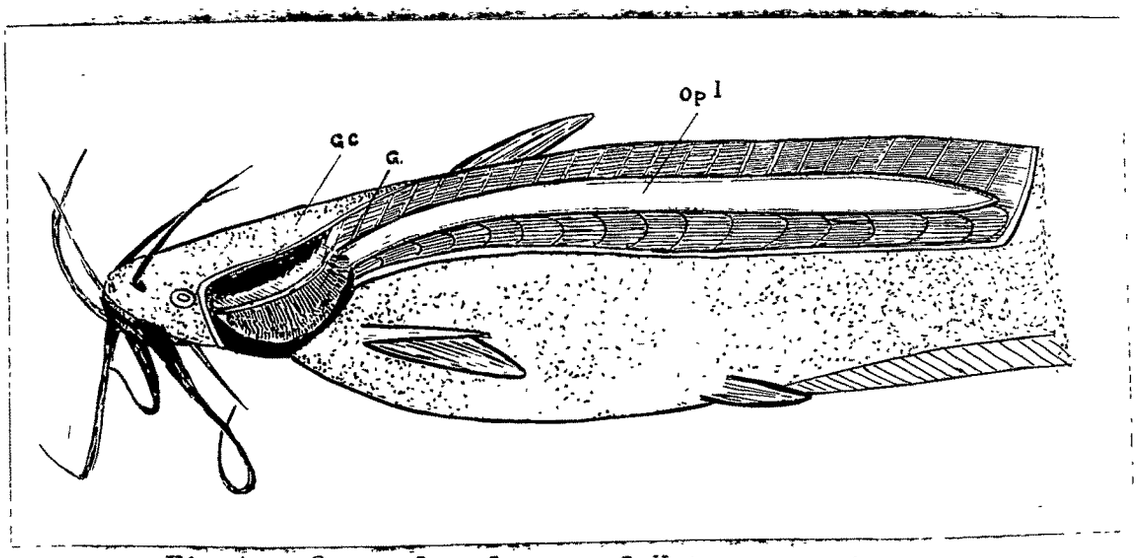

Fig.4. Opercular lungs of Heteropneusteus.
G. - Gills; G.c. - Gill chamber; Op.l. - Opercular lung.

3. OTHER PARTS OF THE BODY SERVING AS AERIAL RESPIRATORY ORGANS

a. The skin

The skin of those fishes which functions as an accessory respiratory organ is very slimy being lined by a thick mucous aqueous layer. The scales may be entirely absent in these forms or they may be minute and degenerate. It is believed that cutaneous respiration is very common among an estuarine eel Ophichthys (Pisoodonophis) boro and a fresh-water eel Anguilla bengalensis. Trypauchen vagina and Amphipnous fossorius are other skin-breathing fish according to Nayar (1951). Fresh-water siluroid fish Rita rita is another skin-breather (Mathur-1953).

b. The intestine

The investigations conducted by Das (1935 & 1940) reveal that Lepidocephalus guntea, a loach belonging to the family Cobitidae breathes air through the intestine. This fish takes in a gulp of air through the mouth and passes it on to the intestine, which is in the form of a simple straight tube. The air admitted into the intestine, is retained there for some time to enable gaseous exchange. The used up air ultimately passes out to the exterior through the anal opening by way of a series of air bubbles.

DISCUSSION

A survey of the air-breathing fishes and their accessory respiratory organs, shows that these fishes belong to different groups, and the different species live in a variety of habitats. The organs utilised by them for breathing atmospheric air also are of diverse nature. They may be the gills, the chambers associated with the aquatic respiratory passage, or special accessory respiratory organs developed in association with aquatic breathing organs or the respiratory passage. A few forms also utilise for breathing, organs such as skin and intestine the primary function of which is other than respiration.

CONCLUSION

From the above statements, it is seen that the air--breathing fishes are distributed over a number of families and inhabit both fresh-water and marine habitats and the organs of aerial respiration are of diverse types. It is also noted that an air-breathing fish may utilise one or more of the above mentioned devices for breathing atmospheric oxygen.

Two tabular statements one showing the representative genera of the Indian air-breathing teleosts and the other showing the various types of air-breathing organs and their occurrence have been given herewith.

1. Representative genera of the Indian air-breathing teleosts.

Name of the fish	Habitat	Authority
Symbranchidae		
Amphipnous	Fresh-water	
Symbranchus	- Do -	
Siluroidae		
Macrones	Marine	Das-1940
Clarias	Fresh-water	
Heteropneusteus	- Do -	
Amblyceps	- Do -	Hora-1935
Rita	- Do -	Mathur-1953
Muraenidae		
Anguilla	- Do -	
Ophichthys	Marine	
Cyprinidontidae		
Haplochilus	Fresh-water	George & Dubale - 1941
Clupidae		
Megalops	Marine	Kulkarni & Jaggi - 1954
Ophiocephalidae		
Ophiocephalus	Fresh-water	
Labyrinthici		
Osphronemus	- Do -	
Anabas	- Do -	
Macropodus	- Do -	

Name of the fish	Habitat	Authority
Gobiidae		
Apocryptes	Marine	Rao-1938
Periopthalmus	- Do -	
Boleopthalmus	- Do -	
Pseudapocryptes	- Do -	Das-1933, Hora-1933 etc.
Taenioides	- Do -	Rao-1938, Nayar-1951 etc.
Trypauchen	- Do -	Nayar-1951
Cobitidae		
Lepidocephalus	Fresh-water	Das-1935, 1936 etc.
Lepidocephalichthys	Hill streams (Fresh-water)	Hora-1921 & 1935
Acanthopthalmus	- Do -	- Do -
Blennidae		
Andamia	Rocky shore (Marine)	Hora-1935
Salarias	- Do -	- Do -
Petroscrites	- Do -	- Do -
Mastecembalidae		
Mastecembalus	Fresh-water	
Rhyncobdella	- Do -	

N.B. :- No references have been quoted for those fishes whose air-breathing habits are too well known.

2. The air-breathing organs and their occurrence among the Indian teleosts

Aerial respiratory organs

Associated with organs of aquatic respiration

Associated with bucco-pharyngeal chamber

1. Air-bladder
   e.g. *Megalops cyprinoides*
2. Epithelial lining of the chamber
   e.g. *Ophichthys*
3. Pharyngeal pouches
   e.g. *Ophiocephalus*
4. Pharyngeal depression
   e.g. *Periopthalmus koelreuteri*
5. Pharyngeal sacs
   e.g. *Amphipnous cuchia*

Associated with branchial chamber

1. Gills
   e.g. *Haplochilus lineatus*
2. Epithelial lining of the chamber
   e.g. *Periopthalmus*, *Andamia*, etc.
3. Labyrinthine organs
   e.g. *Anabas*, *Osphronemus*, etc.
4. Arborescent outgrowths
   e.g. *Clarias*
5. Opercular lung
   e.g. *Heteropneusteus*

Other parts of the body modified for respiration

1. Skin
   e.g. *Anguilla*, *Trypauchen*,
2. Intestine
   e.g. *Lepidocephalus guntea*