Diverse Structural Modifications of Hill Stream Catfishes of Northeast India: A Comprehensive Understanding Rendered by Innovative Scientific Techniques

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Abstract—*Northeastern India comes under the Eastern Himalaya Freshwater Biodiversity Hotspot. The region being mainly a mountainous terrain with numerous hill streams and rivers harbour as many as 129 species belonging to 39 genus and 10 orders of catfishes. Among them, the family Sisoridae exhibits the maximum diversity in the structural modifications for hill stream adaptation. Modern taxonomy is in a state of flux, and certain aspects of structural modifications we considered known some decades ago are being refined with new scientific advancements. In the present account, modifications which are manifested in the form of thoracic adhesive apparatus, paired fins with laminated pads on its ventral surface, asperous skin, oromandibular structures are studied in detail in the genus Exostoma, Glyptothorax, Myersglanis, Pseudecheneis, Pseudolaguvia, Oreoglanis using Environmental Scanning Electron Microscopy (ESEM) recordings. The study reveals the presence of different types of unculi on the special adhesive devices especially important for swift-water inhabiting siluroids. For the genus Glyptothorax, SEM recordings are made for different shapes of thoracic adhesive apparatus. Other features, viz., reduced eye, slender caudal peduncle, skin tuberculations, etc. are examined in the genus Akysis, Amblyceps, Bagarius, Erethistes, Hara, Olyra, Peudecheineis. Having studied the possible functions of the structural modifications as means of adhesion, mechanical protection and hydrodynamic effects, and understanding the mode of life, the study also provides a room for better planning for their conservation by way of habitat preservation, restoration etc.*

1. INTRODUCTION

The diverse structural modification shown by catfishes inhabiting hill streams is one of the most striking myriads of special adaptation shown among organisms. North-East India comes under the Eastern Himalaya Freshwater Biodiversity Hotspot and with its numerous mountain torrents, the region serve as a home to numerous hill-stream catfishes with special adaptive features. Adaptation is the process wherein individuals, populations or species change with vivid manifestation of various structural modifications to cope with their environment or changes in that environment.

Notably, after Carolus Linnaeus's most innovative work on binomial nomenclature in 1735, which provides an overall framework of classification, modern taxonomy is in a state of flux. Though considerable advances were made in the study of animal adaptations in recent years to different types of environment, yet more indepth study using the technological advances of the twenty first century has refined the ideas and knowledge assumed to have known some decades ago. The invention of the light microscopy led to the refinement of studies underlying histochemical nature of various organs involved in hill stream adaptation. High resolution surface topography of the modified organs has been studied using scanning electron microscope (SEM), the most significant innovations of all. Even microscopic structures thought to have no clearly visible external characteristics display a huge variety of shapes and characters under the revealing gaze of the scanning electron microscope.

Hora [5-7] made various studies on torrential fishes with respect to their adaptive modifications in response to a life in the swift current and rocky substratum. In his work he studied *Erethistes, Glyptosternum, Pseudocheneis* and *Glyptothorax* under the Siluroids. A lot of comprehensive studies were made for the adhesive apparatus of Indian sisorids in *Glyptothorax telchitta* [1], *G. pectinopterus* [10], *Pseudocheneis sulcatus* [12]. These studies were limited only to only histological studies based only on light microscopy. SEM studies for hill stream catfishes for the study of adhesive apparatus and other modifications of skin were undertaken [13, 2, 9].

The present paper deals with the various forms of adhesive apparatus with different types of unculi, asperous skin, oromandibular structures, gill opening and branchiostegal rays, reduced eye, slender caudal peduncle etc. which are important structural modifications for hill stream mode of life with the aid of light and scanning electron microscopy. Overall, this study helps in understanding the mode of life of hill stream fishes with a light on planning for preservation and restoration of their pristine habitat.

2. MATERIALS AND METHODS

Fishes were collected from different hill streams of northeast using cast nets, electro-fishing equipment and various methods used locally. Fishes so collected were fixed in 10% formalin and preserved in 70% ethanol. The specimens were deposited in the Manipur University Museum of Fishes (MUMF) and are used for study. The preserved specimens were identified using morphological and meristics counts under stereo zoom light microscope following [11]. For SEM study, the selected specimens in preservative were cut into 1 sq cm and observed and photographed under Environmental Scanning Electron Microscope (ESEM) Quanta™ 250 FEI.

3. RESULTS

As many as 129 species belonging to 39 genus and 10 orders of hill stream catfishes from northeast India have been documented. The family Sisoridae shows maximum diversity in the structural modifications for hill stream adaptation. The study reveals the various hillstream modifications which enable the catfishes to prevent themselves from being washed away by the fast flowing current of water and adapt to the extreme environment. The modifications include external form and size, position of the eye, gill-openings, branchiostegal rays and membranes, oromandibular structures. This study helps in understanding the mode of life in hill streams.

3.1. External form and size

In *Glyptothorax, Oreoglanis* and *Pseudecheneis,* the head and body are greatly flattened, with the ventral profile becoming straight and horizontal throughout and the dorsal profile slightly arched. The head is usually small and semicircular and the snout is trenchant.

a

b

Figure 1. a. ***Glyptothorax*** **b.** ***Erethistes***

In species like *Akysis, Erethistes, Hara, Pseudolaguvia* species are relatively small which gave them more advantage for hill stream mode of life.

3.2. Position and size of eye

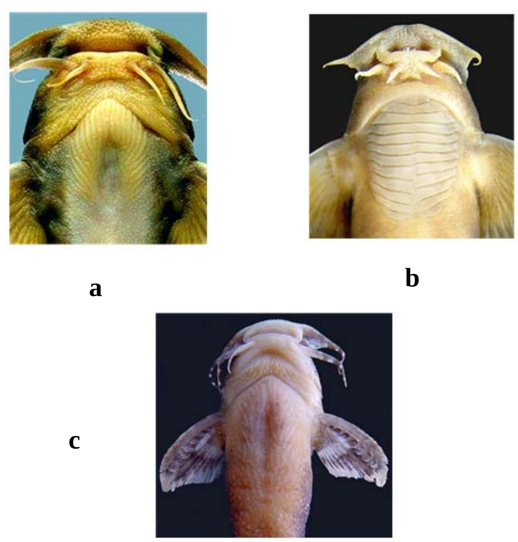
In forms like *Amblyceps, Exostoma, Glyptothorax, Myersglanis, Pseudecheneis,* species, the eyes are located on the dorsal surface and are place closed together. Besides this, the eyes are much reduced in size.

3.3. The gill-openings, branchiostegal rays and membranes and oromandibular structures

The gill openings in these fishes are restricted to the sides and are much reduced. In species like *Glyptothorax, Oreoglanis* the gill openings are situated just above the pectoral-fin base with short narrow passage from the interior of the gill chamber to the exterior. The branchiostegal rays are much reduced since there is reduction in the gill openings and also the mouth is shifted backwards.

3.4. Various forms of thoracic adhesive apparatus

In *Glyptothorax* and *Pseudecheneis,* for adhesion purpose, thoracic adhesive apparatus is present. The thoracic apparatus in *Glytothorax* are of various shapes. It can be of chevron, rhomboidal, elongate ovoid, elliptical, oblong shapes. In *Pseudocheneis* the ridges in the thoracic adhesive apparatus are arranged as horizonatal folds of skin. In *Pseudolaguvia*, the ridges are arranged longitudinally and extend much beyond the posterior base of pectoral fin base.



a b

c

Figure 5 a. Glyptothorax b. Pseudecheneis c. ***Pseudolaguvia***

3.5. Paired fins with or without plicae

The ventral surfaces of the first and adjacent fin rays of paired fins in *Glyptothorax, Pseudecheneis, Oreoglanis* bears plicae.

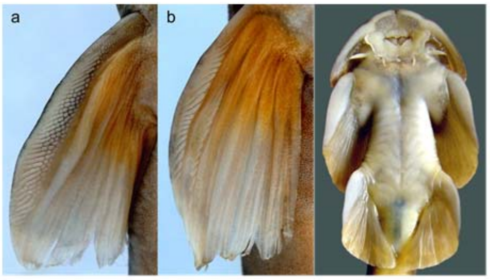


Figure 6 a & b. *Glyptothorax*   *c. Oreoglanis*

3.6. The caudal fin and its peduncle

There is general tendency amongst hill-stream fishes to possess a long, narrow, band-shaped caudal peduncle as in *Glyptothorax, Pseudecheneis, Conta* species. As for the fins, the chief modification consists in the inequality of its lobes. In most cases the upper lobe is somewhat longer than upper as in *Glyptothorax*. In *Sisor*, the caudal fin is modified as a whip-like tail. In *Pseudolaguvia* and *Pseudecheneis*, the caudal peduncle becomes much slender.

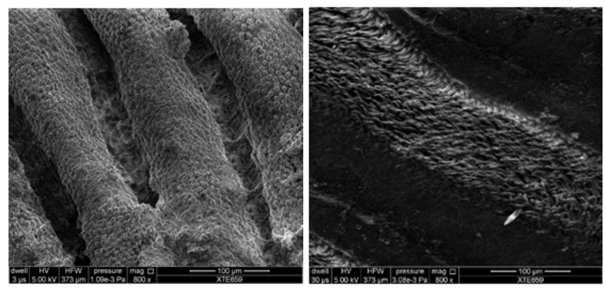
a

b

Figure 7. Different shapes and sizes of caudal fin and caudal peduncle. a. *Sisor* and b. *Pseudolaguvia*.

4. SEM STUDIES

The SEM study of thoracic adhesive apparatus in five *Glyptothorax* (Figures. a-e) and one each of *Pseudecheneis* (Figure. f) and *Pseudolaguvia* (Figure. g) revealed different types of unculi. In *G. cavia* and *G. pantherinus* the unculi are globular structure and are very densely packed while in *G. jayarami*, *G. rugimentum* and *G. clavatus*, it is loosely packed and much elongated, hook shaped with tip of each unculi curved and pointed. Unculi are long, slender and posteriorly directed in *Pseudecheneis koladynae* and *Pseudolaguvia shawi*. Similar unculi which are densely packed also occurs on the laminae of pectoral fin of *Exostoma* sp. and *Myersglanis* sp. with the exception that the unculi present on the inner side laminae of *Exostoma* sp. are globular shaped. (Figures. h-i). Tubercles in *Myersglanis* sp. are unculiferous which are posteriorly directed and in *Glyptothorax clavatus* the tubercles are triangular shaped with single median plaque bearing median ridge (Fig. j-k). High surface topography of oromandibular structures are studied using ESEM observations of *Exostoma* sp., *Glyptothorax clavatus*, *Myersglanis* sp. and *Pseudecheneis koladynae*. The observation shows the presence of stony unculi and taste buds in the barbels of *P. koladynae* (Figure. l), unculiferous papillae with open sensory pores on the upper lip of *G. clavatus* (Figure. m) and also different types of teeth and unculi present along the mouth and barbels of *P. koladynae*, *Myersglanis* sp. and *Exostoma* sp. (Figures. n-p).



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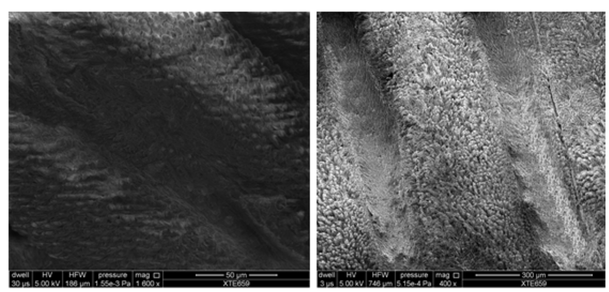

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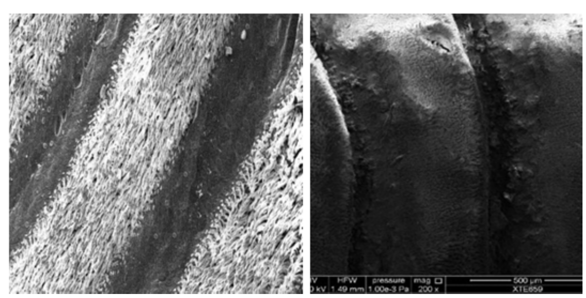

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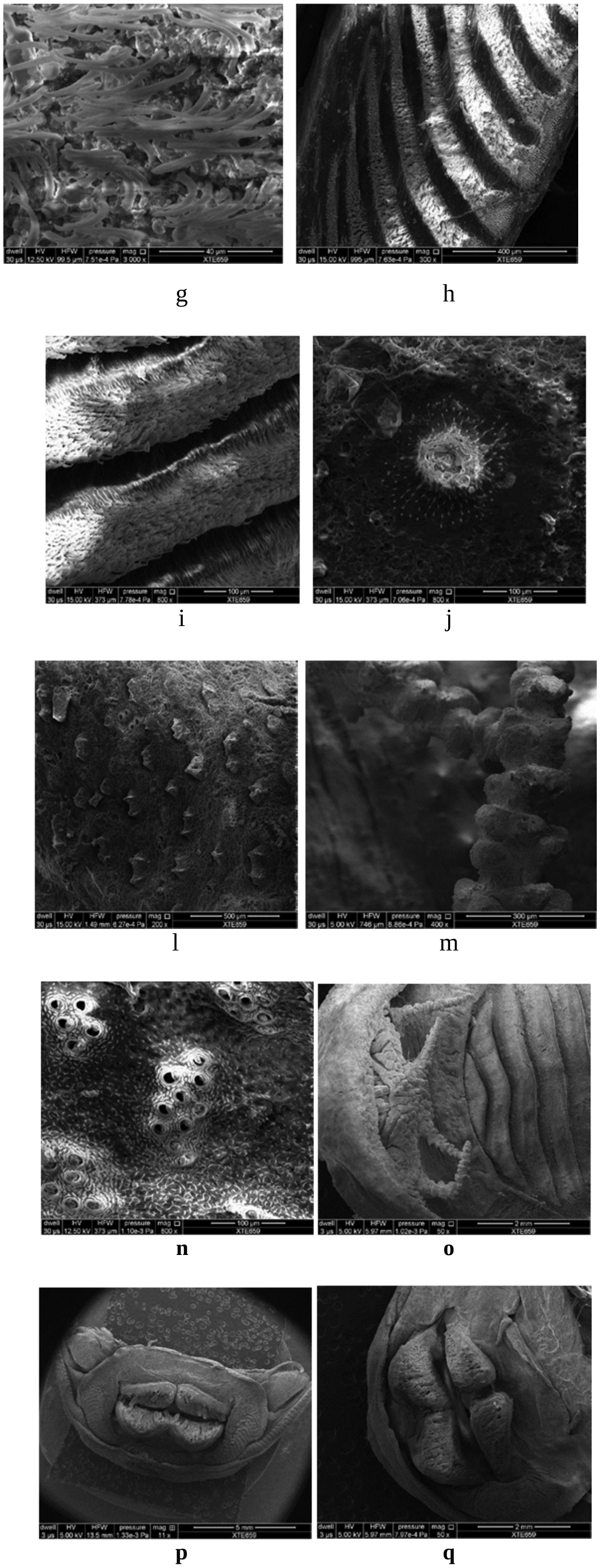

Figure 8. SEM micrographs showing various forms of structural modifications in hill stream catfishes of Northeast India. A-G. Different types of unculi in the thoracic adhesive apparatus of *Glyptothorax cavia, G. jayarami, G. pantherinus, G. rugimentum*, *G. clavatus, Pseudecheneis koladynae, Pseudolaguvia shawi.* H-I. Unculi in the plicae present under the ventral surfaces of *Exostoma* sp. and *Myersglanis* sp. J-K. Plagues and tubercles bearing unculi on the skin of *Myersglanis* sp. and *Glyptothorax clavatus.* L. Taste buds on the barbels of *Pseudecheneis koladynae*. M. Unculiferous papillae with open sensory pores on the upper lip of *Glyptothorax clavatus*. N-P. Oromandibular structures in *Pseudecheneis koladynae*, *Myersglanis* sp. and *Exostoma* sp.

5. DISCUSSION

The hill stream fishes can be divided bionomically into two broad groups other than their taxonomic group namely temporary inhabitants which comprise those forms that migrate upstream at certain periods of their lives for spawning and use muscular effort without showing special adaptations to that extent. The second group are the permanent residents of the streams and of still smaller torrents and many exhibit extreme adaptations [5]. Siluroids come under the second group with family Sisoridae representing the maximum number among catfishes adapted for hill stream mode of life. This is attributed partly to the bottom-dwelling nature of the sisorids where there is greater diversity of food available and also to the diverse microhabitats with different types of substratum.

The shape of the body depends upon the strength of the current and any deviation from the characteristic form of the fish is directly proportional to the rate of flow of water. Thus, the form of those fishes that live in places where the intensity of the flow is intermediate between that of sluggish stream and of a hill-torrent is almost cylindrical, as in *Amblyceps* whereas those in places with great intensity it is variously modified as in *Glytothorax.* Small size is a distinct advantage in hill streams, firstly because the streams are small and secondly because small forms can find more shelter under pieces of rocks and stones during floods as in the case of *Erethistes* species (Jayaram, 2006). With the flattening of the form in hill-stream fishes the eyes are more and more pushed towards the upper surface. In forms like *Amblyceps*, *Glyptothorax*, *Pseudecheneis, Glyptosternum* species, the eyes are located on the dorsal surface and are placed close together. Besides this change in position, they are much reduced in size mainly because of the intensity of the light in the clear shallow waters of the hill-streams.

With the employment of the under surface for the purpose of adhesion to rocks and stones, the gill openings are generally restricted to sides. The greatest modification as regards this character has taken place *Glyptosternum* species like *Oreoglanis*. In these the gill openings are situated above the base of the pectoral fin and there is a short narrow passage from the interior of the gill-chamber to the exterior. It is natural to oppose respiration in some extent, with the restriction of the gill-opening to the sides. Moreover, when a fish is feeding on the algal slime, the under surface of the head and the body are firmly and closely applied to the rock to which it may be clinging at the time, and this also will make respiration difficult. But respiration is helped in hill stream catfishes since the water in the hill stream is better oxygenated and is purer than that of a sluggish stream in. Also, by reducing the gill-openings, the fishes are enabled to retain water in their gill chambers for a comparatively longer time. Lastly, the inner rays of the pectoral fins are held in constant motion due to which the blood remains oxygenated in the rays and water is forced in and out of the gill-opening. With the reduction of the gill-openings and the backward shifting of the mouth on the under surface considerably behind the tip of the snout, the branchiostegal rays and membranes are greatly reduced.

The wide range manifestation of modifications in the form of thoracic adhesive apparatus, paired fins with laminated pads on its ventral surface, asperous skin, oromandibular structure enable the hill stream catfishes to survive in extreme habitat ranging from rocky bottom surface to turbulent. Above these, the scanning electron microscopic observations shows the importance of unicellular horny projections in the form of unculi on the mouth parts, paired fins, adhesive apparatus and plaques or tubercles. Unculi are highly variable in shape and surface texture, with frequently hook-shaped or curved and posteriorly directed evidently facilitate rasping or adhesion by increasing the roughness of the skin. The characteristic rough texture in most of the sisorids is due to ridged unculiferous plaques or unculiferous tubercles covering virtually the entire external surface of the head, body, fins and even barbels of these catfishes. These structures provide protection against wear and tear, providing hardness, durability and also mechanical strength.

The diversity of the siluroid mouth parts depends largely on the unculiferous surfaces which work against each other or against the substrate during feeding or adherence. Sense of taste is an important property in fish for distinguishing a variety of food available to them in the aquatic environment [4]. The presence of large number of taste buds on the labial folds and barbels enhance the ability of the fish to locate food accurately in a particular feeding zone and sense the chemical nature of the surrounding too. The presence of such sensory structures in the snout may compensate for reduced eyes in hill-stream catfishes and the consequently restricted visibility in muddy turbid water.

The ability of bottom dwelling siluroids to inhabit swift-flowing mountain streams involves the development of unculiferous adhesive pads on the ventral surface of their head, abdomen and paired fins. The prominence of unculiferous pads on the paired fins suggest that the fin specializations characteristic of there rheophilic bottom-dwellers could not have evolved in their absence. The creeping and crawling locomotion, stone clinging behaviour might not be possible without the large unculiferous adhesive pads on its expanded pectoral fins, pelvic fins and also on the thorax in *Glyptothorax*, *Pseudecheneis* and *Pseudolaguvia*. Unculi often work in conjunction with a suction device [13]. The well-developed adhesive pads on the ventral surface of the paired fins, in addition to providing adhesion, helps in acting as a seal for the suction device, possibly the seal is enhanced by suction or seizing due to exit of water from the interradial grooves between unculiferous pads.

Judging from the key role played by the various structural modifications in the adaptation of hill stream catfishes living in swift currents, it is proved that the hill stream siluroids could not exist in the extreme environment without them. Even though there is high diversity of hill stream catfishes with unique adaptive features, their survival and sustenance have become difficult due to the high degree of threat and exploitation in the form of habitat destruction, flow modification owing to construction of dams, over exploitation, water pollution, invasion by exotic species and global warming [3]. So it is of utmost importance to implement proper planning and conservation strategies of their habitat since these fishes can thrive only in that particular habitat. At this age, where exploitation is taking at a faster pace than exploration, conservation has become an exigency and before it is too late habitat restoration and conservation programmes should be implemented only with proper communication, co-operation, understanding and awareness among the politicians, scientists, nongovernmental organizations and the common people in a more wholesome manner.

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