Chapter 1
A COMPARATIVE SURFACE-ARCHITECTURAL STUDY OF “GENERAL BODY EPIDERMIS” OF THE HILL-STREAM FISHES; BOTIA ALMORHAE, HOMALOPTERA BRUCEI AND SCHIZOTHORAX RICHARDSONII.
The last common ancestor of fish and mammals is probably more than 350 million years old if one considers this to be the lungfish and more than 420 million years in the case of the Zebra fish. Despite this enormous temporal divide in evolution, fish skin shows architectural similarities with that of mammals, even though it follows specific construction principles that are perfectly adapted to aquatic life: similar to the epidermis of terrestrial vertebrates such as mice or man, the fish epidermis is a multilayered tissue that is separated from the dermis by a distinct basement membrane (Henrickson and Matoltsy, 1968). It is, however, generally a mucus and not a keratinized system. This evolutionary achievement is linked with important features of fish skin: a stratified mucogenic epidermis and alpha-keratogenic potential. In striking contrast to mammals, a cornified cellular envelope is restricted to specific body regions (e.g. the barbel) or found only in some teleosts such as, e.g. *Periophthalmus* or the *Syngnathidae* (sea-horses),
which have some cornified adaptations. This is because the epidermis of fish usually does not contain proteins connected with interkeratin matrices and corneous cell envelope formations (filaggrin, loricrin).

The hill-stream fishes; B. almorhae, H. brucei and S. richardsonii are very well adapted to some specialized conditions of their life in torrential environment where velocity of water current is different for these three fishes.

B. almorhae is a generally peaceful, robust loach that is regularly available. They should be kept in a group of their own species. Water movement is an intrinsic part of their natural habitat.

H. brucei inhabit fast flowing streams under boulders and stones. H. brucei need excellent water flow and aeration, numerous rocky hiding places and smooth pebbles and boulders to graze over.

S. richardsonii is an inhabitant of the fast flowing cold water streams. This fish has a wide range of distribution but is only present in the cold water.

Sehgal, 1988 and 1990 identified several zones in torrential streams on the basis of dominant fish species and hydrological features which further depend upon the elevation: (i) head water zone inhabited by reophilic species of loaches and catfishes (Nemacheilus gracilis, Nemacheilus stoliczkae and Glyptosternum reticulatum), (ii) large-stream zone, formed by head-water streams, inhabited by
*Diptychus maculatus* and *Nemacheilus spp.* In the upper reaches or the most torrential reaches of this zone, reophalic species of the snow trouts *Schizothoraichthys spp.*, *Schizothorax spp.* and *Schizothephygopsis spp.* occur. The intermediate reach of the large stream zones is frequented by *Schizothorax spp.* The least rapid reaches of this zone are occupied by *Garra gotyla* and *Botia almorhae* (iii) slow moving meandering zone is inhabited by a large number of cold to eurythermal species such as *Barilius spp.* and *Tor spp.*., Cat fishes, Homalopterid fish (*Homaloptera spp.*) and snake heads *Channa spp.*

The hill-stream fishes are very well adapted to some specialized conditions of their life in the torrential environment where turbulent flow over rough substratum (rocks, boulders, cobbles and pebbles) of the stream is a feature, directly related to the degree of slope or gradient and elevation.

Hill-stream fishes can be defined as the fishes which inhabit the waters of high altitude streams with adaptive modifications to thrive in the prevailing habitat conditions. The family Cyprinidae is the largest and the most dominant and of immense economic value with the maximum number of endemic species (97 species), followed by the family Balitoridae (46 species) and Sisoridae (21 species).
The sub-Himalayan streams and rivers of India are known to be inhabited by a number of teleost fishes specialized for living in rapids (Day, 1958; Jayaram, 1981). Ecologically, these are perennial shallow-water bodies, characterized by low water temperature, high turbulent current and sandy-rocky substratum (Das and Nag, 2004). In order to thrive against the adverse habitat situations, many species show a number of unique adaptive specializations. Fishes are invariable living components of water bodies. These are important aquatic fauna serving as food, entertainment, biological control agents, animal feed, manure, decoration, sports etc to human beings from time immemorial.

Fishes living in hill-streams show several important modifications and may be conveniently divided into two groups. The members of one group are temporary inhabitants of the hill-streams and migrate upwards only at certain periods of their life for specific purposes such as spawning. These species move up by muscular effort and do not exhibit special modifications. Members of the other groups live permanently in the rivers and streams of the hills and many of them possess genera of two families. Family Cyprinidae: Garra, Balitora, Bhavinia, Psilorhynchus, Parasilorhynchus, Schizothorax, Barilius, Nemacheilus, Barbus (tor) and Crossocheilus. Family Sisoridae: G. pectinopterus and P. sulcatus.
The Cyprinid fishes in the hill-streams of India are represented by the genera belonging to the families Cyprinidae, Cobitidae and Homalopteridae. These fishes show a remarkable uniformity in their body contours. Dorsally their body is slightly arched, while ventrally it is usually flat from snout to anus.

Most species of the genus *Homaloptera* live in fast flowing waters to which they have adapted by developing a depressed body, a flat belly and pectoral and pelvic fins inserted and expanded laterally. The epidermis is a system that forms the border between the body of the biological object and the environment. Traditionally it is considered as a structure devoid of any physical or physiological features, important for the life of an organism. The remarkable abilities of fish are exhibited through their adaption to hill-streams, where the strength of water current is extremely high and the general body epidermis (GBE) is modified according to its role (Joshi, 2010). The superficial epithelial cells remain metabolically active and secrete an extra cellular coat (Whitear, 1970). Various cellular components of the epidermis of fishes vary in abundance and dimensions, between species. This may be related to the mode of living of the fish and its response to the environment. Among the numerous functions of the skin, none is more important than protecting the organism from environmental hazards even while maintaining it in uninterrupted communication with the environment. The
epidermis or the outer thin layer of integument situated as it is in contact with the external environment, forces the assumption that the epidermis must serve as a buffer between the host and the environment. Indeed, the epidermis serves in many ways to protect the organism from the variety of noxious agents and to maintain the constancy of the internal milieu. It protects the body from microbes, from injury to delicate inner tissues, from the injurious effects of chemicals and from damage by the ultraviolet radiation of the sun and also helps as a thermo-regulator for the normal internal physiological functions. The remarkable ability of the epidermis to adapt to its surroundings, accounts not only for the seemingly endless structural and functional differences between the various species but also for certain basic patterns common to all.

Studies of fish skin have indicated that epidermal cells following separate pathways differentiate in different fishes. In most of the fishes the epidermis is related more to the deposition of slime over its surface and undergoes the process of mucogenesis and in some the epidermal cells undergo the process of keratinization forming a layer at the surface (Mittal and Banerjee, 1979). In general, there are two developmental potentials in the epidermis of vertebrates including fish, one related to keratinization and the other to mucogenesis.

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The live fishes viz. *Botia almorhae* (Teleostei: Cobitidae), (approximately 5-7 inches in length) were collected from the Kosi river at Kakrighat of Distt. Nainital (elevation- 1200 m. above mean sea level), *Homaloptera brucei* (Teleostei: Balitoridae), (approximately 3-4 inches in length) from West Ramganga at Chaukhutia in Distt. Almora (elevation-1200 m. above mean sea level) and *Schizothorax richardsonii* (Teleostei: Cyprinidae), (approximately 6-8 inches in length) from the Kosi river at Hawalbagh in Distt. Almora (elevation- 1194 m. above mean sea level) Uttarakhand. The water current is very fast having the velocity between 0.5 to 2.0 m/sec. (Bhatt and Pathak, 1991) and the river bed is rocky.

The fishes were transferred from the site of collection to the laboratory in well ventilated plastic containers and were kept for a period of about 5-6 days in glass aquaria having an artificially prepared rocky bed with aquatic vegetation.
grown therein. The aquaria were cleaned and supplied with fresh spring water on alternate days. The fishes were fed on aqua feed (tropical fish food).

To study the details of the morphological adaptations in some fishes, SEM was done. The following procedure was adopted for the preparation of the specimen for SEM.

The specimen was maintained in laboratory at 25±2°C. The fishes were cold anesthetized following Mittal and Whitear, 1978, for SEM preparation. Skin fragments of about 10×10 mm were cut from their dorsal sides just behind their heads. Tissue were excised and rinsed in 70% ethanol with one change of saline solution to remove debris and then fixed in 3% Glutaraldehyde in 0.1M phosphate buffer at pH 7.4 over night at 4°C in a refrigerator. The tissues were washed with 2-3 changes in phosphate buffer and dehydrated in ascending series of ice cold Acetone (30%, 50%, 70%, 90% and 100% approximate 20-30 mins.) and dried at critical point using a critical point dryer (BIO-RAD England) with liquid carbon dioxide as the transitional fluid. Tissues were glued to stubs, using conductive silver preparation (Eltecks, Corporation, India). The samples were coated with gold using a sputters coater (JFC 1600) and examined under (JEOL, JSM- 6610 LV) scanning electron microscope and the images were observed on the screen.
The aim of the present study is to provide a basis for better knowledge of the surface architecture of the GBE of some hill-stream fishes. The skin of the hill-stream fishes, on the dorsal surface of the body just behind the head, is densely set with scales and composed of an epidermis and a dermis supported by a hypodermis. Each scale is covered externally by the epidermis which reach the posterior free margins transversing a short distance on its inner surface and then continue to the outer surface of the underlying scale. The skin covering the general body surface of *B. almorhae*, *H. brucei* and *S. richardsonii* is rough and provided with a large number of scales. These are minute, poorly developed and hardly overlap in *H. brucei*. The thickness of epidermis is, however, almost uniform at different parts of the scales in *H. brucei*. The surface of the mucogenic epithelium of the GBE is covered by irregular polygonal epithelial cells of varied dimensions. The epithelial cell is characterized by the presence of microridges with the microridges forming different patterns in these fish species.
In *B. almorhae* the entire external body surface is covered by minute scales (Fig.8 and 9). The polygonal epithelial cells are present in the GBE of *B. almorhae* (Fig.10 and 11). The epithelial cells bear numerous short, sinous and branched interwoven microridges (Fig.12 and 13). The epithelial cells bear microridges and are commonly associated with mucus secreting cells, the mucous cells, which are scant in number (Fig.14). The functional significance of microridges has been considered to be related in the spreading of the mucus from mucous cells.

The skin covering the general body surface of *H. brucei* is rough and provided with a large number of scales (Fig.15 and 16). The polygonal epithelial cells are present in the GBE of *H. brucei* (Fig.17); the free surface of the epithelial cells is differentiated into microridges, forming characteristic patterns. The epidermal cells covering the skin surface are intricately patterned with microridges. The microridges on the surface of the epithelial cells generally have a finger print-like structure (Fig.18). The mucous cell apertures are rare comparatively and occur at the border of three or four epithelial cells (Fig.19).

It is interesting to note the presence of epidermal elevations (Fig.20, 21 and 22), of the tubercles. The breeding tubercles are keratin-based epidermal nodules. A large number of tubercles are found on the epidermal surface of *H. brucei*, these
tubercles exist in a well designed pattern. The epithelial cells of each tubercle develop into unculi (Fig.23).

In *S. richardsonii*, the general body surface has a rough covering of small scales (Fig.24). The polygonal epithelial cells are present in the GBE of *S. richardsonii* (Fig.25 and 26) but the free surface of the epithelial cells is differentiated into microridges, forming characteristic patterns. The finger print-like patterns of microridges are often found on the surface of epithelial cells where maintenance of a protective layer of mucus is advantageous (Fig.27). The epidermis is a multipurpose tissue, although its secretory function is dominant. The mucous cells, though distributed throughout the epidermis are, in general, concentrated mainly on the outer layer of the epidermis, often releasing their secretory contents profusely at the surface through small pores (Fig.27). Microridges form the canaliculi that help in the quick spread of mucus (Rumana, 2001). The microridges are often interconnected with fine transverse connections, the microbridges (Fig.28). The mucus secreted by the mucous cells over the skin performs a wide variety of functions. We concentrate here mainly on its role in adapting the fish to its peculiar mode of life in the mountain torrents.
The skin has long been recognized to protect the organisms from deleterious environmental impacts (physical, chemical, microbiological). It is also well-known to be crucial for the maintenance of temperature, electrolyte and fluid balance.

The first and most basic function of the integument is to set up a boundary between the organism and the environment. It provides the scaffold that originally defines the form of the animal. It sets up as a mechanical as well as chemical barrier for protection of the organism from the harsh environment.

The second function likely to it performs is sensory. Organisms have to feel the environment and make appropriate responses for their survival. Although, organs dedicated to specialized sensory functions soon evolve, the skin retains its major sensory function even today. Reflex responses to heat and other ominous stimuli from nerves to the spinal cord are essential for the survival of living organisms.
Fish skin is a multipurpose tissue that serves numerous vital functions including chemical and physical protection, sensory activity, behavioural purposes or hormone metabolism. Further, it is an important first line defence system against pathogens, as fish are continuously exposed to multiple microbial challenges in their aquatic habitat (Rakers et al., 2010). Pathogens are ubiquitous in aquatic habitats, as anywhere, and make for a compelling agent of selection for cellular responses in the skin (Ferrari et al., 2010). Because of the intimate contact of fish with the environment, cutaneous diseases are relatively more common in fish than in terrestrial vertebrates and are one of the primary disease conditions presented to the aquatic animal health practitioner.

The epidermis is ectodermal in origin and consists of several layers of simple cells, of which the outer are being constantly worn away by wear and tear and replaced by newer ones which develop at their base. These layers of cells are composed of flattened cells, known as epithelium cells, of which the deepest layers are made up of columnar cells forming the stratum germinativum in which cells are always multiplying by mitotic division to replace the outer worn out cells. A superficial layer of dead horny cells, forming the stratum corneum is not present in fishes as an adaptation to life in water (Khanna, 1993).
The epidermis or the top-most covering of the body is the outermost defence organ against the surrounding aquatic environment that comes into direct contact with the mechanical hazards. The surface of undamaged teleost epidermis appears as a barren field of epithelial (Malpighian) cell surface (Crouse-Eisnor et al., 1985; Iger et al., 1988). In the literature, other names commonly used for Malpighian cells include keratocytes and filamentous or filament containing cells (Bullock and Roberts, 1974). Migrating epithelial cells cover wounds rapidly to provide a barrier against opportunistic micro-organisms (Phromsuthirak, 1977; Bullock et al., 1978). Indeed, it is normal in both fresh-water and sea-water fish for the superficially located epithelial cells to slough off into the water and is replaced by new cells from deeper within the epidermis (Iger et al., 1988; Wendelaar Bonga and van der Meij, 1989 and Iger and Abraham, 1990). This turnover of cells tends to increase with increasing content of bacteria, parasites and other potentially harmful substances in the water (Iger et al., 1988).

Such observations indicate clearly that epithelial cells have a role in the removal of foreign material from fish skin. Asbakk, 2001 shows that these cells are capable of engulfing foreign material and thus may function as scavenger cells, in Atlantic salmon (Salmo salar). It is interesting to notice the differences exhibited in the patterns of microridges on epithelial cells. The distribution of mucous cells
on the general body epidermis of *B. almorhae, H. brucei and S. richardsonii* may be considered as modifications relating to possible difference in the functional requirement at the different locations and their habitat. The presence of mucous cells in the epidermis would seem to be “little point” it being apparently more economical to retain rather than to synthesize mucus. Microridges are most developed and serve to trap mucus on the epithelial surface.

*B. almorhae* uses the boulders as one of its hiding covers. In nature this freshwater species lives in rivers and their tributaries in India. *Botia* is a very inquisitive fish and it seems very happy when it can visit and learn all about suitable hiding places. We can often see it pressed in slots or floating at an angle (Head down or head up) or buried in the substrate or lying on its side (it looks like it diet). *Botias* are very good jumpers, however, the water in the river should be oxygen-rich, with medium flow, without organic loads. *Botia* prefers rocky and gravelly pools in streams.

The epidermis of the GBE of *B. almorhae* and the structures associated with them show considerable structural modifications. These may be considered as adaptations in relation to its peculiar habit and habitat.

The mucus secreted by the mucous cells over the skin performs a wide variety of functions. The presence of well developed mucus cells in the epidermis
forming a slimy layer on the surface is significant as the GBE of the fish is liable to friction especially when it swims upstream. The protective role of epidermal modification acts as the first line of defence against the colonization of pathogen. This may result in less mucus production and consequently reduction of non-specific defence mechanisms (Shephard, 1994).

The specialized microridges on the epidermal surface had been considered an adaptation to the stress produced by osmotic pressure gradients between the cells and water, physical forces from the water itself and rocks and disease organisms such as fungi and bacteria (Yamada, 1968).

Fish morphology constrains the ability of species to use the habitat with specific hydraulic, trophic and biotic criteria. Body size, shape and subsequent hydrodynamics influence the swimming ability of fishes (Videler and Wardle, 1991 and Videler, 1993), which determines what stream patches are hydraulically suitable for a species or individual. Further, the feeding ability is related to mouth morphology or jaw strength (Wainwright, 1991 and Nilsson and Broenmark, 2000) and body size may influence predation risk (Johnsson, 1993) and competitive ability (Fausch, 1988 and Nakano et al., 1998). Therefore, a defensible method of predicting habitat use may be derived from a mechanistic approach to fish ecology using morphology (Schoener, 1986), an eco-morphological approach.
Eco-morphology is the study of relationships of form and environmental factors (Motta et al., 1995). Such approaches have been successful in understanding resource use at the individual level of many species because the morphology of organisms is related to their habitat through function, including fishes (Aleev, 1969; Gatz, 1979 and Webb, 1984).

*H. brucei* is adapted to life in hill-streams characterized by fast flowing streams under boulders. It is found in mountain streams (high gradient streams).

The general body epidermis of *H. brucei*, exhibits compactly arranged microridges forming intricate mesh-like patterns, which are characteristic of the habitat under the boulders and stones. Furthermore, these microridges may gain a firm base and support from a dense network of fine filaments. The free surface of each epithelial cell is characterized by the presence of a series of microridges. The microridges of the cells appear smooth and uniform in width. A dense network of microridges could be interpreted as a means to retain more and more mucus at the surface of epithelial cells because the epidermis of the general body possesses only a few mucous cells. Fishes are in constant interaction with their aquatic environment, which contains a wide range of pathogenic and non-pathogenic micro-organisms. Fish mucus is believed to play an important role in the
prevention of colonization by parasites, bacteria and fungi and thus acts as a chemical defence barrier.

Frictional force is less under boulder and stones; therefore, the requirement of lubrication is minimum in *H. brucei*.

Individuals of some species are known to secrete an envelope of mucus at night in which they rest (Joseph and Nelson, 2006). Mucous secretion has been shown to increase under stressful living conditions in carps (Iger and Abraham, 1997), during parasitic infection in Atlantic salmon and during incorrect medical treatment in rainbow trouts. Secretions elaborated by the epithelial cells and the mucous cells in the mucogenic epithelia could be regarded as an adaptation to lubricate and protect the epithelia from abrasion (Pinky et al., 2002).

*H. brucei* is found mostly attached to the boulders in fast flowing waters, especially on stones covered with fine algae. The hill-stream fishes usually feel difficulty in respiration due to the restriction of gill slits to the sides, especially when feeding on algal slime or when they are adhered to rocks and stones (Hora, 1922). The presence of the mucous coat may significantly help in respiration by providing extra oxygen to the fish.

The epidermis of *H. brucei* possesses a large number of elevations distributed at irregular intervals. The epidermis with elevations alternates with that
of the non-elevated surface. The average thickness of the epidermis varies in the two regions of *H. brucei* (Non-elevated region: 61.7 µm, at elevated region: 85.9 µm) (Bisht, 1999). In several fish groups, breeding tubercles, or "pearl organs," develop on the head, body, or fins during the spawning season (Wiley and Collette, 1970). These are horny protuberances which are secreted in response to seasonal hormonal changes, primarily in males and presumably function in enhanced contact during spawning. These tubercles slough off after the spawning season.

In the general body epidermis of *S. richardsonii* finger print-like microridges, may in addition impart firm consistency or rigidity to the free surface of the epithelial cells. This could be considered as an adaptation to withstand mechanical stress and protect the surface of the fish, which has the characteristic habit of bottom dwelling.

This specific pattern of microridges helps in the spreading of mucus from mucous cells over a wide area. The sudden spread of mucus is facilitated by numerous canaliculi formed by epidermal microridges. Microridges have been reported to vary considerably in configuration and deposition, constituting varied patterns at different locations in different fish species and have been implicated to play variable roles. These include the retention of mucus secretions to the cell
surface, to increase the surface area for excretion and absorption through the skin, to facilitate the spread of mucus away from mucous cells, to aid in producing laminar flow, to provide reserve surface area for stretching and to have their relation with the process of secretion at the cell apex (Whitear, 1990).

The abundance of mucus on the skin of *S. richardsonii* exhibits its habitat in open water or bottom dwellings, where frictional force is very high. This study indicates that the presence of mucus secretion is performing multifunctional activities, assisting the fish to adapt to their characteristic mode of life for their maintenance against adverse environmental conditions, to which these are exposed. On the other hand open water surfaces have more pathogenic agents, which affect the epidermis; therefore, *S. richardsonii* has a greater more requirement of mucus. It also renders the skin less permeable and prevents the entry of pollutant materials and micro-organisms, which would otherwise infect the fish.

Fish mucus is a dynamic biological interface between the fish and their aqueous environment composed of biochemically diverse secretions from epidermal goblet and epithelial clavate cells (Pickering, 1974; Powell et al., 1992 and Ellis, 1999). It is composed mainly of water and gel forming macro-molecules including mucins and other glycoproteins (Shephard, 1994). The range of roles
which fish mucus is said to play is very large (Ingram, 1980) like respiration, ionic and osmotic regulation, reproduction, excretion and disease resistance Ingram, 1980; Austin and MacIntosh, 1988; Fouz et al., 1990; Lemaitre et al., 1996; Ebran et al., 2000 and Kosuga et al., 2000), communication, feeding, nest building and protection.

Fish skin differs from other exposed vertebrate skin most notably at the surface where living epidermal cells are in direct contact with the environment. Because of its watery environment fish skin is subjected to at least two types of stresses; osmotic pressure gradients between the cells and the water and physical forces not only from the water itself but also from other environmental hazards e.g. rocks, boulders etc. The strength of water current and the intensity of light in these water resources are much higher compared to those of the rivers in the plains.

Skin mucus has several functions: reducing friction (Rosen and Cornford, 1971), reducing mechanical damage (Pinky et al., 2008), osmo-regulation (Van Oosten, 1957), gas exchange (Park et al., 2006) and natural defence against invading micro-organisms (Ingram, 1980). Continual replacement of mucus by secretions from goblet (mucous) cells may prevent colonization by pathogenic microbes on the body surface.
Mucous cells die when they release their glycol-conjugates; hence there is a continuous turnover in the outer layers of the epidermis. Alongside the mucous cells, the club cells and the sensory cells are embedded in this layer.

Fishes and other aquatic vertebrates are covered with a mucous epidermis over their entire body surface. Virtually all fish are covered with an integumental mucus secretion that is involved in many aspects of their biology (Daniel, 1981 a, b). The surface mucus has been claimed to play a role in reducing body friction in water and assists in swimming (Schroder, 1903; Rosen and Cornford, 1971; Shah, 1988 and Choudhary, 1991) protects from abrasion during contact with substratum (Liem, 1967; Mittal and Munshi, 1971 and Sinha et al., 1990) and nest digging (Stoklasowa, 1966) and precipitates mud held in suspension in water (Hora, 1934). The water binding properties of mucus can keep the skin moist if out of water, facilitating cutaneous respiration and protecting the fish from desiccation (Mittal and Munshi, 1971; Mittal and Banerjee, 1975; Agarwal et al., 1980; Shah, 1988 and Choudhary, 1991) when streams get dried up during summer. The other interesting observations regarding the function of mucus secretion that have been recorded by various workers are to give support to developing eggs in angler fish (Dahlgren, 1928), seasonal secretion of mucous cocoon to prevent dehydration in *Protopterus* (Smith and Coates, 1936 and Kitzen and Sweeny, 1968), feeding and
attachment of young in cichelids (Brinley and Eulburg, 1953; Hildemann, 1959 and Ward and Barlow, 1967), forming mucus envelopes for temporary shelter in parrot fishes and wrasses (Winn, 1955; Winn and Bardach, 1959; Bohlke and Chaplin, 1968; Turner et al., 1969, Byrne, 1970 and Willey, 1974). The mucus of Ophiocephalus is said to provide extra strength to mortar and is used for the construction of dams and arches in many of the old Churches in Travancore-Cochin/India (Antony, 1952). Skin mucus also appears to be involved in other aspects of the biology of the teleost fish such as social relations (Saglio, 1982).

Noticeable differences exhibited in the patterns of microridges on epithelial cells, distribution of mucous cells and presence of plaques on the general body epidermis of G. gotyla, P. sulcatus and G. pectinopterus may be considered as modifications relating to possible difference in the functional requirement at the two locations (Joshi, 2010).
Summary
The integumentary system is the first line of defense for fishes against the harsh environmental conditions. Without the protection of the skin, the fish would not survive the environment and the various diseases they could suffer from. The skin of the fish would also be an indication for quality in fish farms. Damaged and unhealthy skin may result to fewer customers and buyers and lesser profits.

In the skin of fish, epidermal cells are directly exposed to an aqueous environment. The surface of the cells is specialized in various ways to accommodate osmotic pressure differences between the cell interior and the aqueous environment and to physical and mechanical stresses to which they may be subjected.

Various cellular components of the epidermis of fishes vary in abundance and dimensions, between species. This may be related to the mode of living of the fish and its response to the environment. Among the numerous functions of the skin, none is more important than protecting the organism from environmental hazards even while maintaining it in uninterrupted communication with the environment.

Studies of fish skin indicated that epidermal cells follow separate pathways of differentiation in different fishes. In most of the fishes, the epidermis is related more to the deposition of slime over its surface and undergoes the process of
mucogenesis and in some the epidermal cells undergo the process of keratinization forming a layer at the surface.

Indeed, the epidermis serves in many ways to protect the organism from the variety of noxious agents and to maintain the consistency of the internal milieu. It protects the body from microbes, from injury to delicate inner tissues, from the injurious effects of chemicals and from damage by ultraviolet radiation of the sun and helps as thermo-regulator for normal internal physiological functions. The remarkable ability of epidermis to adopt its surrounding accounts not only for the seemingly endless structural and functional differences between the various species but for certain basic patterns common to all. Morphological data are also the key to understanding fish nutrition in ecology and aquaculture and during development as well as mechanisms for physiological adaptations to changing environment.

The epidermis is a thin, fragile layer which is constantly sloughed off and renewed. It contains mucous cells which secrete the sliming outer covering of fish. The slime on the epidermis is called mucus which makes the fish slippery to handle. The mucus protects the epidermal layer against abrasion and by lubrication makes the fish more streamlined and also difficult to hold. It also renders the skin-
less permeable and prevents entry of pollutant materials and micro-organisms which would otherwise infect the fish.
Fig. 8 and 9: Scanning electron microphotograph (SEMPH) of the GBE of *B. almorhae*. (Scale bar - 500 µm and 50 µm).

Fig. 10 and 11: SEMPH of the GBE of *B. almorhae* showing polygonal epithelial cells (marked by arrow) (Scale bar - 50µm and 20µm).

Fig. 12 and 13: SEMPH of the GBE of *B. almorhae* epidermis showing microridges at the surface epithelium (Scale bar - 10 µm and 5µm).
Fig.14: SEMPH of the GBE of *B. almorhae* showing the opening of mucous cells (marked by arrows) (Scale bar- 50µm).

Fig.15: SEMPH of the GBE of *H. brucei* showing the scales (Scale bar- 500µm).

Fig.16: SEMPH of the GBE of *H. brucei* showing epidermis (Scale bar- 1mm).

Fig.17: SEMPH of the GBE of *H. brucei* showing polygonal epithelial cells (marked by arrow) (Scale bar- 5µm).

Fig.18: SEMPH of the GBE of *H. brucei* showing that the microridges are generally; fingerprint-like, and are often arranged in the form of small groups (Marked by arrows) (Scale bar- 5µm).

Fig.19: SEMPH of the GBE of *H. brucei* showing the openings of mucous cells (marked by arrows) (Scale bar- 10µm).
Fig.20: SEMPH of the GBE of *H. brucei* showing the well-developed tubercles (marked by arrows) (Scale bar- 200μm).

Fig.21 and 22: SEMPH of the GBE of *H. brucei* showing the well-developed tubercles at high magnification (marked by arrows) (Scale bar- 200μm and 50μm).

Fig.23: SEMPH of the GBE of *H. brucei* of showing polygonal epithelial cells and unculi on the tubercles (Marked by arrow) (Scale bar- 10μm).

Fig.24: SEMPH of the GBE of *S. richardsonii* (Scale bar- 500μm).

Fig.25: SEMPH of the GBE of *S. richardsonii* showing polygonal epithelial cells (marked by arrow) (Scale bar- 10μm).
Fig. 26: SEMPH of the GBE of *S. richardsonii* showing polygonal epithelial cells at high magnification (marked by arrow) (Scale bar- 5µm).

Fig. 27: SEMPH of the GBE of *S. richardsonii* showing finger print-like patterns of microridges (Marked by arrows) and also showing the mucous openings and their secretory contents profusely at the surface through a small pore. (Marked by arrows) (Scale bar- 10 µm).

Fig. 28: SEMPH of the GBE of *S. richardsonii* showing finger print-like patterns of microridges that have canaliculi and microbridges (Marked by arrows) (Scale bar- 5µm).