catfish *H. fossilis* where it is composed of four layers i.e. mucosa, submucosa, muscularis and serosa. In *H. fossilis* the oesophagus mucosal layer shows deep longitudinally arranged folds which have also been reported in the fishes inhabiting divergent environment such as in marine teleost, eel *Anguilla anguilla* and freshwater species, Silverside *Odontesthes bonariensis*. The anterior most covering i.e. the mucosal epithelium in *H. fossilis* is structurally uniform, stratified and made up of basal cuboidal cells, intermediate columnar mucous cells and superficial layer of flattened cells. It has been observed in the present study that the catfish mucosal epithelium also contains large number of columnar mucous cells which secrete abundant quantity of mucus which is spread over epithelium. Based on the above, it is logical to presume that the mucus layer over this region of GIT is performing the function of protection and helping in the process of swallowing of food during ingestion. The muscularis mucosa consisting of stratified muscular fibers and usually helping in the movement of folds has been found absent in the catfish *H. fossilis* and other teleosts species. Similarly, the taste buds are also found to be absent in catfish *H. fossilis* like in many other species. The muscularis, typically, consists of inner longitudinal and outer circular muscles and both are smooth muscles and a similar arrangement is observed also in the catfish oesophagus where the longitudinal muscles are arranged in isolated bundles extending into the submucosa. In the catfish, the serosa which is continuously present externally and is made up of endothelial cells is known to reduce the friction and to protect the surrounding organs. Like oesophagus, the structure of the walls of all regions of stomach of *H. fossilis* resembles with those of other fishes where it is composed of bi-layered muscularis, the connective tissue of submucosa, the muscularis mucosa, lamina propria of connective fibers with gastric glands and inner epithelial layer of mucosa. Externally, the stomach of catfish *H. fossilis* is divided into three regions i.e. cardiac, fundic and pyloric where the gastric glands are present in the cardiac stomach which increase in fundic region but are completely absent in the pyloric region. The cardiac and fundic regions of the stomach of catfish *H. fossilis* are characterized by the presence of compound tubular type gastric glands but these glands are totally absent in the pyloric region. The muscularis mucosa is well developed in the pyloric stomach of *H. fossilis* whereas it is poorly developed in cardiac and fundic regions. This may possibly indicate that the functional significance of combination of well developed musculature and the absence of gastric glands in pyloric region is to mix and push the food distally. The mucosal epithelial cells of *H. fossilis* stomach which lines the lumen and pits, are tall columnar cells with basally placed oval nucleus and numerous apically concentrated granules. These secretory granules secrete mucus which stains positive with PAS/ AB(pH 2.5) and may serve to protect the stomach epithelium from the auto digestion caused by enzyme and acid. Interestingly, in contrast to oesophagus, the arrangement of muscularis of catfish in stomach is reversed with the existence of thin outer longitudinal and slightly thick inner circular smooth muscles towards the external serosa. One of the unique features observed in the fundic region of stomach is a highly significant reduction in the thickness of muscularis layer, perhaps not reported in any other teleost which is concomitant
with highly developed gastric glands occupying most of the thickness of GIT in this region. Such a histological feature seems to have functional significance since the major load of digestion is taking place in this region for which extensively developed gastric glands are extremely important. Simultaneous reduction of the muscularis is possibly because of the lack of any significant function as well as to keep the thickness of entire GIT in a reasonable limit. One is also tempted to suggest the respiratory role due to sudden increase in the vascularisation of this region of GIT. However, concrete evidence needs to be adduced to confirm this assumption. The circular muscles in the pyloric region of catfish tend to be more developed than in cardiac region, assuming the appearance of globular or spindle shape gizzard found in birds. Interestingly, in pyloric region of catfish _H. fossilis_, the muscularis layer is arranged into inner oblique followed by circular and longitudinal muscles. In the intestine of the catfish, a well developed serosa similar to that found in the stomach region, is present and is made up of loose connective tissue with blood cells.

The second aspect of this chapter deals with studies on the function and identification of GPs in the catfish where such studies in other teleosts are very limited. However, the fact remains that GPs plays an important role in the gastrointestinal wall viz lubrication, protection of mucosa layer against chemicals, hypertonic media and acidity in the stomach, defense against parasites, and formation of a diffusion barrier for various ions and possibly role in transepithelial ion transport in intestine. The catfish _H. fossilis_ is omnivorous and the GPs which are present in the whole gastrointestinal tract seem to be both neutral and acidic types whereas in oesophagus and terminal part of stomach these are predominantly neutral. Interestingly, the sulphated glycoconjugates have not been observed in the gut mucosal lining of the catfish _H. fossilis_. The absence of sulphomucin in the GIT of catfish suggests that such a functional necessity in catfish may either be diminished or not required at all. The oesophagus mucosa lining of catfish _H. fossilis_, shows the predominant presence of neutral GP even though acid GPs is also present in small measures. The qualitative differences in the glycoconjugate moiety present in the mucus of oesophagus may be associated with the different functions. The absence of salivary glands in fishes may be duly compensated by the lubrication function provided by the mucus secreted by the oesophagus mucous cells. However, the predominance of neutral GP as observed in catfish may further aid in lubrication function whereas the acidic glycoprotein may protect the mucosal lining from the invasion of various pathogens which may enter with the swallowed food. Significant variations in glycoconjugate composition in stomach have been described in many teleost species. In the present study, the occurrence of GPs on the surface epithelium of stomach which stains positive with PAS and AB (pH 2.5) indicate the mixture of neutral and acidic GP. Similar high quantities of both neutral and acidic glycoconjugates in the stomach mucosa have been reported in the several teleost species. In the present study, the sulphated GP has been found to be absent in the gastric mucosa of _H. fossilis_ even though it has been shown to be present in many other different fishes which may probably be related to diet. An interesting observation of the present study relates to a sudden transition of
neutral GP present in the sphincter region of the stomach leading to the duodenum into predominantly acidic moiety. Although no evidence is adduced but it is likely that this transition may be useful to kill any possible pathogen occurrence in the ingested diet of the catfish.

The intestine of *H. fossilis* shows the uniform distribution of GPs in all portions i.e. duodenum, mid intestine and terminal part (rectum) which are made up of neutral and acidic GPs. In *H. fossilis*, the number of mucous cells increase towards the distal part (i.e. rectum) which may be related to an enhanced need for lubrication for the smooth ejection of faeces as reported in other fish species. Among the functional multiplicity of mucus, acid GPs have been implicated in the increased viscosity of mucus in the fish alimentary tract which lubricates the undigested materials for onward progression into the rectum. Neutral mucosubstance are is said to be involved in the enzymatic digestion of food transforming it into chime and also facilitating absorptive function.

The third aspect of this chapter deals with osmoregulatory functions, if any, of the catfish GIT. In a classical osmoregulatory pattern, gastrointestinal tract (GIT) of a freshwater teleost, unlike its marine counterpart, plays a minimal role. Such a role is largely confined to intestinal uptake of Na\(^+\) and Cl\(^-\) from dietary source to compensate diffusional loss of these ions across the gill to an extremely hyposaline external medium. The catfish *H. fossilis* survives only up to an extremely limited salinity range through the process of passive tissue tolerance. Any substantial role of GIT in higher salinities up to 35% SW as an osmoregulatory organ is clearly not expected. The observations of the changes in GIT internal histology corroborate this assumption. However, there is an overwhelming evidence to show that while there is no significant qualitative and quantitative change on the GPs moiety of the GIT mucosal lining of various segments, there are highly noticeable disruptive changes in the internal mucosal lining and even on the underlying layers of various segments. These changes are in the form of extensively damaged stratified epithelium, necrosis in submucosa and lamina propria, profound vacuolation of submucosa of oesophagus, elongation of gastric glands, hemorrhagic changes and enhanced mucus production. These changes become more pronounced as the salinity increases from 25% to 35% SW. In this study on catfish *H. fossilis*, which has barely 35% SW tolerance limit, none of the changes documented for euryhaline fishes were observed here giving credence to our assumption that GIT is not playing any active osmoregulatory role in catfish in higher salinities. However, the fact of the matter is that there are highly significant degenerative changes in catfish GIT in higher salinities which may have been caused by the process other than osmoregulation. In the present study, a careful analysis reveals that the changes observed in the catfish GIT in higher salinities quite closely resemble to the changes observed in those fish species which have been exposed to various pollutional load. This leads to most likely conclusion that the histopathological changes seen in catfish GIT following transfer to higher salinities are more of a manifestation of salinity induced stress
response rather than an osmoregulatory adaptation which is quite extensively reported in
euryhaline teleosts transferred to marine environment.

Hence this chapter has provided significant data on the histological organization of various
segments of GIT of the catfish H. fossilis, its glycoconjugate distribution and their possible
physiological role in various GIT segments and effects of enhanced salinity on the GIT
organization.

Concluding Remarks

The information thus generated in the above study has built up a comprehensive overview
of better and more precise understanding of the morphology, histology and cellular
composition of skin, gill and GI tract, the important osmoregulatory target organs in fishes.
It has also provided an insight into the biochemical composition of mucus glycoproteins, a
major component of overlying mucus on the above organs, its seasonal profile and salinity
and stress induced changes in these catfishes. The consortium of such an information in
conjunction with the pre-existing documented information on these aspects will greatly
enhance our current understanding of osmoregulatory adjustment in teleost in general and in
tropical freshwater stenohaline fishes in particular.

References