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Physiological adaptive mechanisms of catfish (Siluroidei) to environmental changes

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Abstract

Emphasis on physiological adaptations to environmental changes in the catfish (Siluroidei), is a rather recent development like that of their use in aquaculture. The siluroid fishes with smooth scaleless skin and sensory barbels are adapted to live in a variety of aquatic environments ranging from freshwater and brackishwater to swamps and marshes both in temperate and tropical regions. However, very little has been explored on their expected wide range of physiological adaptations. Most of the results obtained in siluroid fishes are similar to those reported for other teleosts such as cypriniform species. However, there are some air-breathing siluroids, found in the tropical areas, with accessory air-breathing organs. Besides tolerating periods of water deprivation, some of these fishes have been shown to possess special physiological and biochemical adaptive mechanisms to tolerate a wide range of adverse physico-chemical conditions in the ambient environment. Some of the physiological adaptive mechanisms of Siluroidei in general, and air-breathing species in particular, to important physico-chemical factors such as oxygen, temperature, ammonia and xenobiotics are reviewed and discussed.

Keywords: Physiological, biochemical, adaptation, environment, Siluroidei, catfish, air-breathing, ammonia management, urea cycle, xenobiotics.

Mécanismes physiologiques adaptatifs des poissons-chats (Siluroidei) aux changements environnementaux.

Résumé

L'intérêt porté aux adaptations physiologiques des poissons-chats (Siluroidei) aux changements environnementaux est relativement récent et lié à leur aquaculture. Les poissons Siluroidei ont une peau dépourvue d'écaille et des barbillons sensoriels; ils sont adaptés à vivre en divers milieux aquatiques des eaux douces et eaux saumâtres des marais et marécages, à la fois en régions tempérées et tropicales. Cependant, peu d'investigations ont été faites sur l'étendue de leur capacité d'adaptations physiologiques. La plupart des résultats obtenus chez les Siluroidei sont similaires à ceux obtenus chez les autres poissons téléostéens tels que les Cypriniformes. Cependant, il existe des Siluroidei à respiration aérienne, trouvés en zones tropicales munis d'organes accessoires de respiration aérienne. Parallèlement à la tolérance d'absence temporaire d'eau, il a été montré que quelques uns de ces poissons possédaient des mécanismes physiologiques et biochimiques particuliers pour tolérer une large gamme de conditions physico-chimiques défavorables du milieu ambiant. Certains de ces mécanismes physiologiques adaptatifs, des Siluroidei en général et des espèces à respiration aérienne en particulier, comme ceux liés aux facteurs physico-chimiques, tels que l'oxygène, la température, l'ammoniaque et aux facteurs xénobiotiques, sont passés en revue et discutés.

Mots-clés : Physiologie, biochimie, adaptations, conditions de milieu, Siluroidei, poissons-chats, respiration aérienne, thermorégulation, cycle de l'urée.

INTRODUCTION

Most of the freshwater teleost species, which are economically important for human consumption, belong to two major groups, Cypriniformes and Siluroidei. The siluroid fishes with smooth scaleless skin and sensory barbels are adapted to a variety of ecological niches, ranging from freshwater and brackishwater to swamps and marshes, both in temperate and tropical regions. As such, they are expected to exhibit a wide range of physiological mechanisms adapted to diverse environmental conditions. However, very little has been explored on this important topic related to physiological adaptations. Most of the earlier studies on teleost physiology have been carried out mainly on carp, cod, trout, cobitid, herring, eels, flounder etc. Only a few siluroids have been used as models for physiological studies aimed at exploring molecular adaptive mechanisms for survival in the dynamic environment.

The catfish of the genera *Ictalurus, Clarias, Silurus, Plecostomus, Heteropneustes, Mystus, Heterobranchus, Pangasius,* etc. are the common examples of Siluroidei used in aquaculture. Although the American channel catfish, *Ictalurus,* has been extensively studied, the reports on most of its adaptive features are similar to typical freshwater teleosts. However, in most tropical areas, there are a few siluroid genera such as *Clarias, Heteropneustes, Pangasius, Hoplosternum, Heterobranchus* possessing air-breathing potential. Some of them have many other physiological characteristics compensating for wide fluctuations in their environmental parameters. Several reviews (Hoar and Randall, 1969-1979, Hochachka and Somero, 1984, Prosser, 1991, Evans, 1993) have presented data on typical freshwater teleosts. Only one book (Munshi and Hughes, 1992) presents some facts about the air-breathing freshwater teleosts of India including catfish species.

Therefore, while presenting a general overview on the physiological adaptations in Siluroidei, special physiological adaptive mechanisms of the air-breathing siluroid fishes concerning particularly respiration, thermoregulation, ammonia management and xenobiotics have been highlighted.

Respiratory adaptations

Adequate supply of oxygen from the aquatic environment is essential for the survival of fish. Most of the fishes including siluroids use the gills to extract oxygen from water by diffusion. A minimum concentration of dissolved oxygen (DO) in water is, therefore, essential for survival, growth and reproduction of different species of fish. Various branchial adaptations have been reported in fish to low (hypoxic) and high (hyperoxic) DO levels in water (Hochachka and Somero, 1984, Prosser, 1991). All these gill-breathing adaptations in Siluroidei have been similar to those in other gill-breathing teleosts. However, some predominantly tropical siluroid species having varied air-breathing potential (Das, 1927, Lagler *et al.*, 1977, Munshi and Hughes, 1992) are capable of living in oxygen depleted water and for short durations out of water, or tolerate temporary water deprivation.

Air-breathing adaptations

Different types of special air-breathing organs have been reported in freshwater air-breathing teleosts. The accessory respiratory organs are modifications, both structural and functional, of either branchial chamber, swim bladder or alimentary canal. The surface of these organs is highly vascularized, folded and the blood supply modified to extract sufficient oxygen from engulfed air. These fishes have usually lesser developed gills and need access to air while living in water for engulfing air for respiration (Munshi and Hughes, 1992).

The suprabranchial chambers in Clariidae are enlarged into two diverticula opening between second and third gill arches (Munshi, 1961). The diverticula contain bush-like extensions on cartilaginous supports called arborescent organs. They originate from II and IV gill arches. The walls are highly vascularized with blood supply from all four branchial arteries. In *Heteropneustes,* the suprabranchial chambers extend laterally backwards in the form of long sacs, one on each side, embedded in the myotomes in the trunk region. These sacs open into the gill cavity between the second and third gill arches, and the blood is supplied from the fifth branchial artery. The respiratory mucosa on the inner walls of the air-sacs is thrown into folds and ridges for increasing the surface area for gas exchange (Munshi, 1962).

The middle and posterior portion of the intestine serves for aerial respiration in *Hoplosternum* besides serving the usual function of digestion. Oxygen is extracted from the air, taken into the digestive tract by the intestinal mucosa vascularized with blood supplied from the dorsal aorta. The purified blood is collected by the inter-renal vein (Lagler *et al.*, 1977, Munshi and Hughes, 1992). In another siluroid fish, *Pangasius*, the swim bladder with highly vascularized inner wall serves a major role in aerial respiration (Browman and Kramer, 1985, Thakur *et al.*, 1987).

Large interspecies variations in aquatic and aerial respiration under different environmental conditions have been reported in various air-breathing teleosts including the two species of freshwater air-breathing siluroid, *Clarias batrachus* and *Heteropneustes fossilis* (Hughes and Singh, 1971, Singh and Hughes, 1971). The air-breathing fishes thus have the capability to use both gills and air-breathing organs for oxygen uptake while the elimination of carbon dioxide occurs primarily by the gills and skin. The air-breathing organs were found to be inefficient for removal of carbon dioxide from the body.

Seasonal thermal adaptations

Temperature is by far the most pervasive of all environmental stresses disturbing the maintenance of homeostasis in a living system. The effects of temperature on the physiological and biochemical parameters have been enumerated by Hochachka and Somero (1984). Poikilotherms, for example fish, conform their internal temperature to the environmental temperature. However, a number of poikilotherms including fishes are known to be eurythermal and are capable of being tolerant to wide fluctuations of ambient temperature. Regulatory compensation against the effects of environmental thermal alterations, known as thermal "acclimation", is an established fact in a host of poikilotherms (Precht *et al.*, 1973; Hazel and Prosser, 1974; Das, 1984). This has been demonstrated with reference to a wide array of physiological functions in several fishes under laboratory conditions (Hazel and Prosser, 1974; Love, 1980; Hochachka and Somero, 1984, Prosser, 1991). Physiological adaptations to variations of a multitude of environmental parameters including temperature occur during seasonal changes in an annual cycle, and has often been termed as seasonal "acclimatization". Even though seasonal acclimatization to temperature has been demonstrated in a few species of teleostean fish (Das, 1984), Siluroidei seem to have attracted little attention. Only a limited number of siluroid species have been studied.

Seasonal adaptation of respiration

Bimodal respiratory rates (aquatic and aerial) in young and adult air-breathing catfish (*Clarias batrachus* and *Heteropneustes fossilis*), inhabiting Indian swamps, during winter (20-21°C) and summer (30-32°C) months, measured at ambient temperatures (Munshi *et al.*, 1982, Patra *et al.*, 1983) revealed an age-dependent switching from aquatic to aerial mode of oxygen consumption. In the case of *Clarias*, the larger (older) fish remained more aquatic but the smaller (younger) ones became more aerial in summer. In winter, the aquatic respiration exceeded the aerial mode, irrespective of size (age) of *Clarias*. The smaller (younger) *Heteropneustes* exhibited almost equal proportions of aquatic and aerial respiration, while the larger (older) specimens exhibited more dependency on the aerial mode even during colder winter months. With the approach of the warmer summer months, the aerial oxygen consumption by *H. fossilis* exceeded the aquatic mode in both younger and older fishes. The significance of the results obtained can only be ascertained after the respiratory rates (aerial and aquatic) were determined in the two seasons not only at ambiant temperatures, but also at one or more (2-3) constant temperatures.

Seasonal adaptation of enzyme activities

The season-specific physiological and metabolic changes need not always be compensatory, *i.e.* directed primarily towards overcoming the effects of environmental changes (Hochachka and Somero, 1976). Instead, metabolic reorganization induced by alterations of environmental parameters may be useful for a specific biological goal (suh as gametogenesis and reproduction in a seasonal breeder or migration in a migratory fish).

Although seasonal changes in the activities of several enzymes and in the rate of protein synthesis have been documented in some teleosts (Marquez, 1976, Fauconneau, 1985, Mandal and Das, 1991), so far, there are few reports on seasonal changes affecting the enzyme pattern and protein metabolism in catfish. After the classic demonstration of the influence of seasons on the activity of selected enzymes in the channel catfish, *Ictalurus punctatus* (McCorkle *et al.*, 1979), Tripathi and Shukla (1991) have described the seasonal effects on malate and lactate deshydrogenases in liver and skeletal muscle of freshwater air-breathing catfish, *Clarias batrachus* (*fig.* 1 and 2).

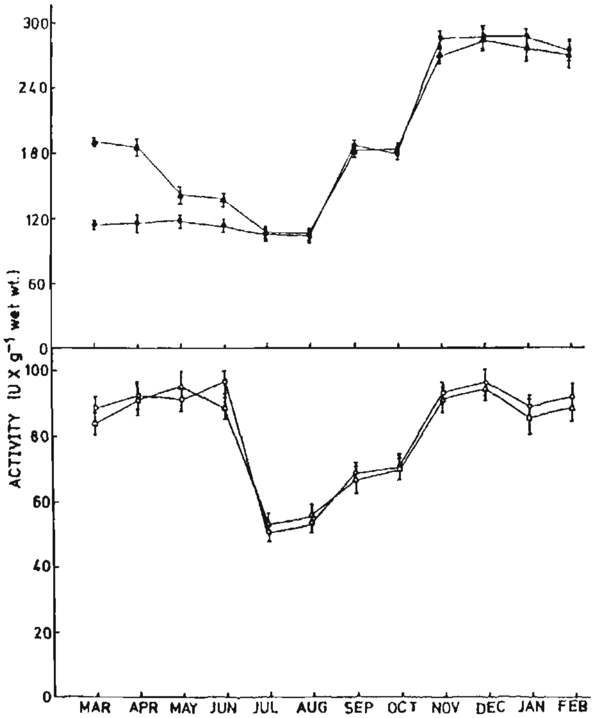

Figure 1. – Seasonal variation in the activity of cytoplasmic malate dehydrogenase (cMDH) in the liver (● - - - ●, male; ▲ - - - ▲, female) and the skeletal muscle (○ - - - ○, male; △ - - - △, female) of the freshwater catfish, *Clarias batrachus* (after Tripathy and Shukla, 1991).

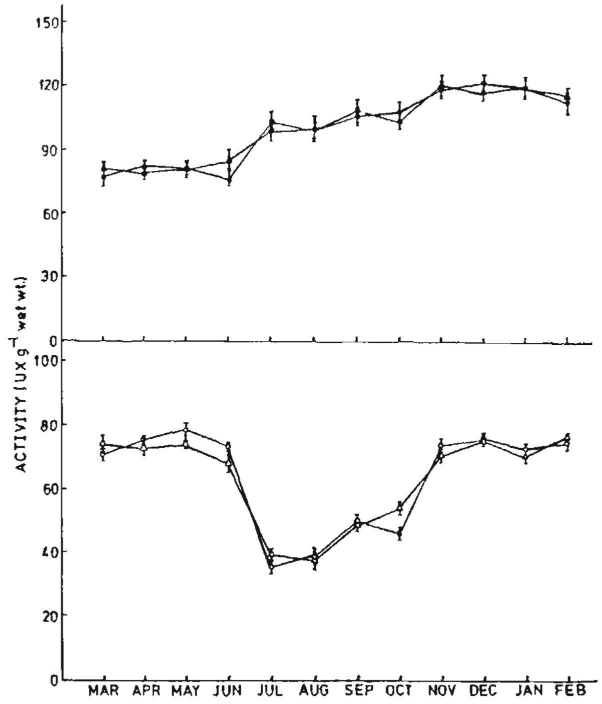

Figure 2. – Seasonal variation in the activity of lactate dehydrogenase (LDH) in the liver (● - - - ●, male; ▲ - - - ▲, female) and the skeletal muscle (○ - - - ○, male; △ - - - △, female) of the freshwater catfish, *Clarias batrachus* (after Tripathy and Shukla, 1991).

The authors have tried to correlate the higher levels of hepatic cytoplasmic malate dehydrogenase (c-MDH) and lactate dehydrogenase (LDH) activities observed during the winter months (November-February) with the restoration of metabolic activities during the post-spawning and resting phase of the breeding cycle. However, the plausibility of a compensatory augmentation of these enzymatic activities in response to a decrease in temperature in winter needs to be verified experimentally.

Homeoviscous adaptation of membrane lipid

The poikilothermic organisms including fish exploit diversity in lipid structure to organize the molecular architecture of phospholipid membranes to the prevalent ambient temperature in such a manner that they become more fluid in the cold-acclimated (or winter acclimated) state and less fluid (more rigid) in a warm-acclimated (or summer-acclimated) state. This compensatory adaptation of phase transition in membrane lipid has been described as "homeoviscous adaptation" (Cossins and Bowler, 1987, Cossins, 1994). This is achieved by the restructuring of phospholipid classes, coupled with modification of the extent of unsaturation of fatty acid chains. Such an alteration is naturally expected to be reflected in a change in micro-viscosity of phospholipid vesicles prepared from membranes. Investigations on this topic have been carried out in a large number of arctic, temperate and tropical (marine as well as freshwater) teleosts. However, in this respect, little attention has been paid to the siluroids, both aquatic as well as air-breathing. The air-breathing catfish, *Clarias gariepinus*, as a representative example of warm-adapted freshwater fish (WAFF), has been compared with several other cold-adapted freshwater fishes (CAFF), with respect to average fatty acid composition (mol %) of total phospholipid in the liver (*fig.* 3). The differences in the fatty acid composition of total phospholipid in the liver of the two categories of fish adapted (genetically) to contrasting temperatures

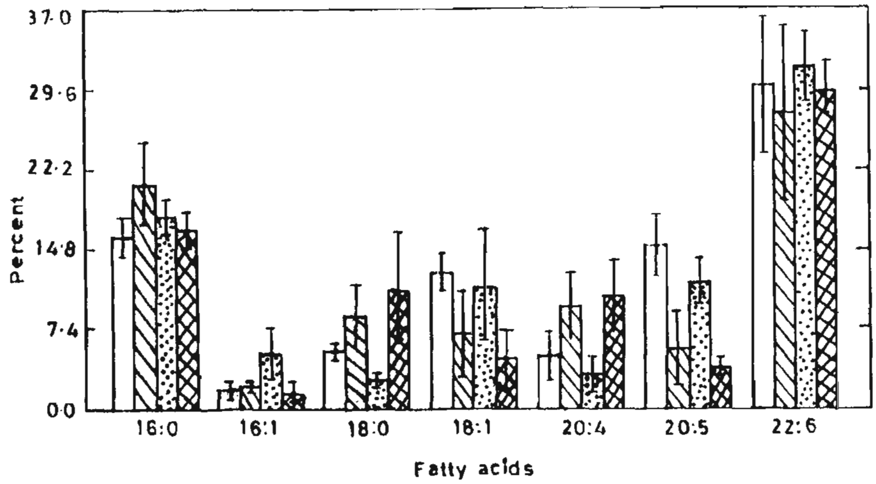

Figure 3. – Average hepatic fatty acid composition (mol %) of total phospholipids from cold adapted marine fishes (CAMF) (open bars: $n = 8$), warm adapted marine fishes (WAMF) (hatched bars: $n = 9$), cold adapted freshwater fishes (CAFF) (stippled bars: $n = 4$), and warm adapted freshwater fishes (WAFF) (cross-hatched bars: $n = 4$). Only the major fatty acids are shown (after Dey *et al.* 1993 *a*).

(Dey *et al.*, 1993 *a*) resemble those exhibited during seasonal acclimatization of several other freshwater teleosts (Dutta *et al.*, 1985). The results obtained from studies on erythrocytes by Dey *et al.* (1993 *b*) indicate that fish can increase not only the number of conical phospholipid molecules (like phosphatidyl ethanolamine) in contrast to the more cylindrical ones (like phosphatidyl choline), but also the degree of conicity of the existing conical molecules (by substitution of 16:0 by 18:1 in the sn-1 position) during cold adaptation.

Temperature mediated changes in immunity

It was demonstrated by an assessment of lymphocyte B and T cell functions in the American channel catfish, *Ictalurus*, under laboratory conditions, that the immune competence of a teleost depends on the environmental temperature. When the fish was subjected to a diminution of water temperature from 23 to 11°C over a period of 24 h, mimicking the winter conditions, *in vitro* responses of B and T cells measured for 3 to 5 weeks were found to be suppressed significantly. However, the compositions of lymphocytes and neutrophils, as well the blood serum chemistry, did not change in a manner which is typical of stress-induced response (Bly and Clem, 1991). The authors concluded from the observations that the channel catfish are probably immuno-compromised during winter months and consequently the syndrome, termed "winter kill", may be attributable partly to a low temperature-induced immuno-deficient state of the fish. In view of the homeoviscous adaptation occurring in lymphocyte and erythrocyte membranes in several teleosts in response to environmental thermal fluctuations (Abbruzzini *et al.*, 1982, Dey *et al.*, 1993 *b*), immuno-suppression of lymphocyte function in the channel catfish induced by low temperature is intriguing and needs to be probed further through suitable experimental strategies. Ainsworth *et al.* (1991) observed a decline in the number of lymphocytes but not in the number of neutrophils due to a diminution of ambient temperature to 10°C (but not 18°C). Although phagocytosis in channel catfish is found to be temperature mediated, the phagocytic neutrophils appear to be more resistant to low temperature than the lymphocytes, which implies greater importance of phagocytosis than chemical immunity in the defence mechanisms of channel catfish at low temperature. Dexiang and Ainsworth (1991) have further demonstrated that the anterior kidney phagocytes from channel catfish remained partially functional at low temperature (10°C), when their bacteriophagic ability was tested with respect to *Aeromonas hydrophila* and *Edwardsiella ictaluri*. However, an improvement in their respiratory burst activity occurred on adaptation to low temperature within five weeks, implying a compensatory improvement of their bacterial killing ability. Thus in channel catfish phagocytosis may play a significant role in preventing disease at low temperature.

Nitrogen excretion and ammonia management

Ammonia is a major nitrogenous metabolic waste produced continuously in the animals. It becomes highly toxic if allowed to accumulate *in vivo* even to a very low concentration. It is either excreted out or converted *in vivo* to some less toxic compounds such as urea, uric acid and/or some amino acids. Marine elasmobranchs and aquatic amphibians are capable of converting ammonia to urea via ornithine-urea (o-u) cycle present in their liver (Cohen, 1976). The former retain the urea for osmo-regulation while the latter excrete urea particularly during its terrestrial life. Most freshwater teleosts lacked a complete and functional o-u cycle and were incapable of effective ureogenesis from ammonia (Brown and Cohen, 1960, Huggins *et al.*, 1969, Wilson, 1973). Metabolically produced ammonia is, therefore, excreted to the ambient aquatic medium by diffusion through the gills in freshwater teleosts (Forster and Goldstein, 1969). Ammonia is also becoming a major pollutant in the freshwater systems affecting the survival, growth and reproduction of fish (Alabaster and Lloyd, 1980).

Two siluroid species of freshwater air-breathing teleosts, *H. fossilis* and *C. batrachus*, which are primarily ammoniotelic in their aquatic habitat (Saha *et al.*, 1988), have a complete o-u cycle in their liver and kidney (Saha and Ratha, 1987, 1989). The activity of all the enzymes was very high and comparable to ureo-osmotic elasmobranchs, and ureotelic amphibians and mammals. These two air-breathing fishes are benthic species living in shallow or sewage-fed water bodies where ammonia level is generally high (Jhingran, 1982). They tolerate water deprivation for 60-70 h (Saha and Ratha, 1989). During this period ammonia excretion was not possible and it accumulated *in vivo* (Saha and Ratha, unpubl. data). Studies on *H. fossilis* showed very high tolerance for ammonia in the ambient medium (75 mM ammonium chloride) and in tissues (up to 4.7 mM in plasma and 40 mol·kg^{-1} in kidney) (Saha and Ratha, 1994 *b*). Ammoniotelic *H. fossilis* became ureotelic with induction of the activity of the enzymes of o-u cycle in its liver and kidney when exposed for four weeks to higher concentrations of ambient ammonium chloride (*fig.* 4) (Saha *et al.*, 1988, Saha and Ratha, 1994 *b*). Excretion of ammonia and urea decreased, accumulation *in vivo* of ammonia increased and the activity of the enzymes of o-u cycle induced during the first week, is followed by accumulation and enhanced excretion of urea which reached an apparent constant level by the end of second week of exposure to ammonium chloride (Saha and Ratha, 1986, 1994 *b*). Using a perfused liver system in *Heteropneustes fossilis*, it has been reported that an

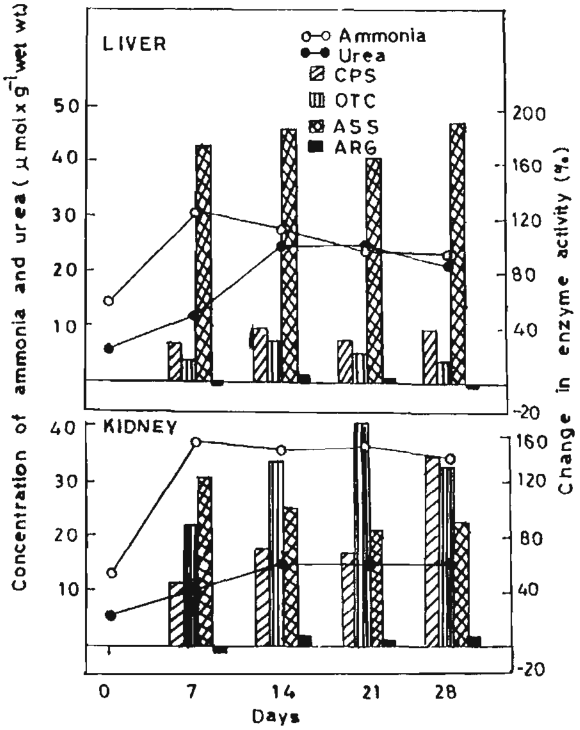

Figure 4. – Alteration in the concentration of ammonia and urea (μmoles·g^{-1} wet wt.), and percent change in the activity of the enzymes of o-u cycle in the liver and kidney of *Heteropneustes fossilis* exposed to 50 mM ammonium chloride for 28 days (CPS: carbamoyl phosphate synthetase, OTC: ornithine carbamoyltransferase, ASS: argininosuccinate synthetase system, ARS: arginase), after Saha and Ratha, 1994).

increase in ammonia load by 3-5 μmol·g^{-1} wet weight from the physiological level was sufficient to initiate and cause maximum induction of the activity of most of the urea cycle enzymes (Saha *et al.*, 1995).

Exposure of *Clarias batrachus* to 34 mg.l^{-1} ($\simeq$ 1 mM) of ammonia (NH_4OH) suppressed its total nitrogen (ammonia-N and Urea-N) excretion within seven days which was restored within the next week (Das, unpubl. data). The level of urea-N excretion increased by 30% over the control value only after three weeks of ammonia stress. Similar ureotelic transition was also observed in *H. fossilis* when the ammonia level *in vivo* increased during conditions of water deprivation (Saha, 1986). Like marine elasmobranchs, *H. fossilis* also showed ureo-osmotic adaptation when exposed to 250 mosm. mannitol in the ambient medium (Saha and Ratha, 1994 *a*).

Mukhopadhyaya and Dehadrai (1987) indicated the possibility of non-protein nitrogen (NPN) from urea, as a component of supplementary diet, being converted into protein (organic) nitrogen in the tissues of *H. fossilis*. Mass spectrophotometric analysis of liver proteins of *H. fossilis* fed with ^{15}N labelled urea (3% of weight of food) indicated that synthesis of liver proteins from preformed amino acids might occur from dietary urea. Enzymatic conversion of ammonia to amino acids such as glutamate (by glutamate dehydrogenase) and glutamine (by glutamine synthetase) occurs in most vertebrate tissues for immediate detoxification and transport of ammonia from different tissues to liver and kidney for ureogenesis, and to gills for excretion. The enzyme profiles related to glutamate and glutamine metabolism studied in different tissues of *H. fossilis* suggest synthesis of glutamate and glutamine as a strategy for detoxification (maybe utilization) of accumulated ammonia *in vivo* (Chakravorty *et al.*, 1989, Chakravorty, 1990, Das, 1991, Das *et al.*, 1991). Sub-cellular distribution of glutamine synthetase (Chakravorty *et al.*, 1989) and the enzymes of o-u cycle (Dkhar *et al.*, 1991) showed biochemical features of *H. fossilis* to be different from those already known for freshwater teleosts including other siluroid species.

The tolerance of *Heteropneustes fossilis* and *Clarias batrachus* to higher ammonia, osmolarity and water-deprived ambient medium, and some of the special metabolic features (*table* 1) reported indicate their suitability in commercial aquaculture in swamps and marshes, and in derelict water bodies. However, more studies on various physiological and biochemical adaptive mechanisms must be conducted in freshwater air-breathing teleosts to develop suitable protocols for their effective use in waste water aquaculture.

Table 1. – Some biochemical features found in the liver and kidney of a freshwater air-breathing teleost, *Heteropneustes fossilis* which are different from those of purely aquatic species.

Fish	o-u cycle	Glutamine synthetase activity	Arginase activity
Purely aquatic freshwater teleosts	Incomplete/ physiologically nonfluctional	Cytoplasmic	Completely cytoplasmic
Air-breathing freshwater teleost (*H. fossilis*)	Complete and physiologically regulated	Mitochondrial	Both cytoplasmic & mitochondrial

Xenobiotic stress and adaptation

Intensive and extensive industrial and agricultural activities have on the one hand improved the quality of human life, on the other created the problem of environmental pollution. To understand the impact of these pollutants on target and non-target organisms, and to discover methods of alleviating these problems, research in the area of eco-toxicology or xenobiotic stress physiology has been reinforced in the recent past. The literature concerning the effects of diverse xenobiotic stresses on aquaculture organisms (primarily fish) and the basic information regarding their adaptive mechanisms (stress avoidance and stress tolerance) is too voluminous to be synthesized within this review. Hence, a brief summary on a few well studied adaptive responses in siluroid fishes is presented with emphasis on air-breathing species.

Smooth scale-less skin, besides the gills of siluroid fish provides a large surface area for the chemical pollutants in the aquatic medium to interact before entering the body. The epidermal layer of their skin and gills contains a large number of goblet cells which secrete mucus rich in mucopolysaccharides to keep the skin moist and clean. The mucus probably creates a barrier between the fish and the toxin in the medium. Enhanced activity of the mucous cells have been reported in *Clarias batrachus* and *Heteropneustes fossilis* exposed to various concentrations of detergents (Garg and Mittal, 1993), heavy metal ions, ammonia and pesticides (*see* review by Banerjee, 1993), suggesting that mucus at least to some extent prevents entry of toxicants into the fishes.

Xenobiotics such as organophosphate and organochlorine pesticides, heavy metals, industrial chemicals etc. accumulate in various tissues of fish during its chronic exposure, even at sublethal concentrations. They elicit responses in blood parameters, tissues respiration and metabolism, neuro-transmission and membrane transport, reproductive activities etc. Decrease in the number of erythrocytes, leukocytes and platelets, decrease in serum protein and amino acid concentration, and increase in blood glucose level have been reported during exposure to a variety of toxicants (Das *et al.*, 1980, Mukhopadhyaya and Dehadrai, 1980, Sastry and Subhadra, 1982, Mishra and Srivastava, 1983, Srivastava and Mishra, 1987). Stress-induced release of catecholamines has been suggested to be the controlling factor for these effects (Nakano and Tamlinson, 1967). Decrease in tissue glycogen level, aerobic and anaerobic respiration, activity of energy releasing enzymes such as malate dehydrogenase (MDH) and lactate dehydrogenase (LDH) (Tripathy and Shukla, 1990), or electron transport chain activity have been reported due to the formation of metal-enzyme complexes (Shaffi, 1993). The impairment of the activity of some hydrolyzing enzymes and cholinesterase affecting neuro-transmission have been reported (Mukherjee and Bhattacharya, 1974, 1975) during xenobiotic stress. Reproductive dysfunction due to inhibition in steroidogenesis (Haider and Upadhyaya, 1985, Singh and Singh, 1987, Chakravorty *et al.*, 1992), thyroid activity (Sinha *et al.*, 1991) and vitellogenesis (Chakravorty *et al.*, 1992) have been reported in *Clarias batrachus* and *Heteropneustes fossilis* exposed to sub-lethal concentrations of pesticides and industrial effluents. Most of these effects have been found to be reversible, requiring different time periods after the removal of the xenobiotic stress.

Most of the pesticides and synthetic industrial chemicals are poorly biodegradable. Their pharmacokinetics, tissue distribution, metabolism and clearance have been studied in channel catfish, *Ictalurus punctatus* using radio-labelled (^{14}C) chemicals. More than 90% of the chemicals studied such as benzoic acid, aflatoxin, 1-naphthol and phenol red (Plakas and James, 1990, Plakas *et al.*, 1991, 1992, Stenly and Plakas, 1992), and a herbicide, propanil (Schlenk and Moore, 1993) remained unmetabolized. They were removed from the fish primarily by renal and biliary excretion. However, their tissue distribution, elimination half-life and total body clearance were different. The role of hepatic and extra-hepatic cytochrome P-450 in detoxification of xenobiotics in teleosts is relatively less known, particularly in siluroid species, although they have been reported in a marine fish, *Stenotomus chrysops* (Smolowitz *et al.*, 1991).

CONCLUSION

Spatial and temporal distribution of various species during evolution occurred on the basis of their ability to adapt to the ambient environmental conditions. Deviation of the conditions beyond certain limits afects successful growth, development and breeding, even complete elimination of species in extreme conditions. Therefore, it is essential to identify the tolerance limits and understand the adaptational mechanisms of commercially important siluroid species for their use in profitable aquaculture. In the past, research has been focused mainly on reproduction (breeding) and nutrition (feeding) for the enhancement of the production and growth of the fish. However, physiological adaptations to various environmental factors have now been recognized as very important for optimal growth.

Some of the unique physiological adaptations of two air-breathing siluroid species were highlighted to emphasize their potential in developing aquaculture in derelict water bodies and swamps where traditional aquaculture is not possible. However, experimental studies remain to be carried out for the development of appropriate culture methods, suitable for those fishes and specific derelict systems.

REFERENCES

Abbruzzini A. F., I. O. Ingram, L. W. Clem 1982. Homeoviscous adaptation in teleost lymphocyte. *Proc. Soc. Exp. Biol. Med.* **169**, 12-18.

Alabaster J. S., R. Lloyd 1980. In: Water quality criteria for freshwater fish. Butterworths, London, 297-365.

Ainsworth A. J., C. Dexiang, P. R. Waterstart, T. Greenway 1991. Effect of temperature on the immune system of channel catfish (*Ictalurus punctatus*) – I. Leucocyte distribution and phagocyte function in the anterior kidney at 10°C. *Comp. Biochem. Physiol.* **100**, 907-912.

Banerjee T. K. 1993. Response of fish skin to certain ambient toxicants. *In*: Advances in Fish Research vol. 1. B. R. Singh ed. Narendra Publishing House, Delhi, 185-192.

Bly J. E., L. W. Clem 1991. Temperature mediated processes in teleost immunity: *In vitro* immunosuppression induced by *in vivo* low temperature in channel catfish. *Vet. Immunol. Immunopathol.* **28**, 365-377.

Browman M. W., D. L. Krammer 1985. *Pangasius sutchi* (Pangasiidae), an air-breathing catfish that uses the swimbladder as an accessory respiratory organ. *Coepia* **1985**, 994-998.

Brown G. W. Jr., P. P. Cohen 1960. Comparative biochemistry of urea biosynthesis-III. Activities of urea cycle enzymes in various higher and lower vertebrates. *Biochem. J.* **75**, 82-91.

Chakravorty J. 1990. Glutamine metabolism in regulating ammonia level *in vivo* in an air-breathing freshwater teleost, *Heteropneustes fossilis*. Ph. D. thesis North-Eastern Hill University, Shillong, India.

Chakravorty S., B. Lal, T. P. Singh 1992. Effect of endosufan (thiodon) on vitellogenesis and its modulation by different hormones in the vitellogenic catfish, *Clarias batrachus*. *Toxicology* **75**, 191-198.

Chakravorty J., N. Saha, B. K. Ratha 1989. A unique pattern of tissue distribution and sub-cellular localization of glutamine synthetase in a freshwater air-breathing teleost, *Heteropneustes fossilis* (Bloch). *Biochem. Int.* **19**, 519-527.

Cohen P. P. 1976. Evolutationary and comparative aspects of urea biosynthesis. *In*: The urea cycle. S. Grisolia, R. Baguena, F. Mayor eds., John Wiley & Sons, New York, 21-28.

Cossins A. R. 1994. Temperature adaptations of biological membranes. Portland Press.

Cossins A. R., K. Bowler 1987. Temperature biology of animals. Chapman & Hall, London.

Das A. B. 1994. Molecular strategies of thermal adaptation in Indian poikilothermic animals. Indian Rev. Life Sci. **4**, 1-18.

Das B. K. 1927. The bionomics of certain air-breathing fishes of India, together with an account of the development of their air-breathing organs. *Phil. Trans. R. Soc.* (London) **216**, 183-219.

Das J. 1991. Role of glutamate dehydrogenase in ammonia management in a freshwater air-breathing teleost, *Heteropneustes fossilis*. Ph. D. thesis, North Eastern Hill University, Shillong, India.

Das J., N. Saha, B. K. Ratha 1971. Tissue distribution and sub-cellular localization of glutamate dehydrogenase in a freshwater air-breathing teleost, *Heteropneustes fossilis*. *Biochem. Syst. Ecol.* **19**, 207-212.

Das K. K., S. G. Dastidar, S. Chakraborty, S. K. Banerjee 1980. Toxicity of mercury: A comparative study in air-breathing and non-air-breathing fish. *Hydrobiologia* **68**, 225-229.

Dey I., C. Budda, T. Wick, J. E. Alver, T. Farkas 1993 *a*. Molecular and structural composition of phospholipid membranes in livers of marine and freshwater fish in relation to temperature. *Proc. Nat. Acad. Sci.* **90**, 7498-7502.

Dey I., T. Szegletes, C. Budda, J. Nemcsok, T. Farkas 1993 *b*. Fish erythrocytes as a tool to study temperature induced responses in plasma membranes. *Lipids* **28**, 743-746.

Dexiang C., A. J. Ainsworth 1991. Effect of temperature on the immune system of channel catfish, *Ictalurus punctatus*-II. Adaptation of anterior kidney phagocytes to 10°C. *Comp. Biochem. Physiol.* **100**, 913-918.

Dkhar J., N. Saha, B. K. Ratha 1991. Ureogenesis in a freshwater teleost: An unusual sub-cellular localization of ornithine-urea cycle enzymes in the freshwater air-breathing teleost, *Heteropneustes fossilis*. *Biochem. Int.* **25**, 1061-1069.

Dutta H., A. Das, A. B. Das, T. Farkas 1985. Role of environmental temperatures in seasonal changes of fatty acid composition of hepatic lipid in an air-breathing Indian teleost, *Channa punctatus*. *Comp. Biochem. Physiol.* **81**, 341-347.

Evans D. H. 1993. The physiology of fishes. CRC Press, London.

Fauconneau B. 1985. Protein synthesis and protein deposition in fish. *In*: Nutrition and feeding in fish, C. B. Cowery, A. M. Mackie, J. G. Bell eds., Academic Press, London, 17-46.

Forster R. P., L. Goldstein 1969. Formation of excretory products. *In*: Fish Physiology vol. 1 W. S. Hoar, D. J. Randall eds. Academic Press, New York, 313-350.

Garg T. K., A. K. Mittal 1993. Observations on the functions of mucous cells in the epidermis of the catfish, *Clarias batrachus* exposed to sodium dodecyl sulfate. *Biomed. Environ. Sci.* **6**, 119-133.

Haider S., N. Upadhyaya 1985. Effect of commercial formulation of four organophosphorous insecticides on the ovaries of a freshwater teleost, *Mystus vittatus* (Bloch) – A histological and histochemical study. *J. Environ. Sci. Health* **20**, 321-340.

Hazel J. R., C. L. Prosser 1994. Molecular mechanisms of temperature compensations in poikilotherms. *Physiol. Rev.* **54**, 620-677.

Hoar W. S., D. J. Randall (eds.) 1969-1979. Fish physiology vol. I-VIII, Academic Press, New York.

Hochachka P. W., G. N. Somero 1984. Strategies of biochemical adaptations. W. B. Saunders, Philadelphia.

Hughes G. M., B. N. Singh 1971. Gas exchange with air and water in an air-breathing catfish, *Saccobranchus fossilis*. *J. Exp. Biol.* **55**, 667-682.

Huggins A. K., G. Skutsch, E. Baldwin 1969. Ornithine-urea cycle enzymes in teleostean fish. *Comp. Biochem. Physiol.* **28**, 587-602.

Jhingran V. G. 1982. Fish and fisheries of India. Hindustan Publishing Co., New Delhi.

Lagler K. F., J. E. Bardach, R. R. Miller, D. R. M. Passino 1977. Ichthyology (2nd edn.), John Wiley & Sons.

Love R. M. 1980. The Chemical Biology of fishes. Academic Press, New York.

Mandal G., A. B. Das 1991. Seasonal dynamics of protein synthesis in the tissues of *Channa punctatus* (Block), an Indian air-breathing teleost. *J. Aquac.* **1**, 1-10.

Marquez E. D. 1976. A comparison of oxalo-acetate transaminase, lactate dehydrogenase, α-hydroxy butyrate dehydrogenase and creatine phosphokinase in non-spawning, pre-spawning and spawning salmon. *Comp. Biochem. Physiol.* **54**, 121-127.

McCorkle F. M., J. E. Cheambers, J. D. Yarbrough 1979. Seasonal effects on selected tissues enzymes in channel catfish, *Ictalurus punctatus*. *Comp. Biochem. Physiol.* **62**, 151-153.

Mishra J., A. K. Srivastava 1983. Malathion induced haematological and biochemical changes in the Indian catfish, *Heteropneustes fossilis*. Environ. Res. **30**, 393-398.

Mukherjee S., S. Bhattacharya 1974. Effect of some industrial pollutants on fish brain cholinesterase activity. *Environ. Physiol. Biochem.* **4**, 226-231.

Mukherjee S., S. Bhattacharya 1975. Changes in the kidney peroxidase activity in fish exposed to some industrial pollutants. *Environ. Physiol. Biochem.* **5**, 300-307.

Mukhopadhyaya P. K., P. V. Dehadrai 1980. Biochemical changes in the air-breathing catfish, *Clarias batrachus* exposed to malathion. Env. Pollut. *Asia Ecol. Biol.* **22**, 149-158.

Mukhopadhyaya P. K., P. V. Dehadrai 1987. Metabolic fate of dietary non-protein nitrogen in *Heteropneustes fossilis* (Bloch). *Indian J. Fish.* **34**, 237-244.

Munshi J. S. D. 1961. The accessory respiratory organs of *Clarias batrachus* (Linn.). *J. Morphol.* **109**, 115-140.

Munshi J. S. D. 1962. On the accessory respiratory organs of *Heteropneustes fossilis* (Bloch). *Proc. R. Soc.* (Biol.) Edin. **68**, 128-146. Munshi J. S. D., A. K. Patra, G. M. Hughes 1982. Oxygen consumption from air and water in *Heteropneustes fossilis (Saccobrachus fossilis)* (Bloch) in relation to body weight at three different seasons. *Proc. Indian Nat. Sci. Acad.* **48**, 715-729.

Munshi J. S. D., G. M. Hughes 1992. Air-breathing fishes of India. Oxford & IBH Publishing Co., New Delhi.

Nakano T., N. Tamlinson 1967. Catecholamine and carbohydrate concentration in rainbow trout (*Salmo qairdneri*) in relation to physical disturbances. *J. Fish. Res. Board Can.* **24**, 1701-1715.

Patra A. K., J. S. D. Munshi, G. M. Hughes 1983. Oxygen consumption of the freshwaer air-breathing Indian siluroid fish, *Clarias batrachus* (Linn.) in relation to body size and seasons. *Proc. Indian Nat. Sci. Acad.* **49**, 566-574.

Plakas S. M., M. O. James 1990. Bioavailability, metabolism and renal excretion of benzoic acid in the channel catfish (*Ictalurus punctatus*). *Drug Metabol. Dispos. Biol. Fate Chem.* **18**, 552-556.

Plakas S. M., P. M. Loveland, G. S. Bailey, V. S. Blazer, G. L. Wilson 1991. Tissue disposition and excretion of 14C-labelled aflatoxin–B1 after oral administration in channel catfish. *Food Chem. Toxicol.* **29**, 805-808.

Plakas S. M., G. R. Stehly, L. Khoo 1992. Pharmacokinetics and excretion of phenol red in the channel catfish. Xenobutica **22**, 551-557.

Prect H., J. Christopherson, H. Hensel, W. Larcher, K. Bruck 1973. Temperature and life. Springer-Verlag, New York, 293-354.

Prosser C. L. (Ed.) 1991. Comparative animal physiology – Environment and metabolic animal physiology (4th edn), Wiley-Liss, New York.

Saha N. 1986. Ureogenesis and its regulation in a freshwater air-breathing teleost, *Heteropneustes fossilis.* Ph. D. thesis North Eastern Hill Univ. Shillong, India.

Saha N., B. K. Ratha 1986. Effect of ammonia stress on ureogenesis in freshwater air-breathing teleost, *Heteropneustes fossilis. In*: Contemporary Themes in Biochemistry vol. 6. O. L. Kom. M. C. Chung, P. L. Hwang, S. Leong, K. H. Loke, P. Thiyagaraja, P. T. Wong eds., Cambridge University Press, Cambridge, 342-343.

Saha N., B. K. Ratha 1987. Active ureogenesis in a freshwater air-breathing teleost, *Heteropneustes fossilis. J. Exp. Zool.* **241**, 137-141.

Saha N., B. K. Ratha 1989. Comparative study of ureogenesis in freshwater air-breathing teleost. *J. Exp. Zool.* **252**, 1-8.

Saha N., B. K. Ratha 1994. Induction of ornithine-urea cycle in a freshwater air-breathing teleost, *Heteropneustes fossilis,* exposed to high concentrations of ammonium chloride. *Comp. Biochem. Physiol.* **108(B)**, 315-325.

Saha N., J. Chakravorty, B. K. Ratha 1988. Diurnal variation in renal and extra-renal excretion of ammonia-N and urea-N in freshwater air-breathing teleost, *Heteropneustes fossilis* (Bloch). *Proc. Indian Acad. Sci.* **97**, 529-537.

Saha N., J. Dkhar, B. K. Ratha 1995. Induction of ureogenesis in perfused liver of a freshwater teleost, *Heteropneustes fossilis,* infused with different concentrations of ammonium chloride. *Comp. Biochem. Physiol.* **112(B)**, 733-741.

Sastry K. V., K. Subhadra 1982. Effect of cadmium on some aspects of carbohydrate metabolism in a freshwater catfish, *Heteropneustes fossilis. Toxicol. Let.* **145**, 45-56.

Schlenk D., C. T. Moore 1993. Distribution and elimination of the herbicide propanil in the channel catfish. (*Ictalurus punctatus*). *Xenobiotica* **23**, 1017-1024.

Shaffi S. A. 1993. Comparison of sub-lethal effect of mercury and lead on succinate dehydrogenese system in three inland teleosts. *Physiol. Res.* **42**, 7-15.

Singh B. N., G. M. Hughes 1971. Respiration of an air-breathing catfish, *Clarias batrachus* (Linn.). *J. Exp. Biol.* **55**, 421-434.

Singh S., T. P. Singh 1987. Impact of malathion and hexachlorocyclohexane on plasma profiles of three sex hormones during different phases of the reproductive cycle in *Clarias batrachus. Pest. Biochem. Physiol.* **27**, 301-308.

Sinha N., B. Lal, T. P. Singh 1991. Pesticide induced changes in circulating thyroid hormones in the freshwater catfish, *Clarias batrachus. Comp. Biochem. Physiol.* **100**, 107-110.

Smolowitz R. M., M. E. Hahn, J. J. Stegeman 1991. Immuno histochemical localization of cytochrome p-450 IAI induced by 3, 3′, 4, 4′-tetrachlorobiphenyl and by 2,3,7,8-tetrachloro dibenzoafuran in liver and extrahepatic tissues of the teleost, *Steriotomus chrysops. Drug Metabol. Dispos. Biol. Fate Chem.* **19**, 113-123.

Srivastava A. K., J. Mishra 1987. Heptachlor induced haematological and biochemical changes in the Indian catfish (*Heteropneustes fossilis*) Bloch. *Acta Hydrobiol.* **29**, 489-495.

Stenly G. R., S. M. Plakas 1992. Disposition of 1-napthol in the channel catfish (*Ictalurus punctatus*). Drug Metabol. Dispos. *Biol. Fate Chem.*, **20**, 70-73.

Thakur N. K., B. R. Dutta, B. B. Satpathy 1987. *Pangasius pangasius* Ham. – An addition to the list of air-breathing teleosts. *Curr. Sci.* **56**, 315-317.

Tripathy G., S. P. Shukla 1990. Malate and lactate dehydrogenases of a freshwater catfish: impact of endosaulfan, *Biomed. Environ. Sci.* **3**, 166-182.

Tripathy G., S. P. Shukla 1991. Seasonal effects on malate and lactate dehydrogenases of the freshwater catfish, *Clarias batrachus. Zool. J. Physiol.* **95**, 1-11.

Wilson R. P. 1973. Nitrogen metabolism in channel catfish, *Ictalurus punctatus*-II. Evidence for an aparent complete ornithine-urea cycle. *Comp. Biochem. Physiol.* **46**, 625-634.